Challenges in Future Satellite Communications

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Acknowledgements

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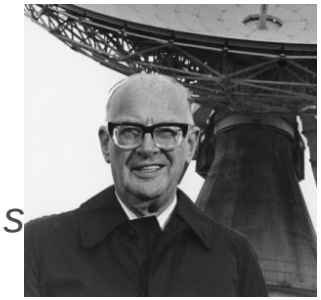
A look into the past…

- Sir Arthur Charles Clarke described the Geostationary satellite concept in a paper titled *Extra-Terrestrial Relays — Can Rocket Stations Give Worldwide Radio Coverage?*, published in Wireless World in October 1945



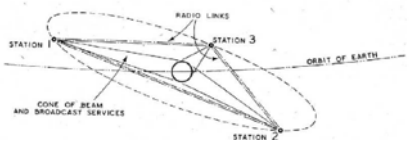
EXTRA-TERRESTRIAL RELAYS

Can Rocket Stations Give World-wide Radio Coverage?

By ARTHUR C. CLARKE

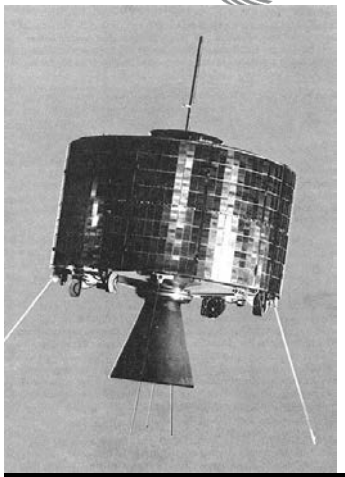
- In 1957 Sputnik was the first artificial Earth Satellite

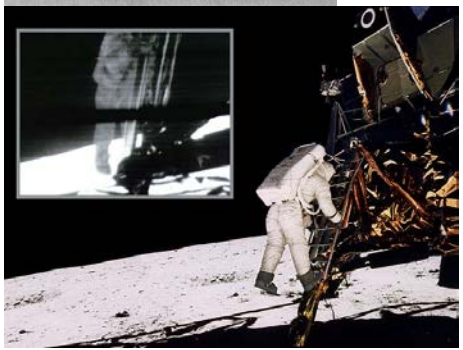
- The first telecommunication satellite was Telstar launched by AT&T in 1962- It successfully relayed through space the first television pictures, telephone calls, fax images and provided the first live transatlantic television feed



A look into the past…

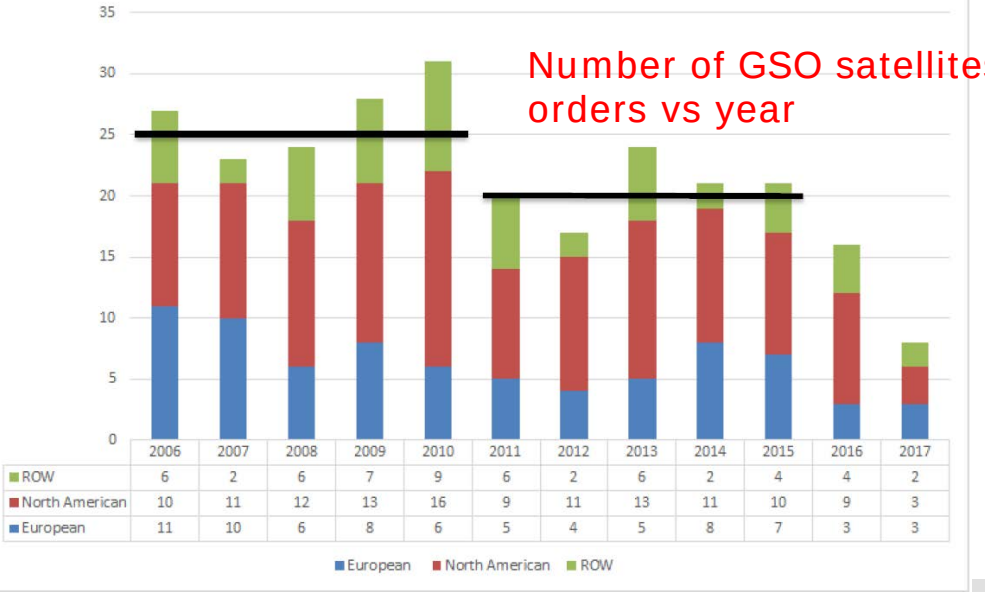
- Syncom started as a 1961 NASA program for active geosynchronous communication satellites, developed and manufactured by Hughes Space and Communications
- Syncom 2, launched in 1963, was the world's first geosynchronous communications satellite
- 1 July 1969: The world's first global satellite communications system is completed with the Intelsat III satellite covering the Indian Ocean Region
- 20 July 1969: Intelsat transmits television images of the moon landing around the world - a record 500 million television viewers worldwide see Neil Armstrong's first steps on the moon "Live via Intelsat"



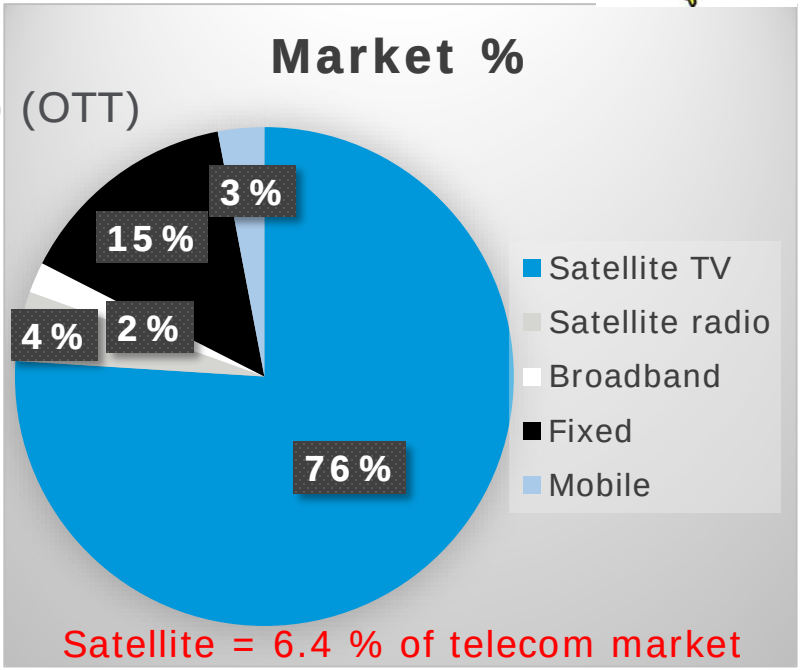


The Challenges Ahead - Satellite Broadcasting from the milk cow to the dead duck?

- Digital broadcasting represents the current operators' main income
- Commercial GEO satellite orders are declining
- Linear TV is declining in favor of Over The Top (OTT)

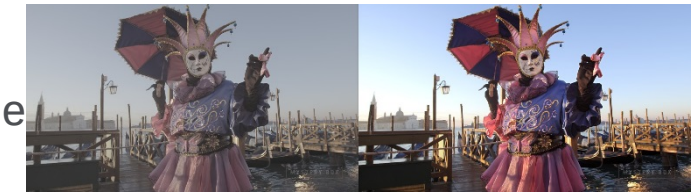


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ROW	6	2	6	7	9	6	2	6	2	4	4	2
North American	10	11	12	13	16	9	11	13	11	10	9	3
European	11	10	6	8	6	5	4	5	8	7	3	3



Satellite Digital Broadcasting – Way forward

- Satellite can play a role in less developed countries:
  - Providing linear TV at low-cost
  - Low-cost return link for interactive services
  - Broadband access for the digital divide
- ..and in more developed countries to provide:
  - Affordable ultra HD real-time events
  - Content for operators caching close to the user
- Key to provide flexible coverage, beam size and resource allocation over the satellite lifetime to cope with unpredictable market evolutions



The Broadband Satcom Challenge

- User expectations are growing exponentially but non uniformly

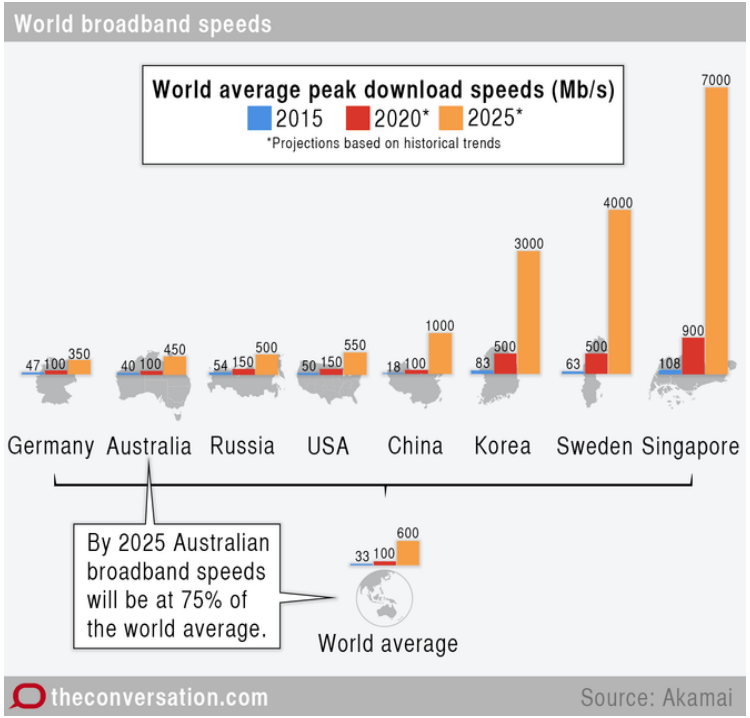
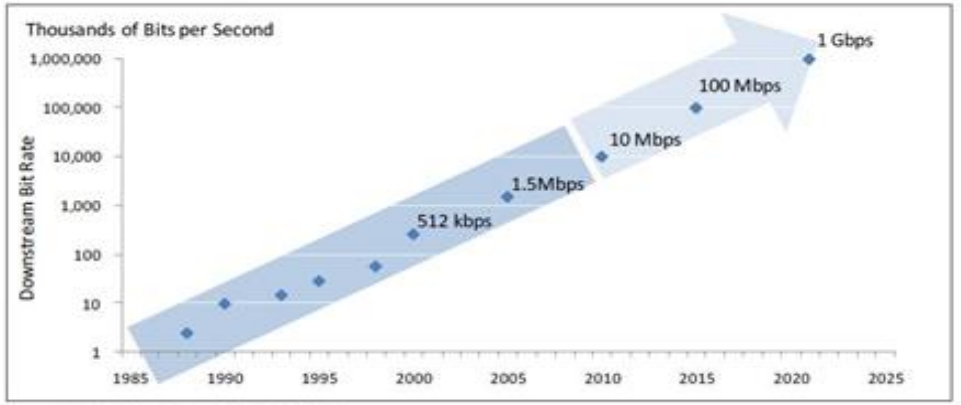
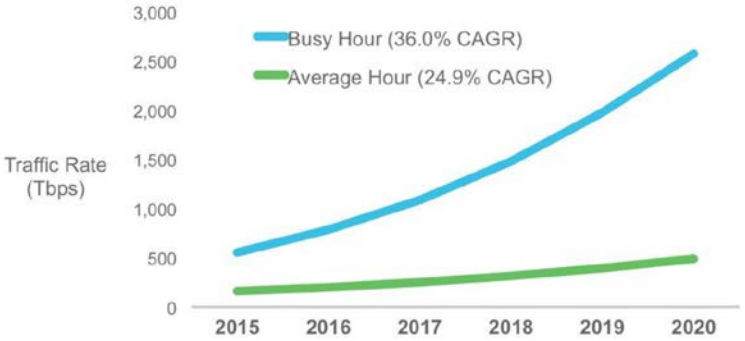


Exhibit 2.12: Download Speeds since 1985



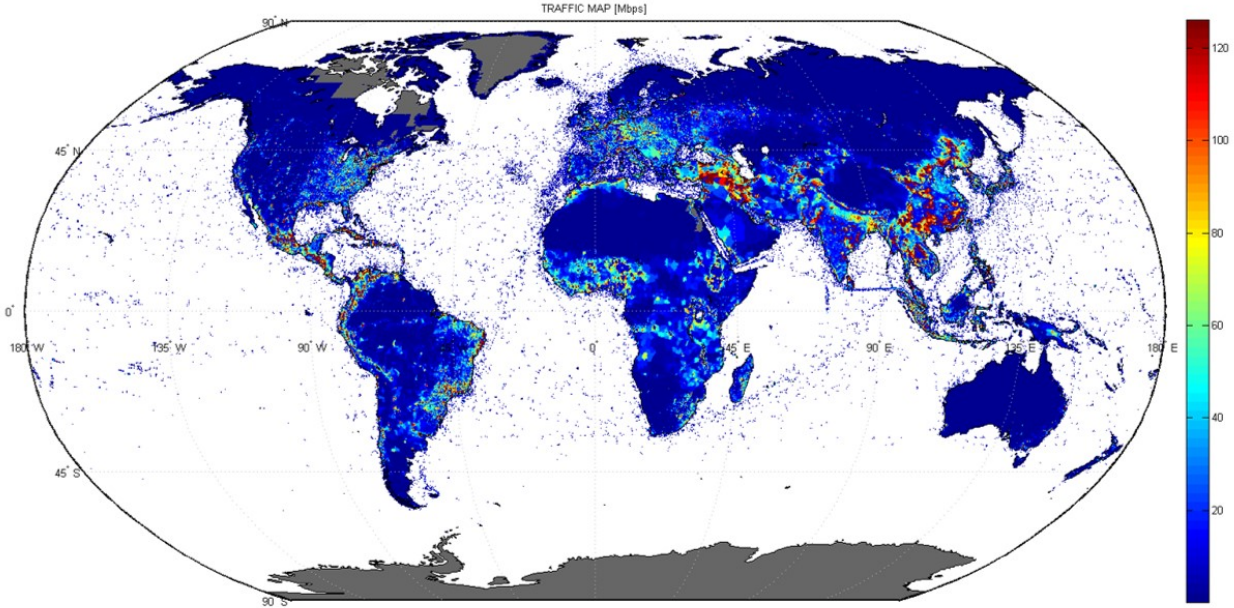
Source: NBN Co, Alcatel-Lucent (refer Exhibit 9.21)



Busy-hour traffic (or traffic in the busiest 60-minute period of the day) continues to grow more rapidly than average (over 24 hours) rates

Predicted Satellite Broadband Spatial Traffic Distribution

- Based on population, enterprises, vessels, (airplanes) density requiring satcom
- Traffic is spatially highly non uniform & time variant!



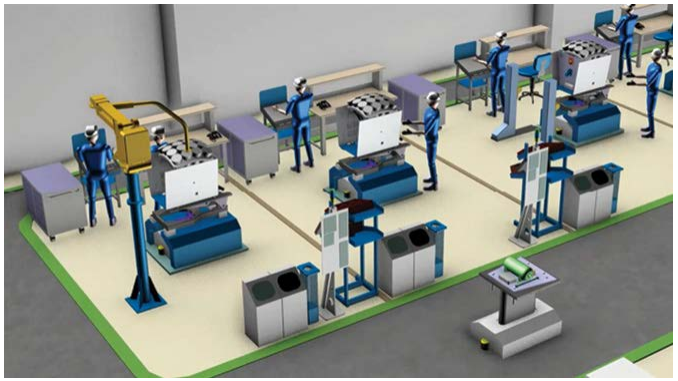
Market Requirements – Overall Summary

ARPU= Average Revenue per User

Market segment	Current	2023	2028
Broadcast in developing markets	SES, Eutelsat, Hispasat, DirecTV, EchoStar, Intelsat	Constant ARPU Lower set-top box cost, easy installation, iTV	Constant ARPU High quality premium pay TV services, iTV
Broadcast in developed markets	SES, Eutelsat, Dish, DirecTV, EchoStar, Hispasat, Intelsat	Constant ARPU Higher quality, push VoD iTV	Constant ARPU (basic services) higher for premium, DiY installation
Enterprise broadband (including aeronautical, maritime, rail, backhaul, SNG, government)	Inmarsat, Viasat, SES, Eutelsat, iDirect, HNS, Intelsat	Constant ARPU Data rate x 6-8	Constant ARPU Data rate x 20-45
Consumer broadband	Viasat, Eutelsat, SES, Dish, HNS	Constant ARPU (consumer/low-end/mobile) Peak rate x 7 / 5 / 3 Average rate x 4 / 30 /10	Constant ARPU (consumer/low-end/mobile) Peak rate x 20 / 20 / 7 Average rate x 17 / 600 /85
M2M/IoT	Iridium, Orbcomm, Globalstar, Eutelsat, Inmarsat	Terminal cost reduction by factor 2-4 ARPU reduction by 5 Installation cost -> 0	Terminal cost reduction by factor 5-10 ARPU reduction by 10 Installation cost = 0

Satellite Broadband Access – Way Forward

- Likely consolidation among classical operators the emergence of new players, and a shift of strategy to a **combined broadcasting, broadband**
- **Strong push for cost reduction (up to factor 10) / shorter development / manufacturing time** also for GEO **(from 3 to 1 year)**
- **High re-configurability & modularity** of the payload/system in terms of coverage, orbital location, resource allocations, power and bandwidth
- New concepts of **reliability / redundancy** (reduced life time, COTS exploitation) and production for a lower cost
- From medium to very high throughput up to **few terabit / s per GEO satellite** for an improved service efficiency



OneWeb production facility – artistic view

P. Angeletti, R. De Gaudenzi, D. Petrolati, E. Re, *"Satellite Networks Architectures and Technologies for 5G Broadband Services"*, submitted to IEEE Networks, February 2018.

Satellite Broadband Access – System Aspects

- High level of resource allocation flexibility in time and space
- Flexible sharing of different type of missions on the same satellite
- Capability to deal with hot and cold spots
- High peak bit rates and affordable cost for Mbyte

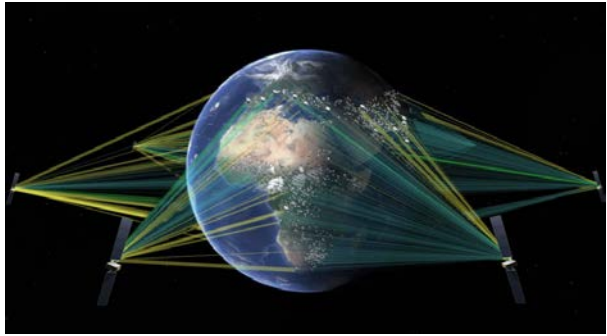
- Flexible space segment for coverage, power, frequency allocations
- High level of frequency reuse
- Beam size adapted to the traffic density
- Affordable ground segment

GEO or Non-GEO?

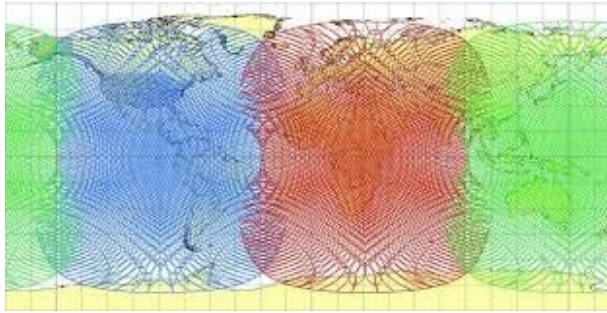
- 3 GEOs provide global coverage except polar regions
- O3b MEO provides global coverage except polar regions with 4-20 satellites
- OneWeb/Starlink LEOs provide global coverage with hundreds to thousands satellites with:

+ Limited latency
+ Smaller satellites / series production
+ Larger # satellites
+ Possible polar areas coverage
- Shorter lifetime, high launch cost
- User terminal tracking antenna
- More complex infrastructure deployment and management
- More difficult spectrum sharing

SES/O3b 'mPower' MEO constellation



Viasat 3 GEO constellation



OneWeb LEO constellation

Future Payloads - High Level Requirements

MISSION REQUIREMENTS

Requirements change during lifetime
Flexible coverage (area, beam shape)
Orbital location flexibility
Type of service in-flight re-configurability
Time and geographical traffic variation
Flexible gateway locations
Progressive service deployment

Very high throughput where needed
High user peak rate

Low cost and production time

PAYLOAD REQUIREMENTS

Coverage and beam size
Payload resource allocation
Flexible Feeder link

→ FLEXIBILITY

Large user and feeder link bandwidth
Small beam size
High frequency re-use

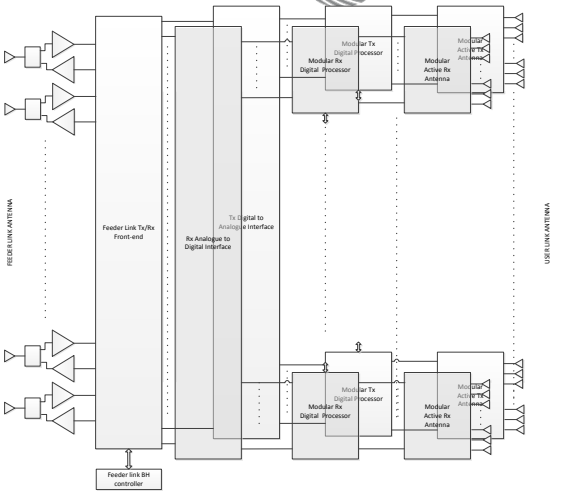
→ HIGH THROUGHPUT

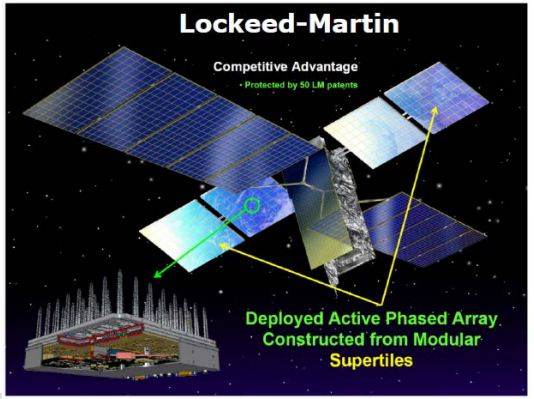
Generic payload architecture through scalable/modular approach

→ MODULARITY

The future satellite payload

- **Efficient / very flexible payload architecture** which allows for modularity/scalability and series production
- **End-to-end space-ground optimized design**
- **Key basic technologies** (see next slides)
- **Payload modules to be standardized and re-used in both NGSO and GSO spacecraft's** thus leveraging the high volume of NGSO's
- **Large volume production facilities for modules and payloads**
- **Satellite platforms** optimized for active antennas (in particular geometry, thermal aspects)





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Possible Technical Solutions – Hybrid Microwave/Digital Payload

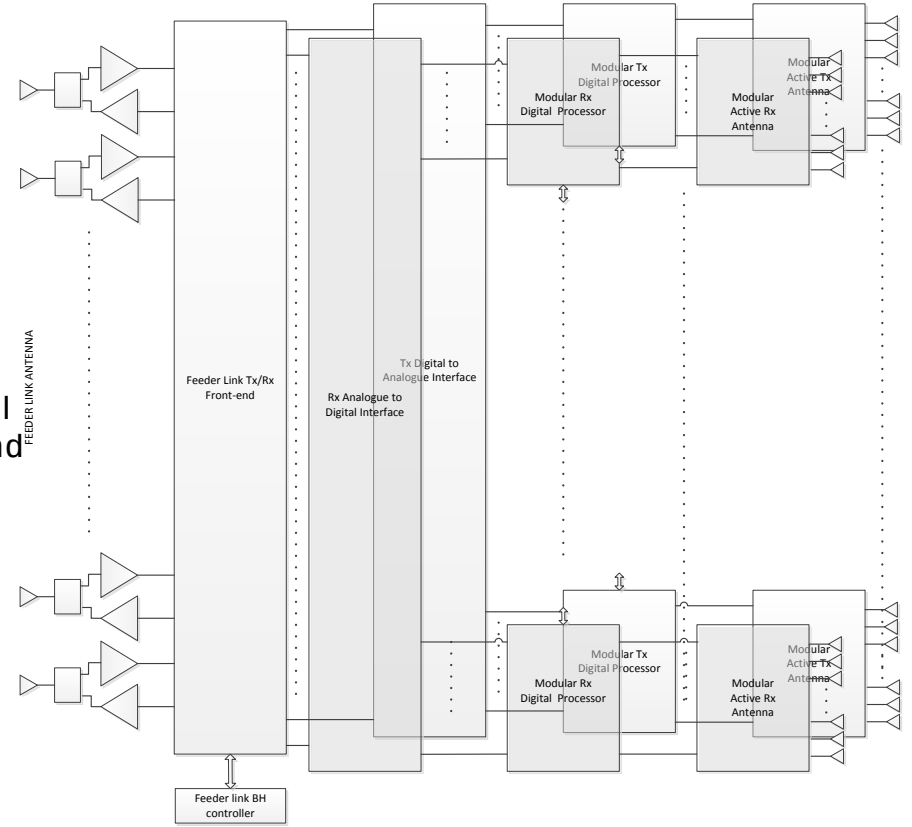
Active antennas for full coverage and power reconfigurability:

- o Deployable Direct Radiating Arrays
- o Array-Fed Reflectors or Imaging Arrays

Digital processors to support flexible beam-forming (preferred: hybrid (analogue/digital) BFN), channelization and routing

Feeder Link may reuse the Ka-band active antennas avoiding dedicated antennas/input section and offering full reconfigurability in support to Smart Gateway Diversity and progressive Gateway deployment

Generic, fully reconfigurable and modular payload architecture allowing reduction in cost and satellite lead time



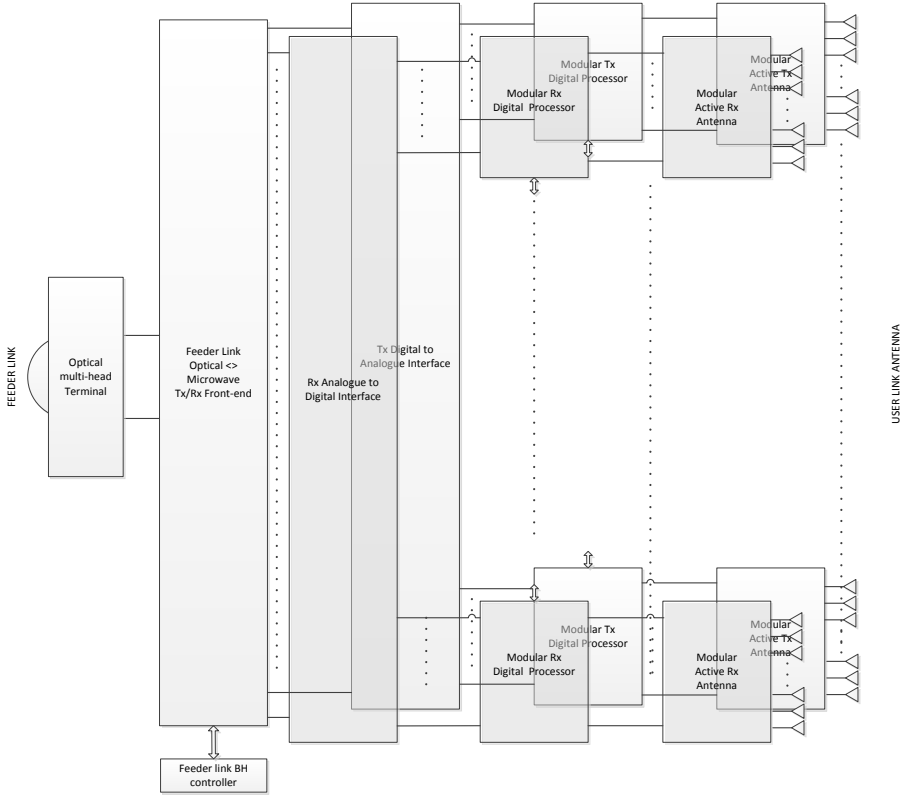
Possible Technical Solutions – Hybrid Optical/Digital/Microwave Payload

Active antennas for full coverage and power reconfigurability:
- o Deployable Direct Radiating Arrays
- o Array-Fed Reflectors or Imaging Arrays

Digital processors to support flexible beam-forming (preferred: hybrid (analogue/digital) BFN), channelization and routing

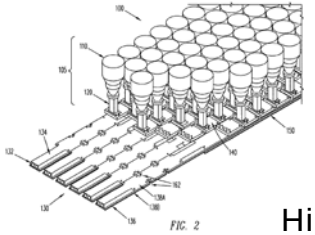
Feeder Link: High throughput single head optical feeder link with gateway space diversity

Generic, fully reconfigurable and modular payload architecture allowing reduction in cost and satellite lead time

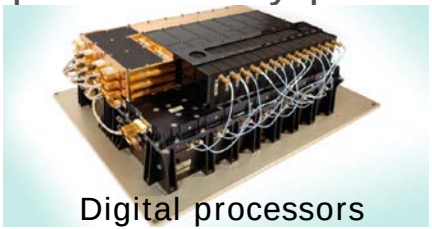


Next GSO Frontier – Fully flexible payload

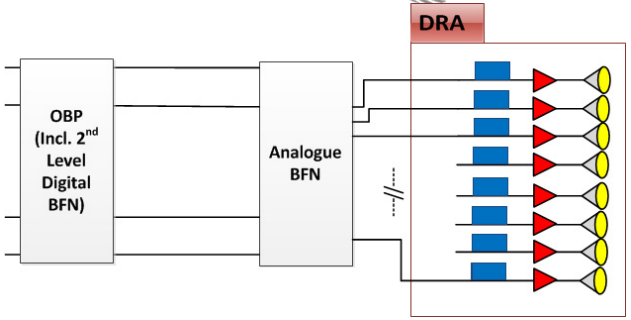
In-space foldable modular active phased array panels



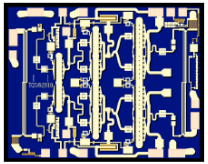
Compact Array feeds



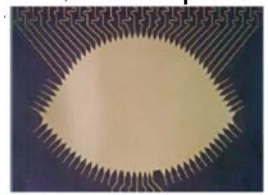
Digital processors



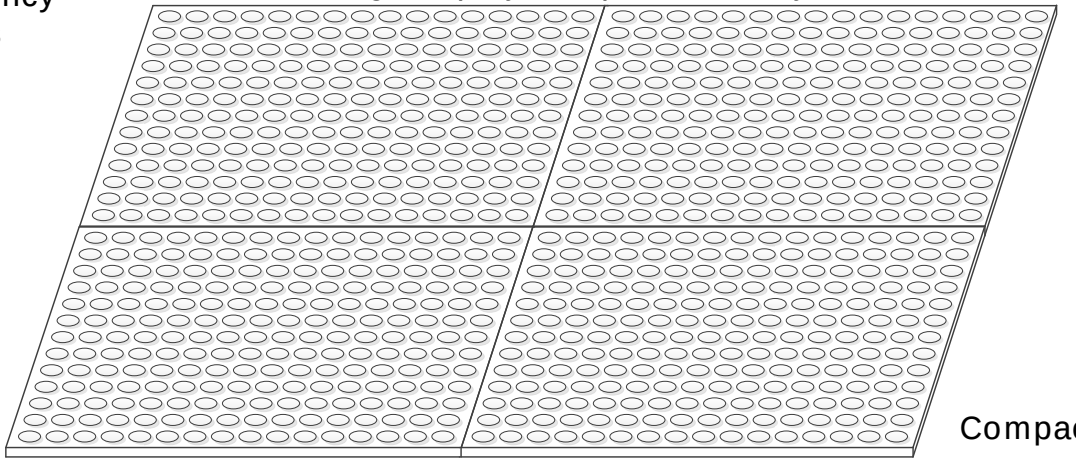
High efficiency GaN SSPAs

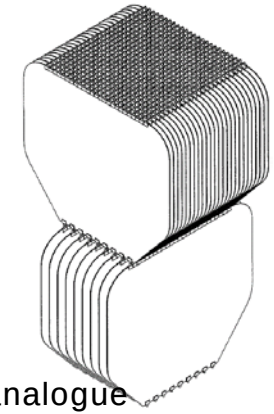


Compact analogue BFN



Large deployable phased arrays



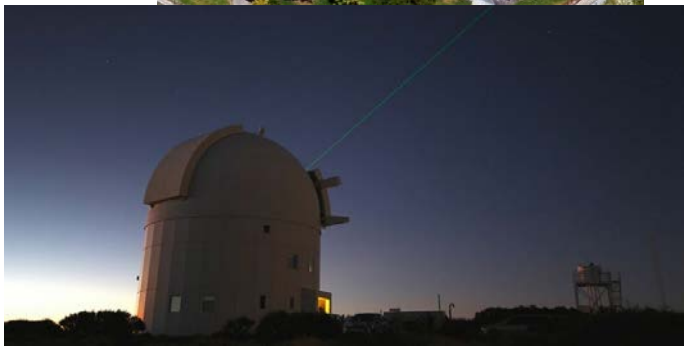


Compact analogue BFN

Massive MIMO-ready architecture?

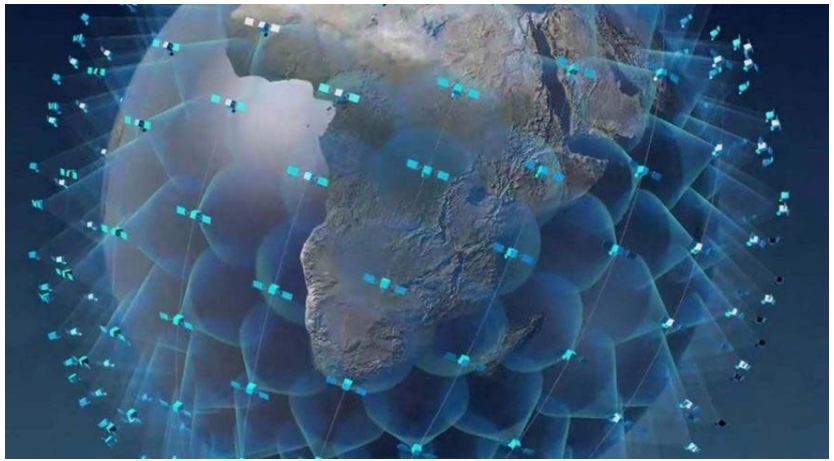
The future ground segment - GSO

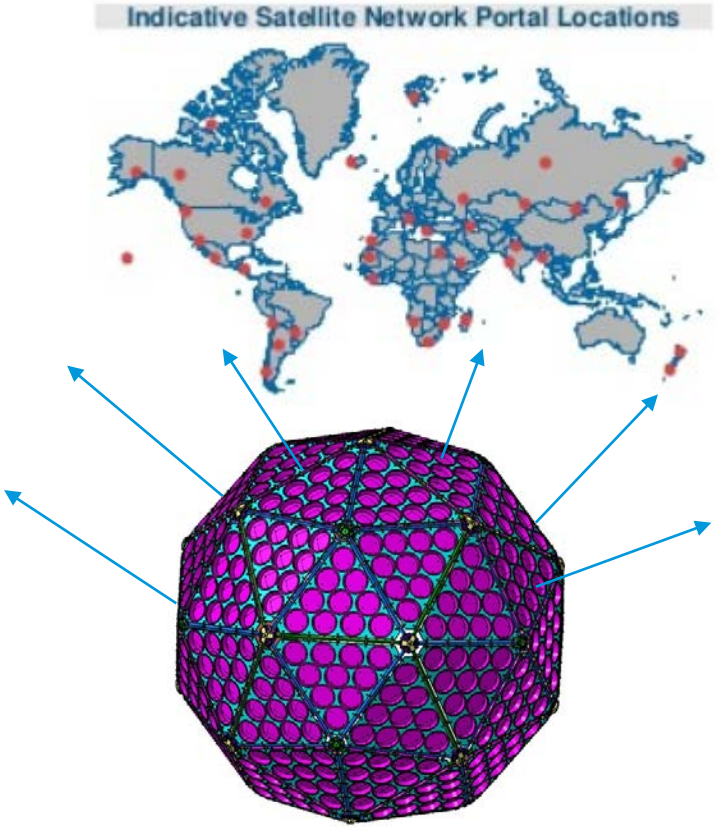
- For VHTS the ground segment cost represents a high percentage of the overall system cost (e.g. 40 GWs using Q-V/band)
- Large number of GWs to split the feeder link throughput plus extra GWs in spatial diversity for link availability reasons
- Optical feeder link being investigated as alternative to RF links to reduce the number of GWs
- The gateway-backbone interconnection cost can become prohibitive for optical GWs -> Smart optical GW concept being considered



The future ground segment - NGSO

- Megaconstellations like OneWeb require 55-75 gateways each pointing tens of satellites
- R&D to develop active electronically steerable antennas simplifying the gateway deployment





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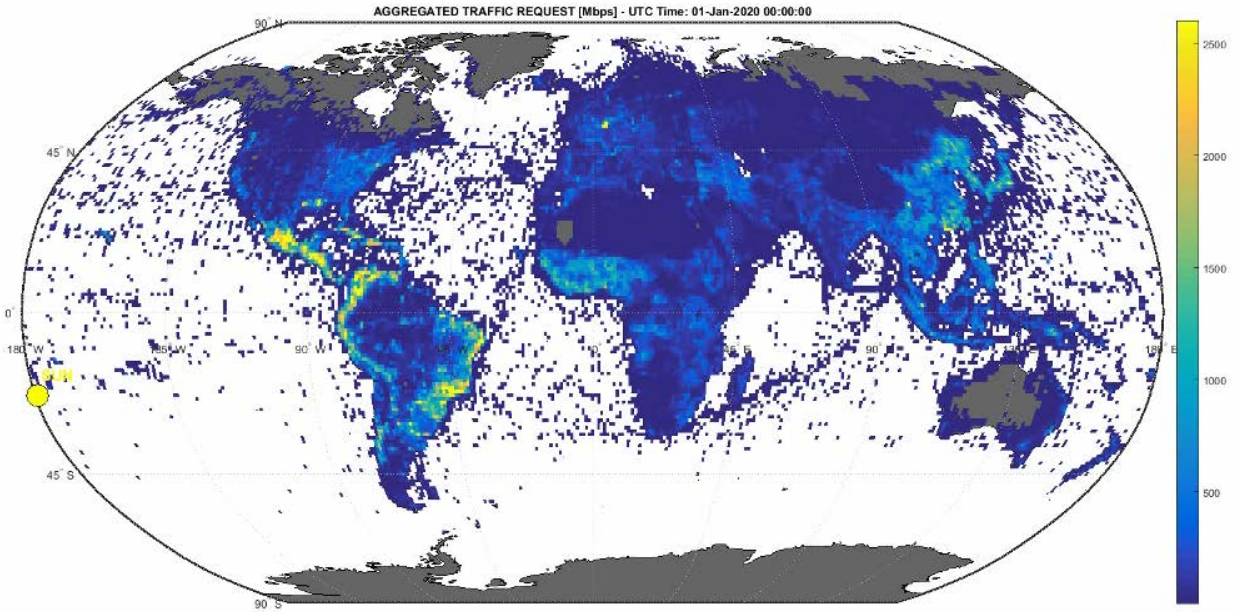
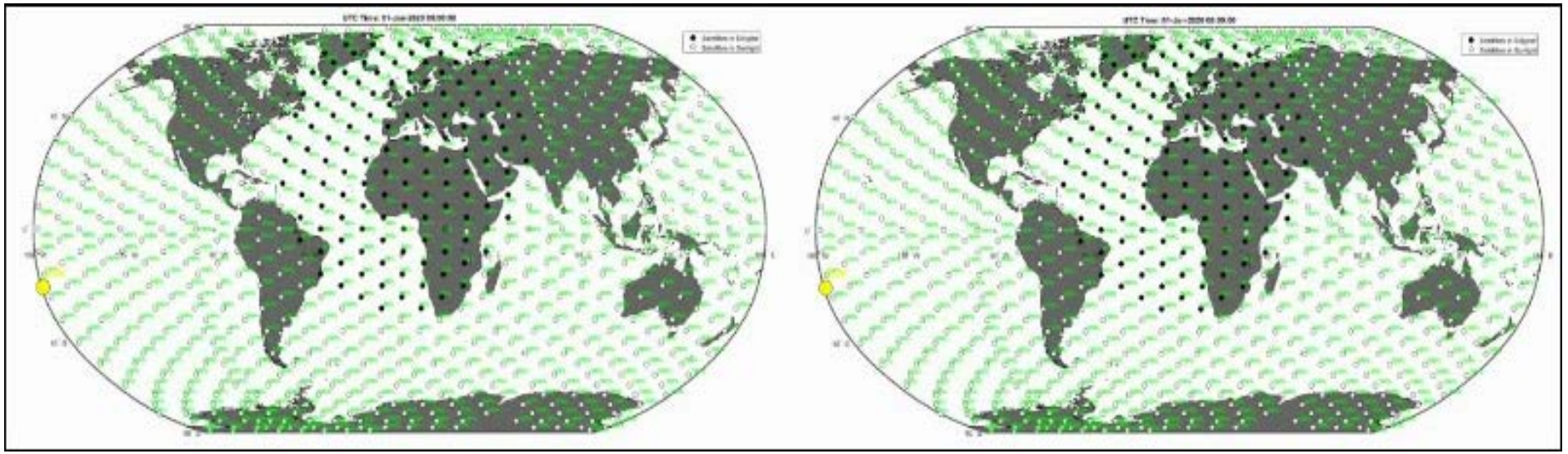
NGSO System Challenges

- Overall design much more complex than GSO systems
- Very high dynamic traffic variations to which the system shall adapt
    - Satellite battery/power dynamic management
    - RF (bandwidth/power) resources dynamic management
    - Possible beam steering to reduce the users' hand-off rate
- Gateways with multiple tracking satellite capability (tenths of satellites)
- Interference to other GSO and NGSO constellations

NGSO Traffic Request vs Time



Mega Constellations – The Need for Power Management



Carriers always on

Satellite batteries
Initially charged

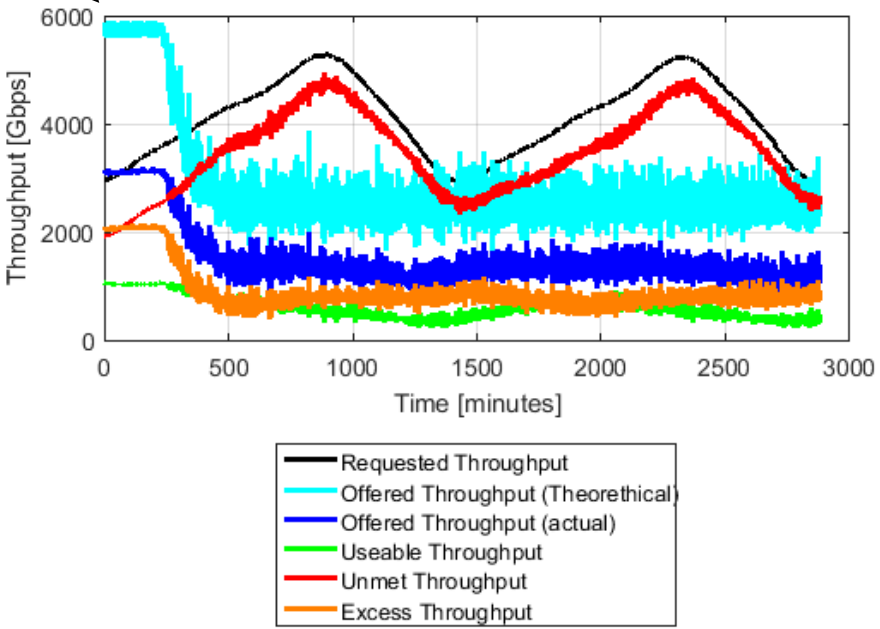
Pilots-only carrier if no traffic requested

Useable vs Offered Throughput

Full initial battery charge

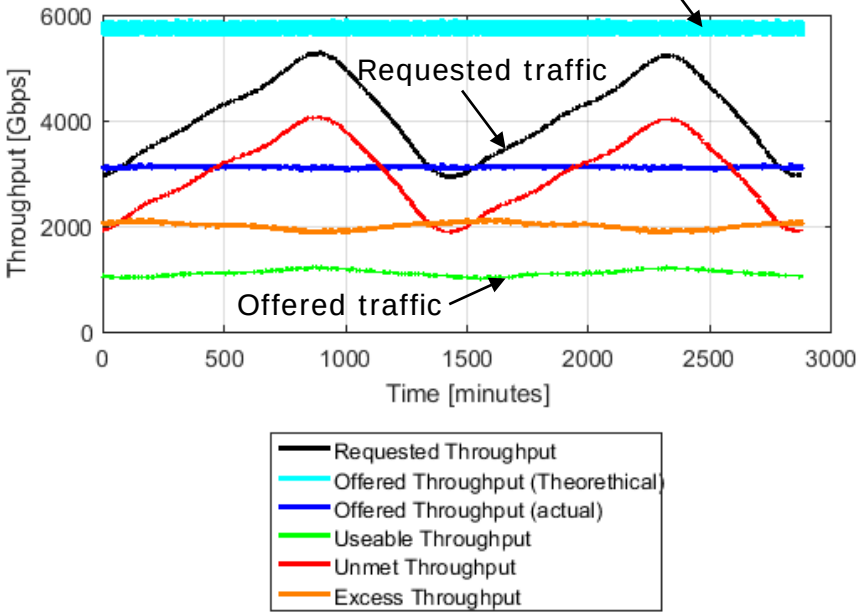
System Throughput

Variable Traffic request vs time



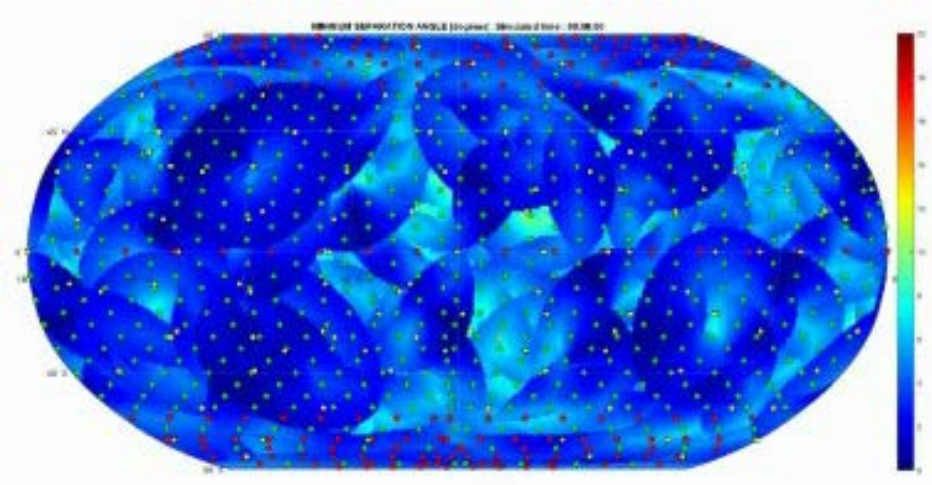
Carriers always on

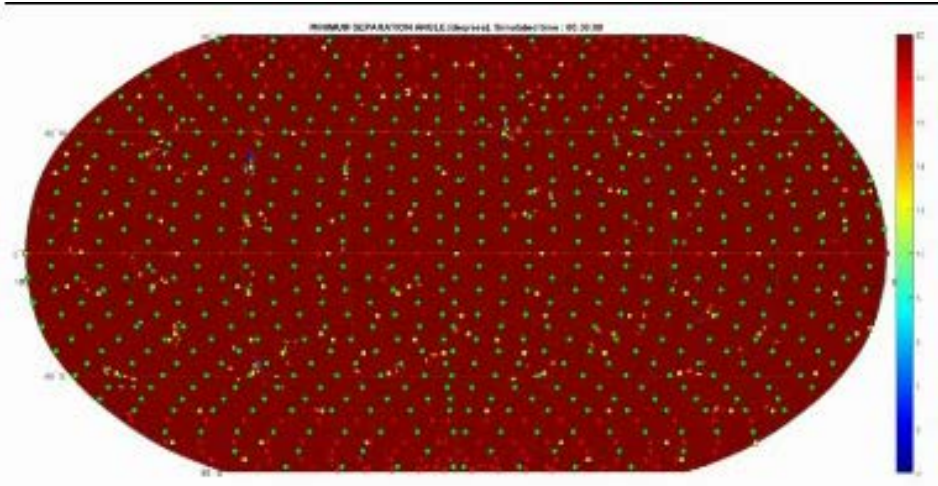
Theoretical offered traffic



Pilots-only carriers if no traffic requested

The Need for Interference Coordination





Uncoordinated operations

CONST 1 – Active Satellite

CONST 1 – Inactive Satellite

CONST 2

Coordinated operations

Increasing Throughput - When (not) to use NOMA

Key challenge is to cope with the hot spots in satellite multi-beam networks with maximum flexibility and minimum impact on the satellite payload complexity

Way forward:

- Dynamic resource allocation in particular frequency/time allocation/beam (possibly exploiting active antennas)
- Full frequency reuse in the high traffic region(s)
- Advanced signal processing on-ground to mitigate increased co-channel interference

Dealing with co-channel interference

Three possible approaches for dealing with co-channel interference:

- Option 0: treat the interference as AWGN (Single User Matched Filter) and play with MODCOD range extension or limit the amount of frequency reuse
- Option 1: centrally mitigate the interference at the gateway exploiting pre-coding techniques
- Option 2: use decentralized Multi User Detector (MUD) solutions

The vast majority of MUD research has been focusing on the reverse link not on the forward link

The pre-coding way

PRE-CODING AS IMPLEMENTED IN LTE TERRESTRIAL NETWORKS

NTT DOCOMO Technical Journal Vol. 12 No. 2

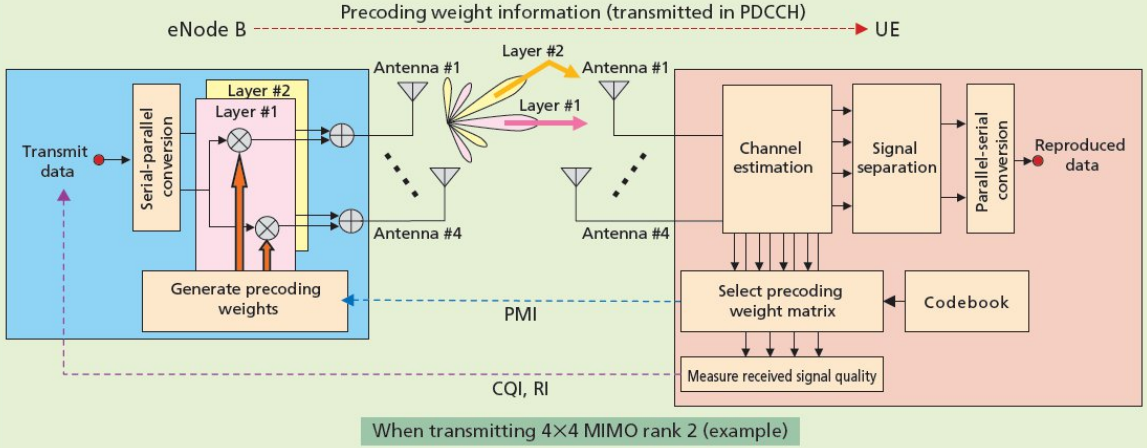


Figure 1 Closed-loop SU-MIMO transmission using code-book-based precoding

Via: 3g4g.blogspot.com

Pre-coding issues

- Centralized pre-coding to mitigate the interference requires a good knowledge of the multi-beam channel seen by each user terminal
- Each physical layer frame is normally multiplexing a number of users located in different beam's locations
- Needs regular terminal channel estimation and reporting to the gateway -> signaling is scaling up with the size of the network
- The system has to ensure a high level of phase/time coherency among the payload transponders and feeder link carriers or put in place accurate calibration techniques
- HTS architectures are typically served by a large number of gateways reducing the pre-coding benefits

Precoding in Satcom

System requirements:

- Full frequency reuse or two colors -> more feeder link bandwidth, more complex payload (# RF chains) or need for an active antenna
- Minimum number of gateways to reduce decentralized precoding impact

System imperfections affecting precoding:

- Group delay variation across the transponders (max ~ 5-6 ns)
- Phase and frequency offsets among payload chains
- Imperfect channel matrix estimation at the receivers
- Outdated channel estimates due to feedback delay
- Rain fading

INTERNATIONAL JOURNAL OF SATELLITE COMMUNICATIONS AND NETWORKING
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DVB-S2X-enabled precoding for high throughput satellite systems

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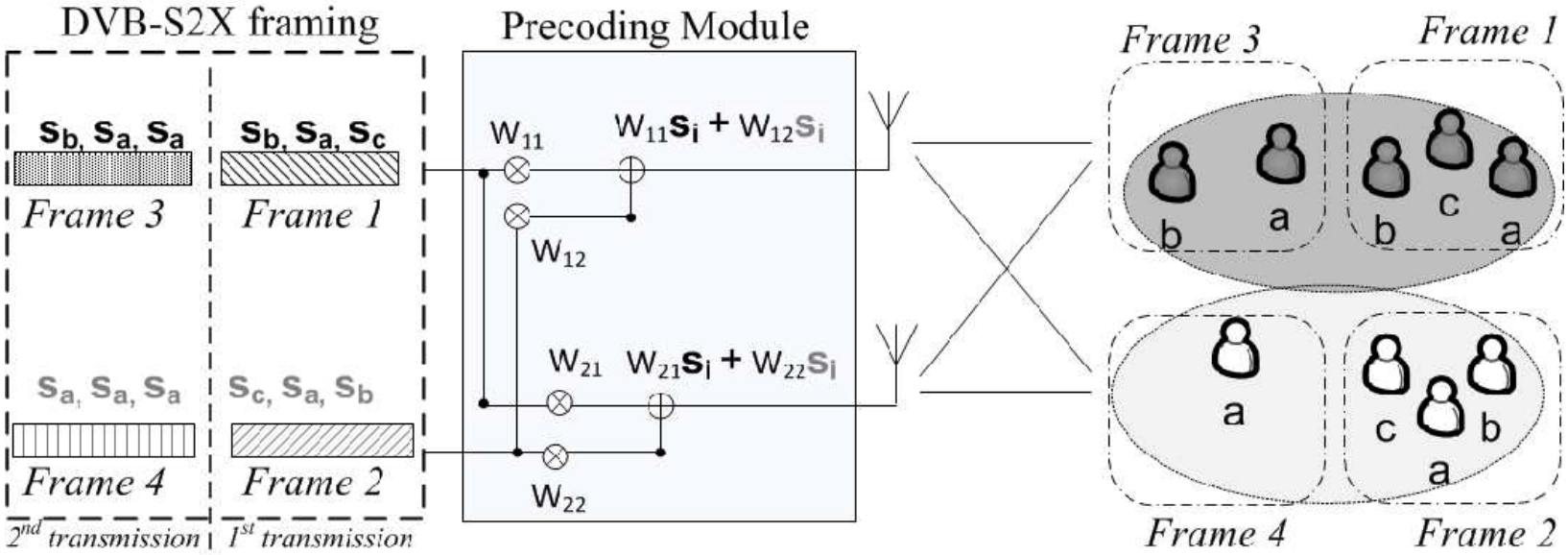
[3]*University of Bologna, Bologna, Italy*

Precoding in Satcom



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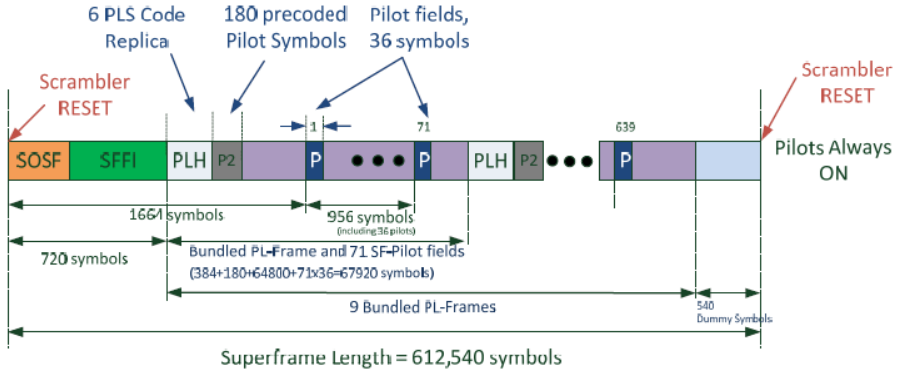
Impact of Channel Estimation on Pre-coding

- DVB-S2X has an optional frame structure supporting pre-coding channel estimation



There are 71 pilot fields per each bundled frame (summing up to a total of 639 pilot fields). In this super-frame format, the pilot fields are always present. There is no signalling w.r.t. pilot presence.
The pilot fields are determined by a Walsh-Hadamard (WH) sequence of size 32 plus padding of 4 bits. Thus, a set of $2^5 = 32$ orthogonal WH sequences results from the following recursive construction principle:

$$\text{Apply } H_{2m} = \begin{bmatrix} H_m & H_m \\ H_m & -H_m \end{bmatrix} \text{ starting from } H_1 = [1] \text{ until } H_{32} \text{ is deduced.}$$

- Coverage: 60 beams – 0.2 deg size
- User frequency- entire Ka band 2.5 GHz (17.7-20.2 GHz)
- 75 cm user terminal antenna
- Simulation results include (sub-optimum) channel estimation errors

2 users/frame & 100 users/beam
2 color scheme with precoding:
320 Gbps

2 users/frame & 100 users/beam
4 color scheme: **220 Gbps**

~15% throughput penalty due to channel estimation errors

~45% throughput improvement

C. Rohde, N. Alagha, R. De Gaudenzi, H. Stadali, G. Mocker, *"Super-Framing: A Powerful Physical Layer Frame Structure for Next Generation Satellite Broadband Systems"*, Accepted for Publication on Wiley Int. Journal of Satellite Communications and Networking, Special issue on DVB-S2X Standard, Volume 34, Issue 3, May/June 2016, Pages 321455. http://onlinelibrary.wiley.com/doi/10.1002/sat.1153/full

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Impact of Number of Users/frame (Clustering)

- Typically one downlink frame supports several distinct users -> need to group them to minimize the precoding gain reduction or smaller frames
- Channel conditions will not be the same (multicasting)
- Ad-hoc techniques to group users

PRECODING IN MULTIBEAM SATELLITE COMMUNICATIONS: PRESENT AND FUTURE CHALLENGES

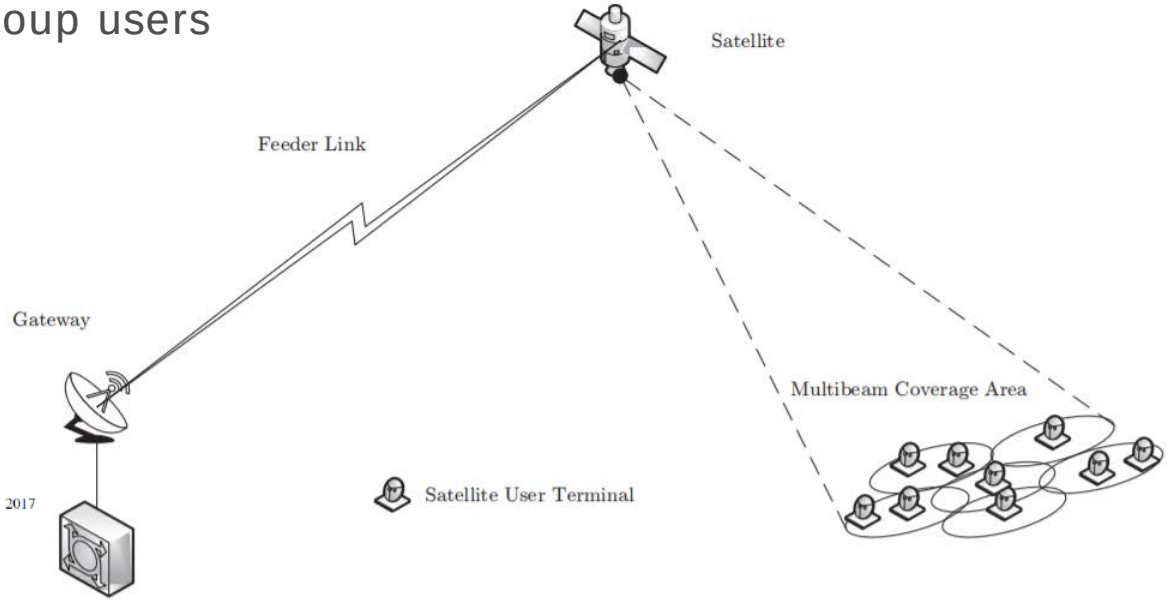
MIGUEL ÁNGEL VÁZQUEZ, ANA PÉREZ-NEIRA, DIMITRIOS CHRISTOPOULOS, SYMEON CHATZINOTAS, BJÖRN OTTERSTEN, PANTELIS-DANIEL ARAPOGLOU, ALBERTO GINESI, AND GIORGIO TARICCO

IEEE Wireless Communications • December 2016

Generalized Multicast Multibeam Precoding for Satellite Communications

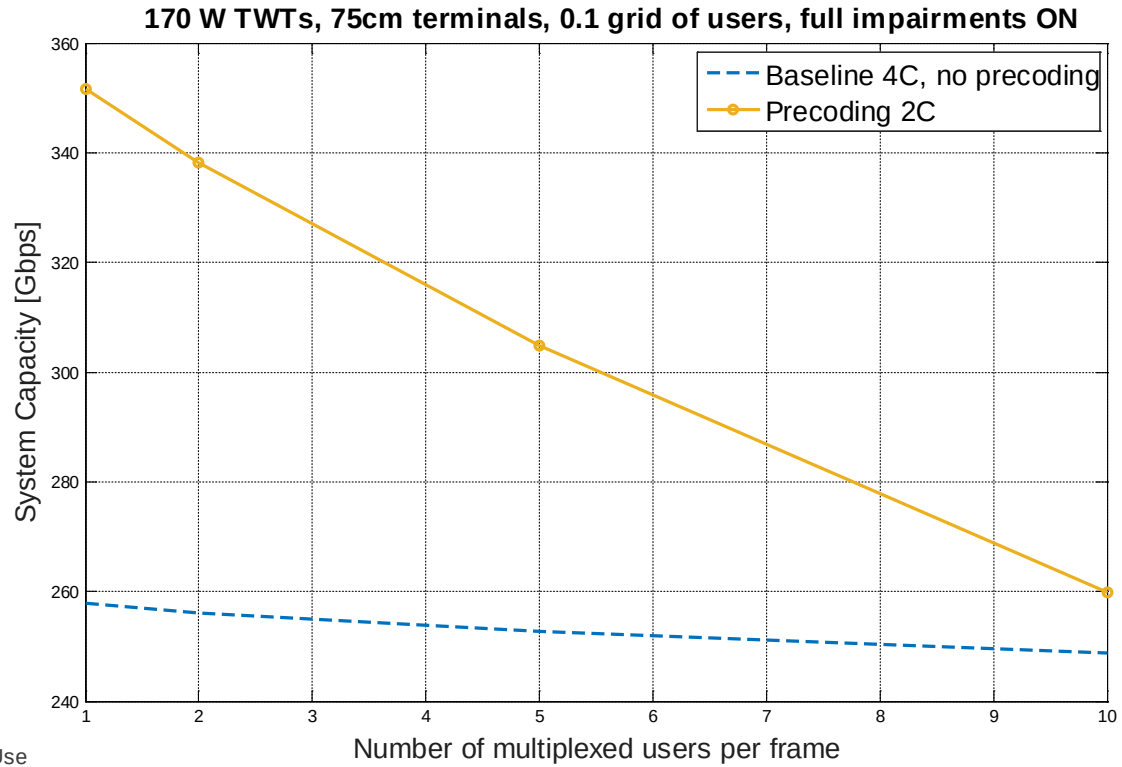
Vahid Joroughi, Miguel Ángel Vázquez, and Ana I. Pérez-Neira, *Senior Member, IEEE*

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 16, NO. 2, FEBRUARY 2017



Impact of Number of Users/frame (Clustering)

- The precoding performance degrades clustering more users in the same FEC frame



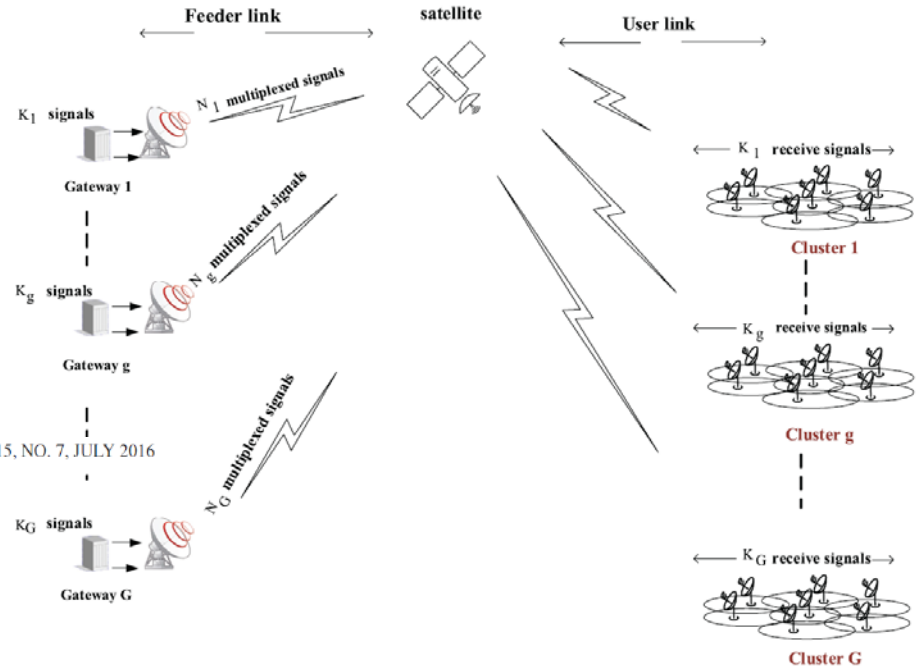
Impact of the Number of Gateways

- The (V)HTS feeder link needs to be split in a number of GWs each serving a distinct cluster – partial pre-coding possible

Precoding in Multigateway Multibeam Satellite Systems

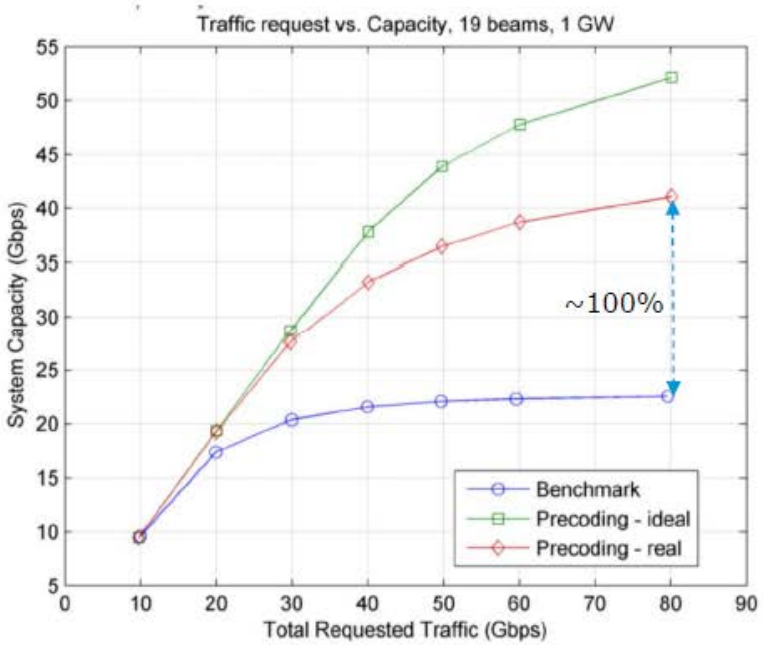
Vahid Joroughi, Miguel Ángel Vázquez, and Ana I. Pérez-Neira, *Senior Member, IEEE*

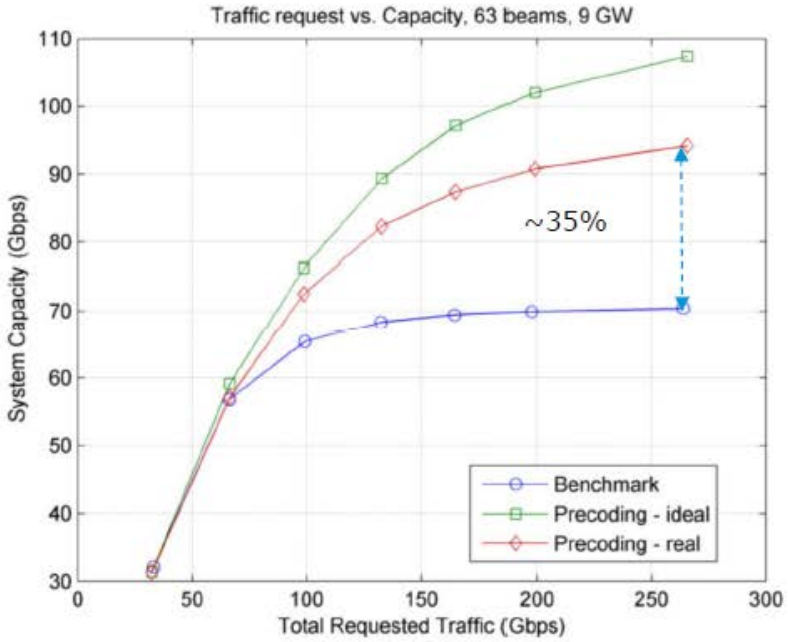
IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 15, NO. 7, JULY 2016



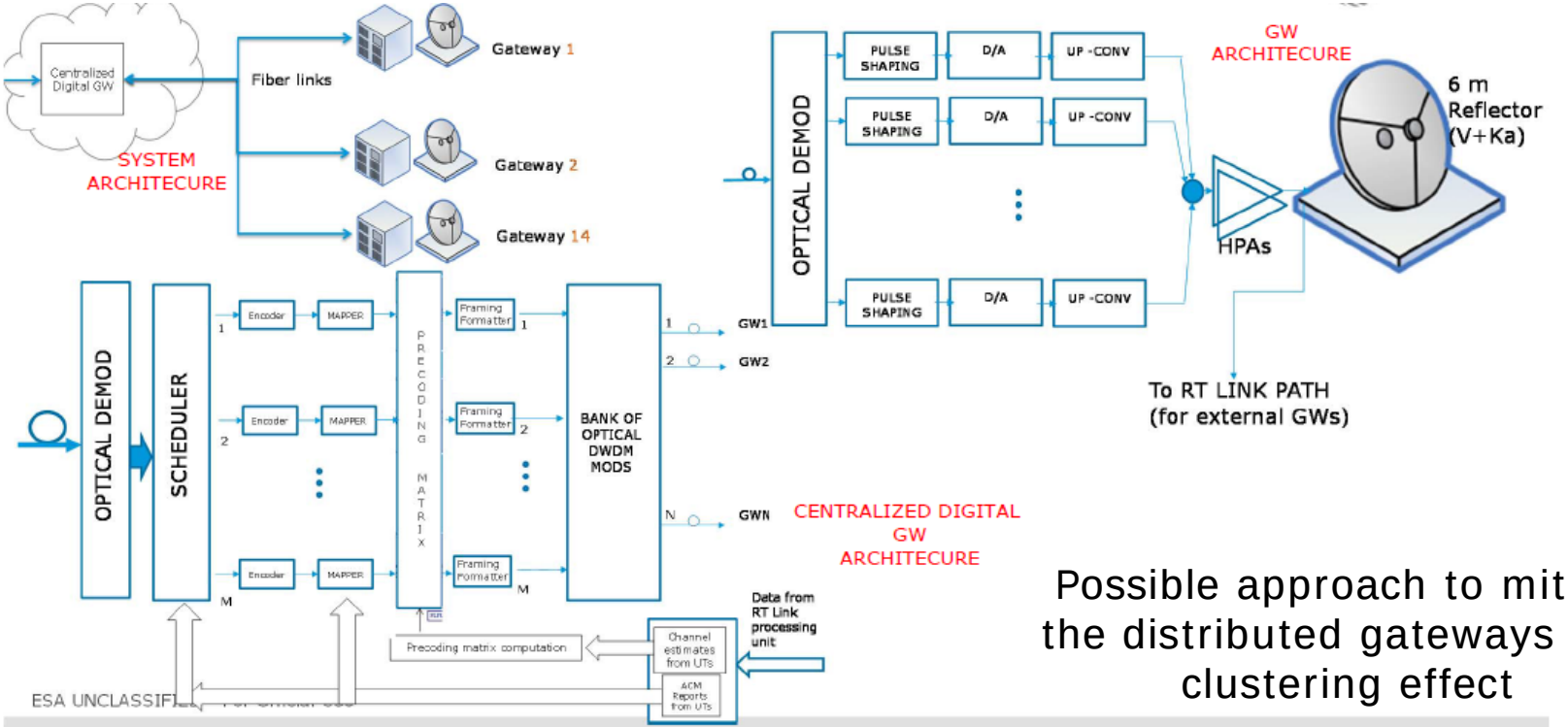
Impact of the Number of Gateways

- Distributed Gateways are reducing the precoding gain





Centralized Precoding Approach



Possible approach to mitigate the distributed gateways beam clustering effect

The distributed MUD way

Use FFR when higher throughput needed and push the interference mitigation to the user terminal side demodulating more than one beam at the time

ADVANTAGES:

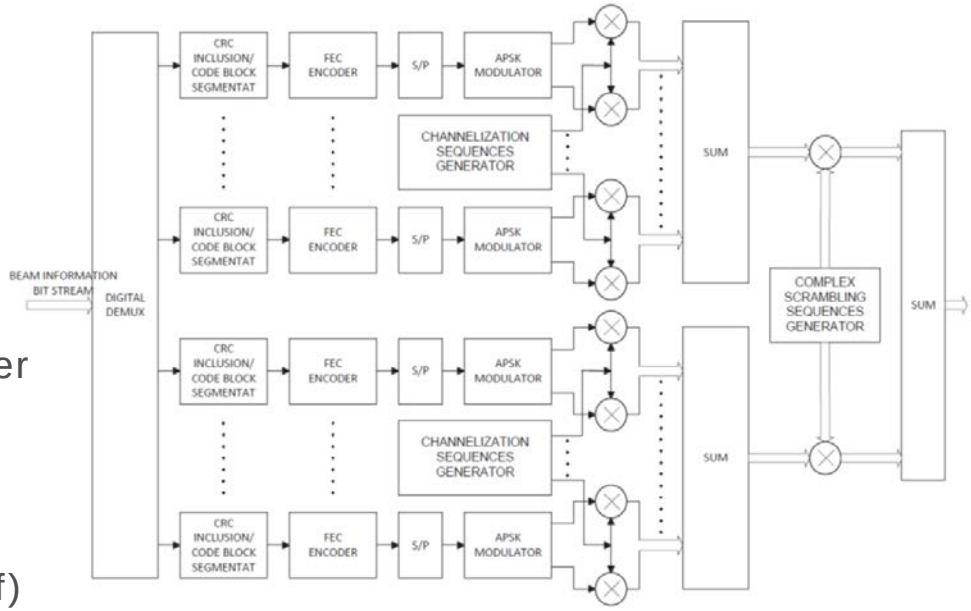
- No need for centralized signal processing
- No need for “fast” terminal channel estimate reporting
- No need for carrier phase/time coherency in the satellite transponders or calibration techniques involving the payload
- No degradation in performance for HTS satellites with multiple gateways for the feeder link
- Can be exploited in existing MSS Inmarsat/Globalstar satellites

DRAWBACKS:

- Increased complexity at the user terminal side / reduced gain???

The distributed MUD approach – Modulator

- CDM beam multiplex with
  - DVB-S2X FEC coding, APSK modulation, Walsh-Hadamard CDM component orthogonal channelization, complex beam unique scrambling
  - When CDM components/beam larger than the spreading factor SF than second complex scrambling sequence
  - Orthogonality is only inside (part of) the beam
- Full frequency reuse among active beams



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DOI: 10.1002/sat.1215
WILEY

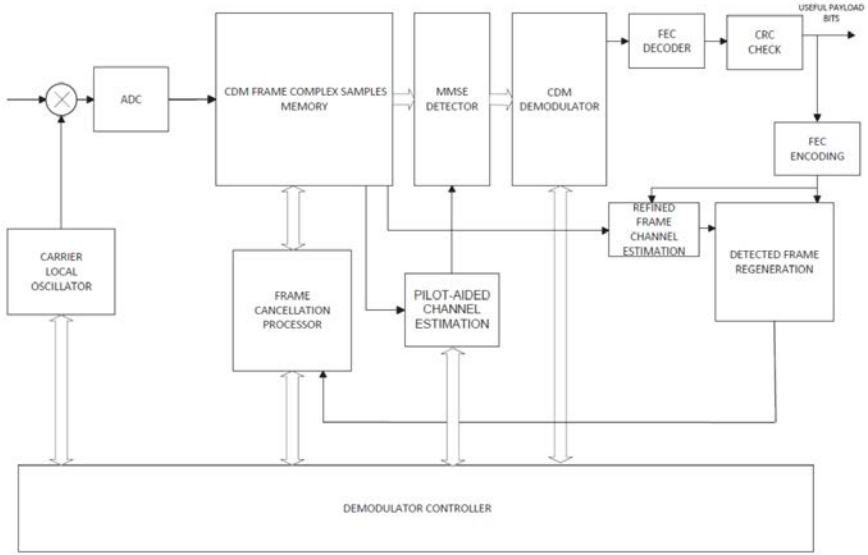
RESEARCH ARTICLE

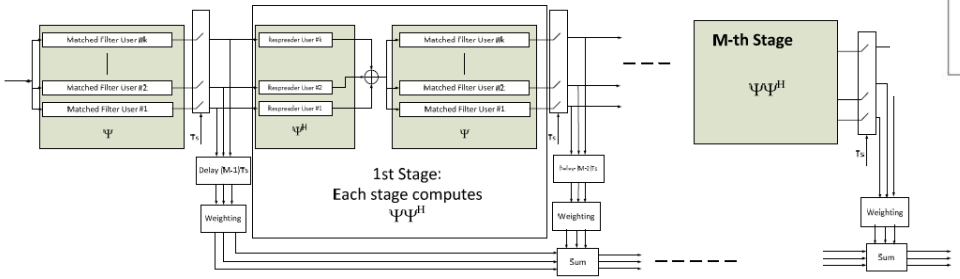
Exploiting code division multiplexing with decentralized multiuser detection in the satellite multibeam forward link

Riccardo De Gaudenzi[1] | Nader Alagha[2] | Martina Angelone[3] | Gennaro Gallinaro[4]

The distributed MUD approach - Demodulator

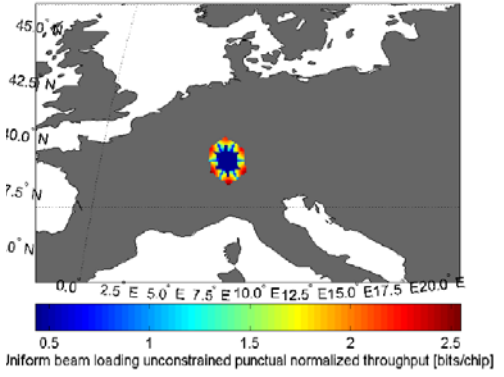
- MMSE-SIC CDM demodulator using multi-stage MMSE implementation
- Up to 3 dominant beams simultaneously demodulated
- Up to 32 CDM codes active per beam with SF=16 with ACM
- MUD with “smart” CDM allocation



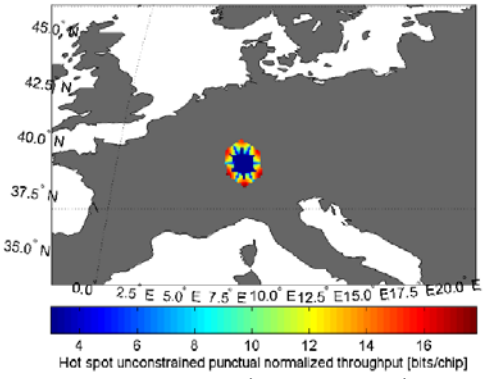


The distributed MUD approach – Realistic Results

Case	Number of colours	Beam throughput in B_u^{tot} uniform traffic distribution	Beam throughput B_u^{tot} hot spot	
FDM/TDM SUMF (with freq. flexibility)	4	1.02	2.0	[bits/symbol]
FDM/TDM with soft IC MUD	2	1.11	2.22	[bits/symbol]
CDM with MMSE-SIC MUD ($SF = 16$, $K_{beam}^{tot} = 28$)	1	0.89	5.86	[bits/chip]
TDM with precoding (10-1 users/frame)	1	0.77-1.18	4.34-6.40	[bits/symbol]



(a) Uniform beam traffic distribution (UD) case



Large loss due to the low performing DVB-S2X low SNR MODCODs

Large loss due to the multiplexing of 10 users/frame

Potential CDM distributed MUD attractive performance but… smart SUMF can do well too… see next one

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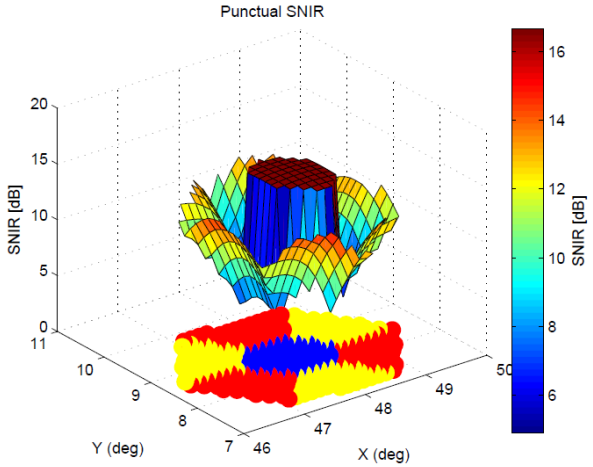
Adjacent Beam Resource Sharing for Hot Spot

Idea is to reuse adjacent beams for the hot spot traffic with a conventional 3 or 4 colors scheme and SUMF

- For 3 colors the throughput is 5 % higher than CDM with distributed MUD
- For 4 colors the throughput is 12 % lower than CDM with distributed MUD

- The scheme can be implemented with no changes in the modulator and demodulator!



Adjacent Beams Resource Sharing to Serve Hot Spots

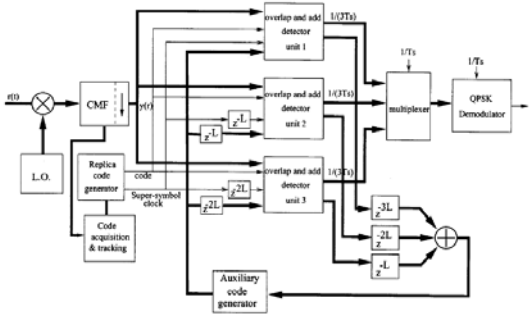
Nader Alagha, ESA
35th AIAA International Communications Satellite Systems Conference Trieste, Italy

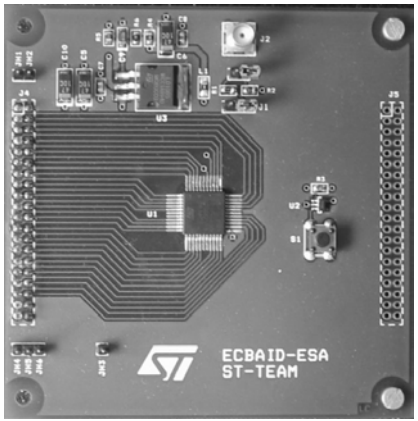
Adjacent Beams Resource Sharing to Serve Hot Spots

Nader Alagha[1]
European Space Agency Technical Research Centre, Noordwijk, The Netherlands

Is Satellite ahead of Terrestrial in adopting NOMA?

- The use of NOMA for satellite was identified quite early i.e. around 1998 with the development of FPGA/ASIC implementing Blind MOE detectors for CDMA
- A large amount of R&D performed starting in 2005 for enhancing Random Access ALOHA performance
- Several new RA schemes were quickly adopted in satellite standards and prototyped first and commercial products developed then

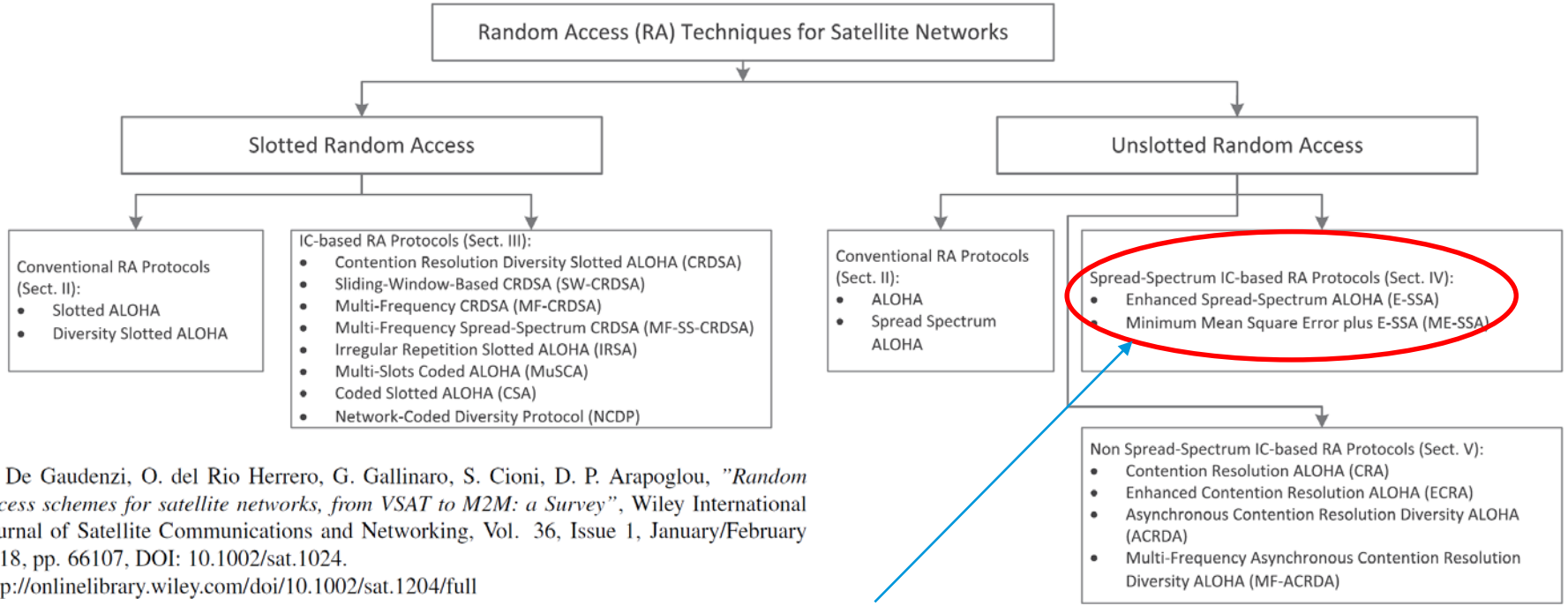




J. Romero, R. De Gaudenzi, F. Giannetti, M. Luise, *"A Frequency Error Resistant Blind CDMA Detector"*, IEEE Trans. on Comm., Vol. 48, No. 7, July 2000, pp. 1070-1076. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=855511

L. Fanucci, E. Letta, R. De Gaudenzi,F. Giannetti, M. Luise, *"VLSI Implementation of a CDMA Blind Adaptive Interference-Mitigating Detector"*, IEEE Journal on Sel. Areas in Communic., Vol. 19, No. 2, February 2001, pp. 179 - 190.

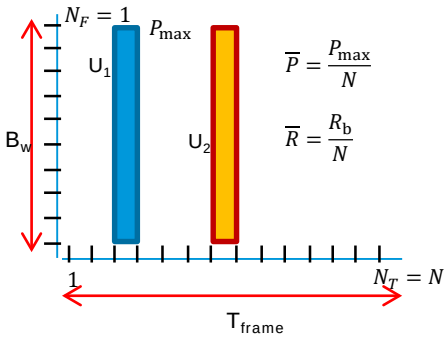
Is Satellite ahead of Terrestrial in adopting NOMA?



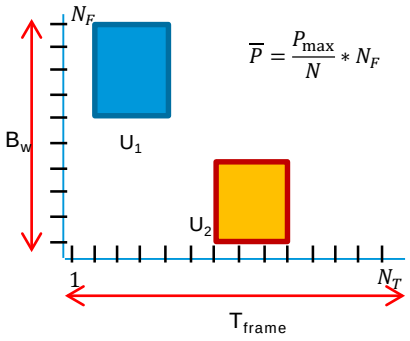
R. De Gaudenzi, O. del Rio Herrero, G. Gallinaro, S. Cioni, D. P. Arapoglou, *"Random access schemes for satellite networks, from VSAT to M2M: a Survey"*, Wiley International Journal of Satellite Communications and Networking, Vol. 36, Issue 1, January/February 2018, pp. 66107, DOI: 10.1002/sat.1024.
http://onlinelibrary.wiley.com/doi/10.1002/sat.1204/full

Most interesting option

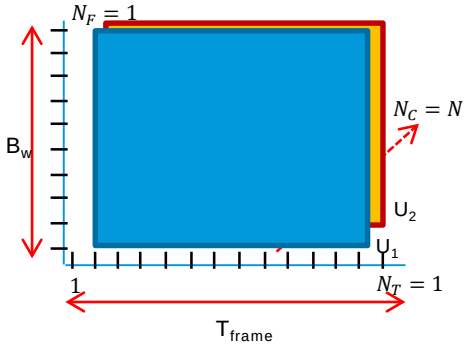
Terminal Peak-Power Trade-off



Time-slotted



Time / Frequency slotted



Spread-Spectrum

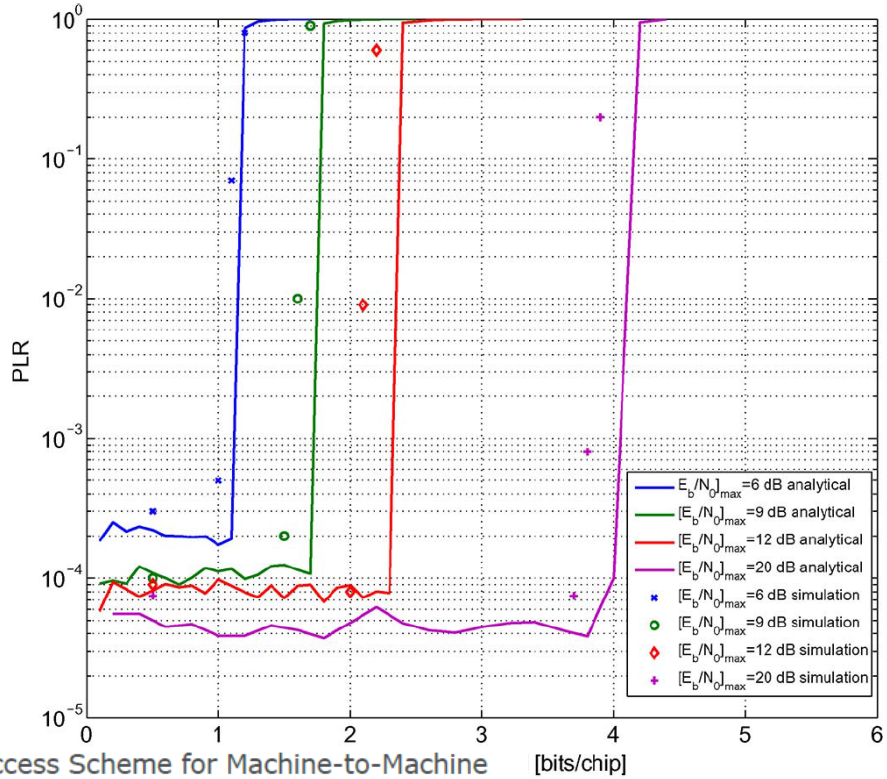
- The total bandwidth, B_w, and the resource allocation window, T_{frame}, are fixed
- The same quantity of user information is assumed to be transferred per T_{frame}
- The available multi-dimensional resources (number of slots / carriers / codes) are kept constant: $N_T * N_F * N_C = N$
- It is easy to verify that the "*time-slotted*" access requires the highest peak power per user (SS the lowest):

$$\frac{P_{\max}^{TS}}{P_{\max}^{SS}} = N \qquad \frac{P_{\max}^{TS}}{P_{\max}^{MF}} = N_F$$

Why Enhanced Spread Spectrum Aloha?

E-SSA has the following advantages:

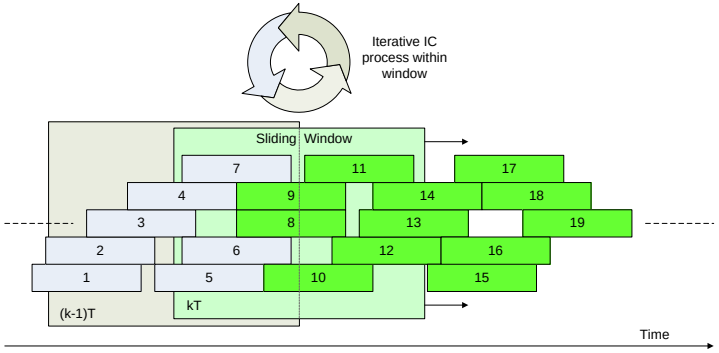
- Allows operations in a truly asynchronous mode, with no overhead for burst synchronization
- The terminal EIRP is in principle linked to the single user data rate
- Operates with a very large number of interfering packets thus reducing the instantaneous traffic fluctuation around its mean value
- The achievable throughput in pure RA mode is 2000 times larger than ALOHA!



O. del Rio Herrero, R. De Gaudenzi, "High Efficiency Satellite Multiple Access Scheme for Machine-to-Machine Communications", IEEE Trans. on Aerospace and Electronic Systems, Vol. 48, No. 4, Oct. 2012, pp. 2961-2989.

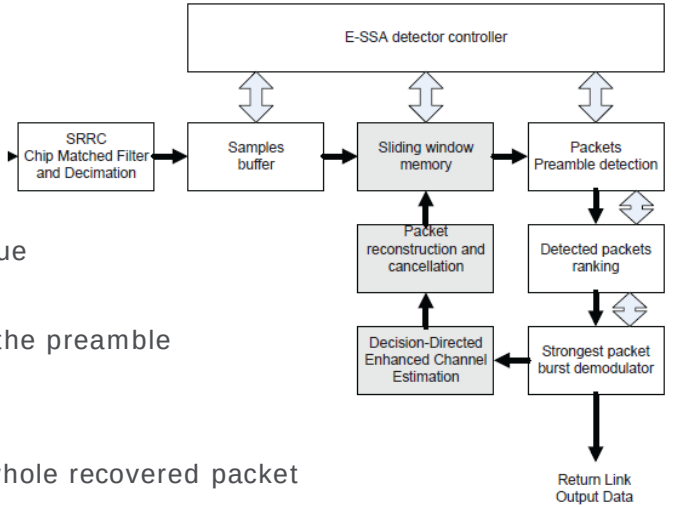
E-SSA Detection Algorithm Description

Window-based RA Iterative SIC Principle



Typical E-SSA detector parameters

- Sliding window size is 3 times the packet length (typical)
- Sliding window step is 1 packet length
- 3-4 IC iterations



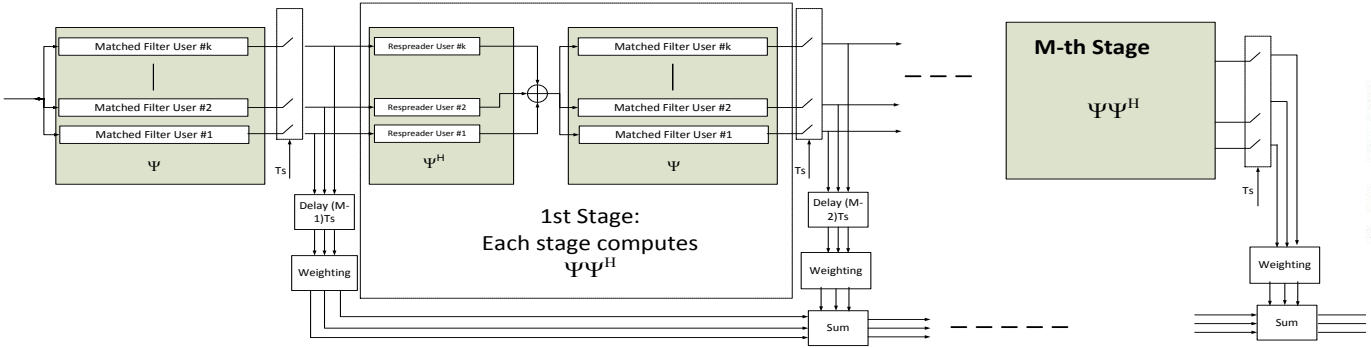
On each window step, iterate number IC times:

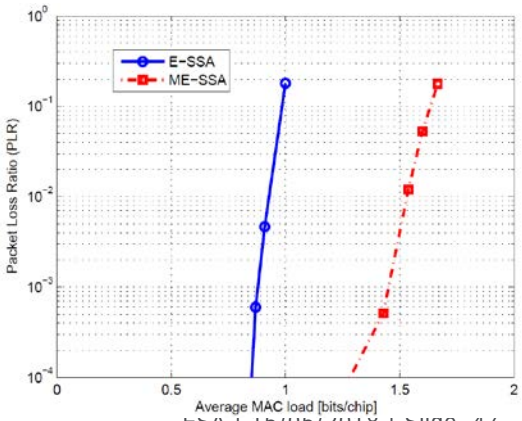
- Perform packets preamble detection and rank packets with highest SNIR value
- For each preamble that is detected:
  - Perform data-aided channel estimation for the selected packet over the preamble
  - Perform FEC decoding of the packet
  - If FEC decoder output is good after CRC check:
    - Perform enhanced data aided channel estimation over the whole recovered packet
    - Perform IC of the recovered packet

ME-SSA Key Features

G.Gallinaro, N. Alagha, R. De Gaudenzi, K. Kansanen, R. Müller, P. Salvo Rossi, "ME-SSA: an Advanced Random Access for the Satellite Return Channel", 2015 IEEE International Conference on Communications, London, United Kingdom, June 8-12, 2015, pp. 1-6.

- ME-SSA add an MMSE stage in front of the E-SSA SIC
- The use of multistage MMSE implementation allow a linear complexity with SF instead of matrix inversion cubic dependency
- ME-SSA can operate with long spreading sequences as E-SSA thus allowing single spreading sequence utilization for SF > 32
- Throughput very close to the theoretical bound adopting affordable complexity





...and why not for 5G mMTC???

E-SSA is a commercial reality for IoT

S-IoT
SATELLITE IoT TERMINAL

GEO HTS Ku or Ka based IoT/M2M connectivity solution
S-IoT revolutionizes the satellite IoT/M2M market enabling the lowest cost of ownership solution for M2M connectivity service over geostationary satellites.

The M2M terminal is powered by SatixFy's SX-3000 chip base band platform, paired with a small size electronic steerable antenna array, which enables the terminal to be compact, low-power, affordable, and self-install.

Low power
Sophisticated power management capabilities are implemented in the S-IoT terminal, resulting in efficient and long lasting battery/ solar operation. The terminals are constantly in deep sleep mode and consume power only upon transmission. At a typical M2M application, transmissions occur every 15 minutes and the ratio between active receive mode and deep sleep mode, can easily reach 1:1000 or more, resulting in very low average power consumption.

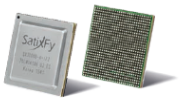
Low cost
The efficient waveform and system architecture, paired with self-install capability, reduces to a minimum the terminal and operational expenses. The satellite connectivity can be complemented by a cellular/terrestrial modem for dual mode use case. The Electronic antenna coupled with an Android or IOS application makes the system easy to install (no tools / equipment required).

IoT/M2M Wide Area Network
The terminals are part of a highly modular and flexible network, satellite-provider independent global service. The terminal data is tunneled over the satellite to a public cloud computing infrastructure that enables the network to be scaled-up rapidly with minimal support. The cloud-based data enables users to view the data on any devices i.e. smartphones and tablets, and send alerts through SMS.

Privately owned self operated IoT system
SatixFy's IoT solution enables quick deployment of hub and terminals using any Ku/Ka GEO space segment

The terminal supports low data rate on both the forward and return links based respectively on DVB-S2X, and spread ALOHA standard waveforms. The Extremely Low SNR modem is based on SatixFy's SX-3000 chip, enabling antenna size lower than 15cm.

HIGHLIGHTS
- Self-Install
- Low power
- Low cost
- Small size
- GEO Ka/Ku operation
- Software Defined Radio flexibility
- Low data rate



SatixFy's dedicated System on Chip (SoC) for 2 way satellite communications. The SoC is a highly integrated modem based on Software Defined Radio (SDR) architecture and includes 500MHz demodulator and modulator, DSPs, Dual core CPU and dedicated hardware accelerators.

A. Arcidiacono, D. Finocchiaro, F. Collard, S. Scalise, F. Lazaro Blasco, R. De Gaudenzi, S. Cioni, N. Alagha M. Andrenacci, *"From S-MIM to F-SIM: Making Satellite Interactivity Affordable at Ku and Ka-band"*, Invited paper for Wiley Int. Journal of Satellite Communications and Networking, Special issue on Ka-band Satellite Systems, Vol. 34, Issue 4 July/August 2016, pp. 575601, DOI: 10.1002/sat.1158.
http://onlinelibrary.wiley.com/doi/10.1002/sat.1158/full

https://www.eutelsat.com/en/services/broadcast/direct-to-home/SmartLNB.html

STiD337
satellite transceiver

ARM Cortex-based SoC with integrated DVB-S2/S2X forward link and IQ-streamer for return link

The STiD337 is a system-on-chip (SoC) for bidirectional interactive satellite applications.
The forward link comprises an integrated demodulator and data demultiplexer. The compute platform is based on a dual ARM® Cortex®-A9 architecture with Neon coprocessors and multiple ST231 DSP offload processors.
The return link implements an IQ streamer which streams a linked list of pre-calculated data to the integrated DACs for IQ output to external up-converters.
Accurate Network Clock Recovery (NCR) with precision real-time control is implemented for the most demanding applications.
A full range of interfaces and peripherals are provided to achieve very low cost solutions.

KEY FEATURES & BENEFITS
- Best in class power consumption exploiting 28 nm FDSOI process
- Integrated DVB-S/S2/S2X demodulator up to 60 Msps
- Dual- core ARM® Cortex®-A9 application CPU with NEON™ accelerator
- Quad ST231 offload CPUs to ensure sufficient compute for the most demanding applications
- High quality return channel processing including integrated FIR filters and dual 10 bit DACs.
- Range of peripherals
  - High-precision DACs, ADCs, USB, PCIe, SD card, eMMC, I²C, UART, etc.
  - Integrated Ethernet PHY
- Secure version with safe-boot and preloaded keys

KEY APPLICATIONS
- Outdoor 'Smart LNBs'
- Low-cost satellite modems
- Feeder and back-haul satellite infrastructure solutions
- Internet of Things (IoT) machine-to-machine (M2M) satellite comms
- Point-to-point telecoms

Egatel via eutelsat

The 'smart LNB' opens the door to a new wide range of satellite services. Based on a very low bit rate connection and sharing of the RF bandwidth among users, it allows satellite operators to offer these services in either unconnected or connected areas at a low cost at the equipment and service level.

The 'smart LNB' is the most flexible and versatile two-way satellite terminal in the market, featuring the most advanced technology in satellite transmission. It makes use of a high spectrum-efficiency modulation for the uplink to enable the provision of innovative Broadcast services and M2M applications, like Interactive TV, e-Health or domotics for the consumer market. Furthermore, it is nicely suit for or an effective deployment of smart grids for professional organizations such us Utilities (Electricity, Water, Gas...) in a very affordable way.

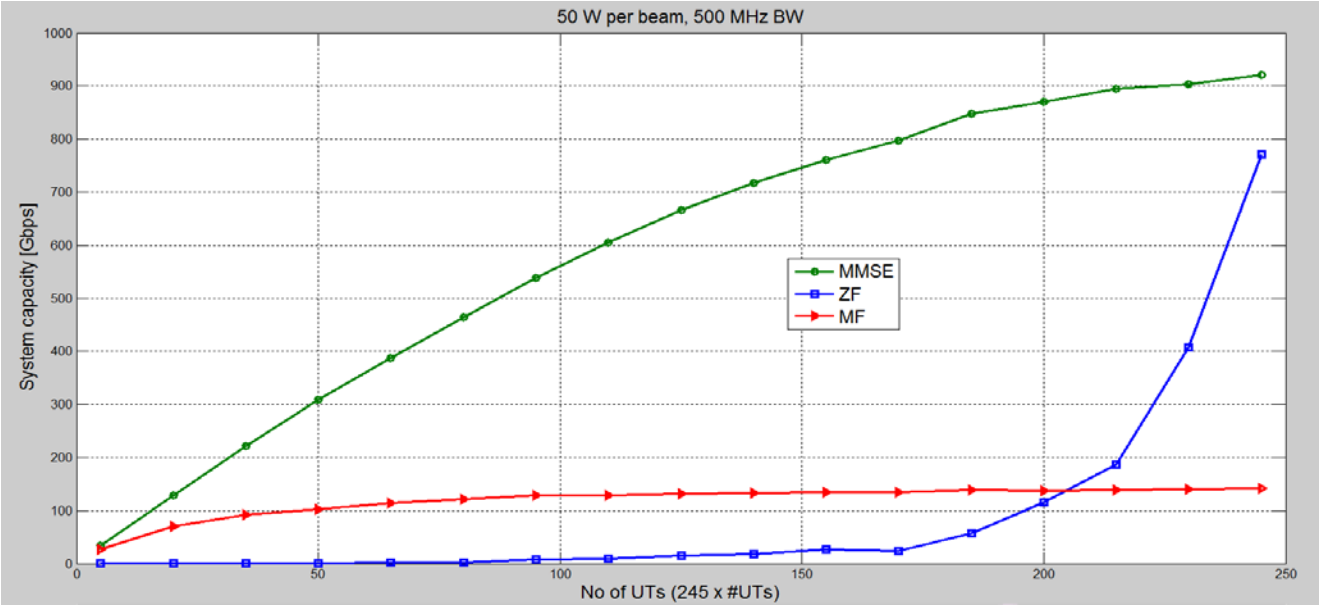
It has been design keeping in mind the ease of installation, so that it can be done rapidly by a non-professional user.

- Efficient return link based on Cutting-Edge technologies.
- Operation in Ku band (Rx: 10.7- 12.75GHz | Tx: 12.75GHz - 14.5GHz).
- Maximum output power (rms): 27 dBm.
- Double LNB with independent polarization for the reception of either interactive or broadcast services.
- Transmitter with dual polarization selectable from the Web Interface.
- High added-value M2M and Broadcast services for consumer (home control automation, e-health, connected TV...) and professional (smart grids, smart metering, telemetry...) markets.
- Reception and transmission of high and sustainable IP throughput.
- One single coaxial cable between ODU and IDU. Reuse of buildings existing infrastructure.
- Powerful and friendly Web GUI for management and configuration.
- Express and simple installation: From the packet to operation in a few steps.
- Huge compactness: 46x150x100mm.

...and the first ME-SSA prototype is under development!

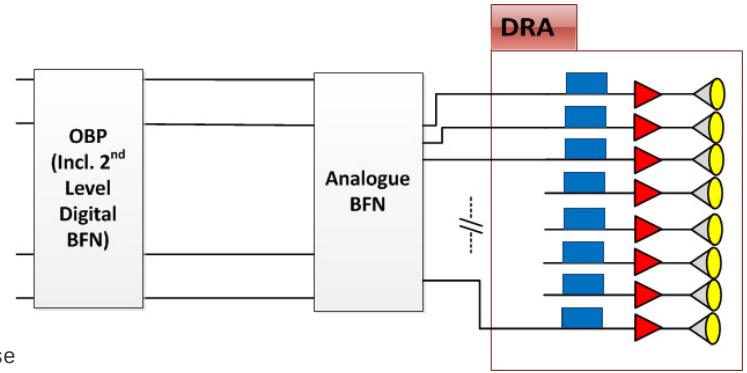
Will massive MIMO Work over Satellite?

Will massive MIMO have a chance in current single feed per beam multibeam satellites? - First analysis does not show any potential for ZF



Will massive MIMO Work over Satellite?

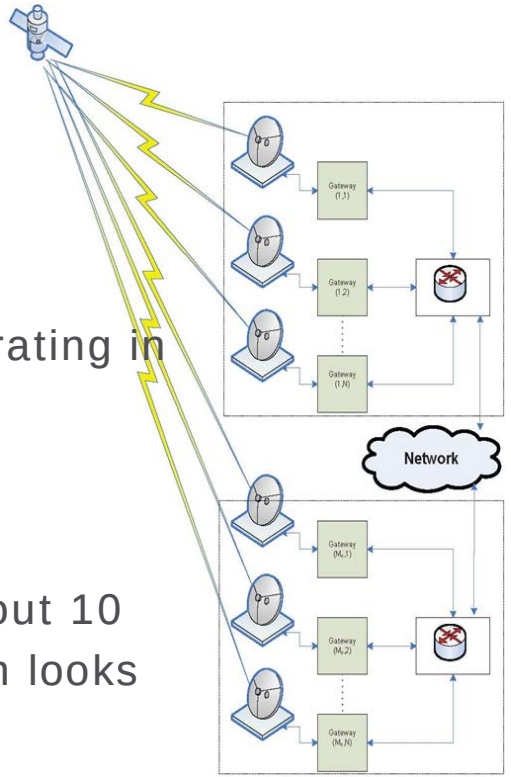
- VHTS will require active antennas with large number of feed elements
- Will massive MIMO have a chance in satellites with active antennas?
  - VHTS calls for using Ka-band or above with users having a directive antenna -> AWGN channel -> no multipath fading to combat
  - First analysis results assuming ideal channel estimation….
  - .. but satellite bands typically do not support TDD but FDD => channel estimation is cumbersome



The Feeder Link Bottleneck

- High throughput (GEO) satellites require a very high speed feeder link with ground
- Different approaches possible:
    1. Large RF GWs operating at Q/V or even W-band
    2. Small RF GW sharing the Ka-band user link band
    3. Optical GWs with very high rate optical links

1. Expensive approach – tenths of large RF GWs required operating in smart diversity – terrestrial interconnection costly
2. Easier to install, lower connection cost but reusing user link precious bandwidth
3. In principle a single gateway can feed a VHTS but then about 10 GWs in proper location for availability – smart GW approach looks more promising – new technologies



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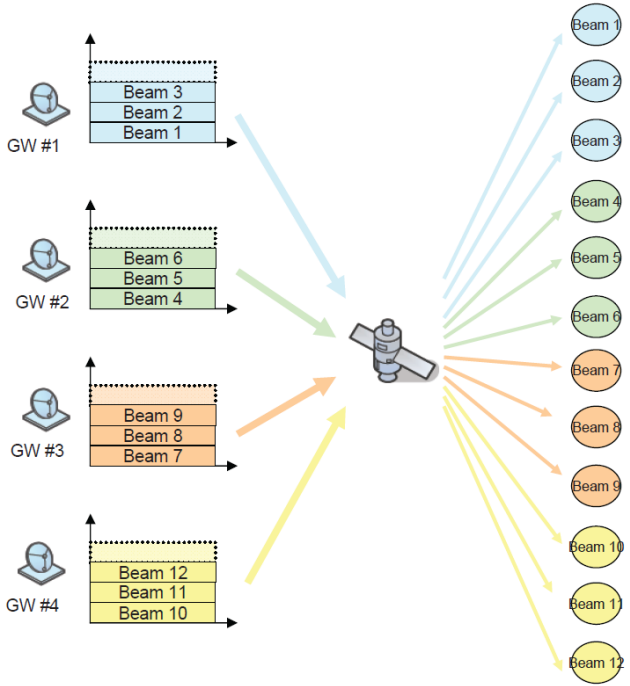
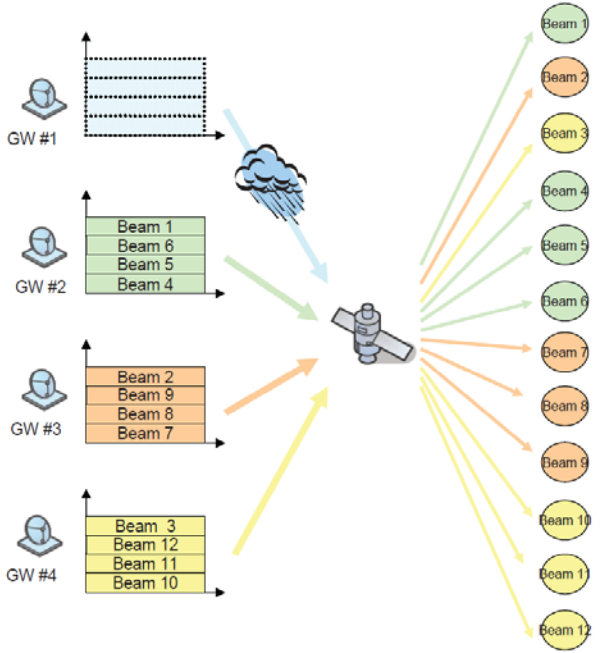
The Feeder Link Smart Gateway Concept





If one GW is faded the extra capacity of the others is used to replace the faded one

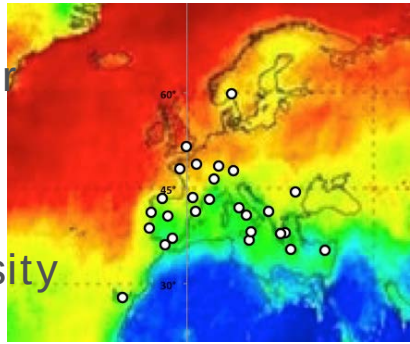
P. Angeletti, R. De Gaudenzi, E. Re, PCT/IB2012/001742, "Multibeam Satellite Communication System and Method and Satellite Payload for Carrying out such a Method", PCT filing, September 11, 2012, US filing US/2015/0188623 A1, July 2015.

Optical Feeder Link Open Issues

Optical feeder link is potentially attractive but:

- Heavily affected by atmospheric impairments (clouds, turbulence) -> Spatial diversity + pre-correction techniques
- Most robust optical modulation is digital with 3 options:
  - a) On-board user link signal regeneration -> complex and inflexible payload solution
  - b) Sampling and quantizing the analogue signal on-board -> bandwidth expansion of a factor 16 or so
  - c) RF over optical analogue transmission -> Best solution for the payload but power inefficient unless coherent SSB modulation/demodulation feasible
- Single GW interconnection cost too high -> N+P smart GW diversity to reduce bit rate by N (e.g. 3 active with 9 extra in diversity)

99% Availability N+P	99.9% Availability N+P
1+3	1+6
3+9	3+13



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Thank you for your attention!
European Space Agency