Ingegneria delle Telecomunicazioni

Satellite Communications

13. Satellite Services and Standards

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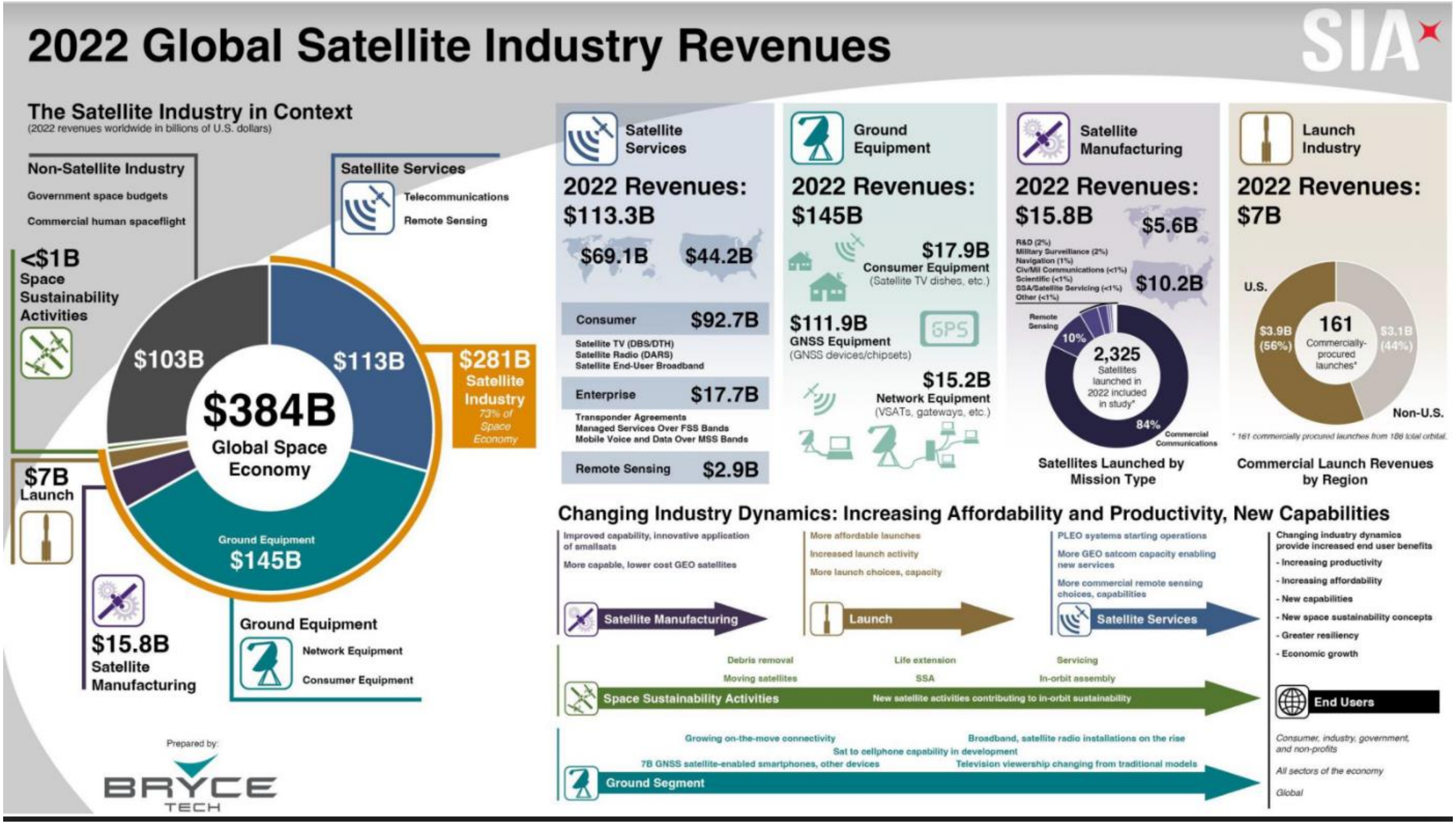
PART 1 – SATELLITE MARKET

The Satellite Market 2022

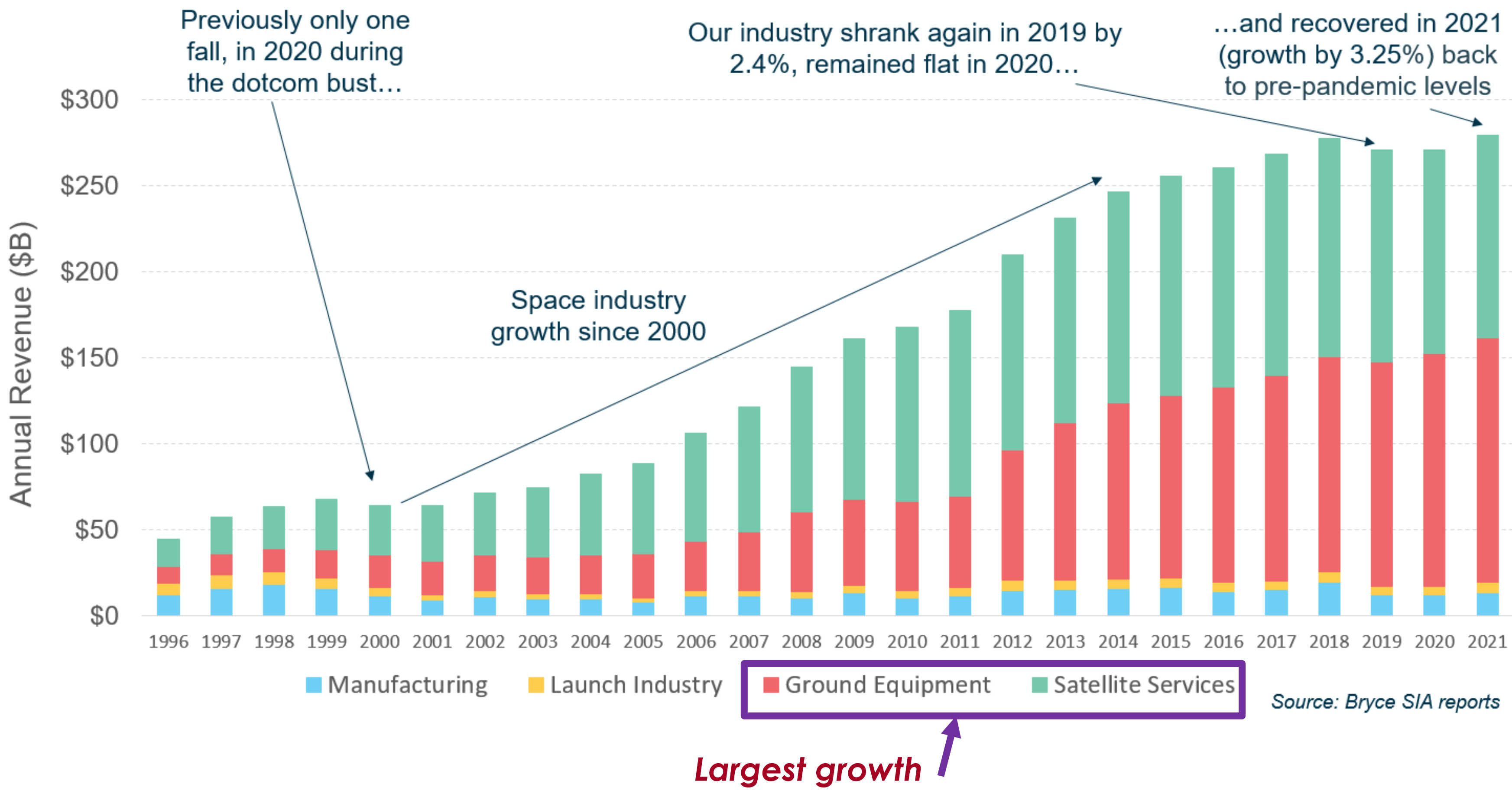


The Satellite Market 2022

- **The market is dominated by:**
  - Satellite ground equipment (145 B US$) and services (113 B US$)
  - Sizeable budget for governmental and human spaceflight (103 B US$)
  - 7 billions of GNSS enables mobile devices – the largest satellite market!

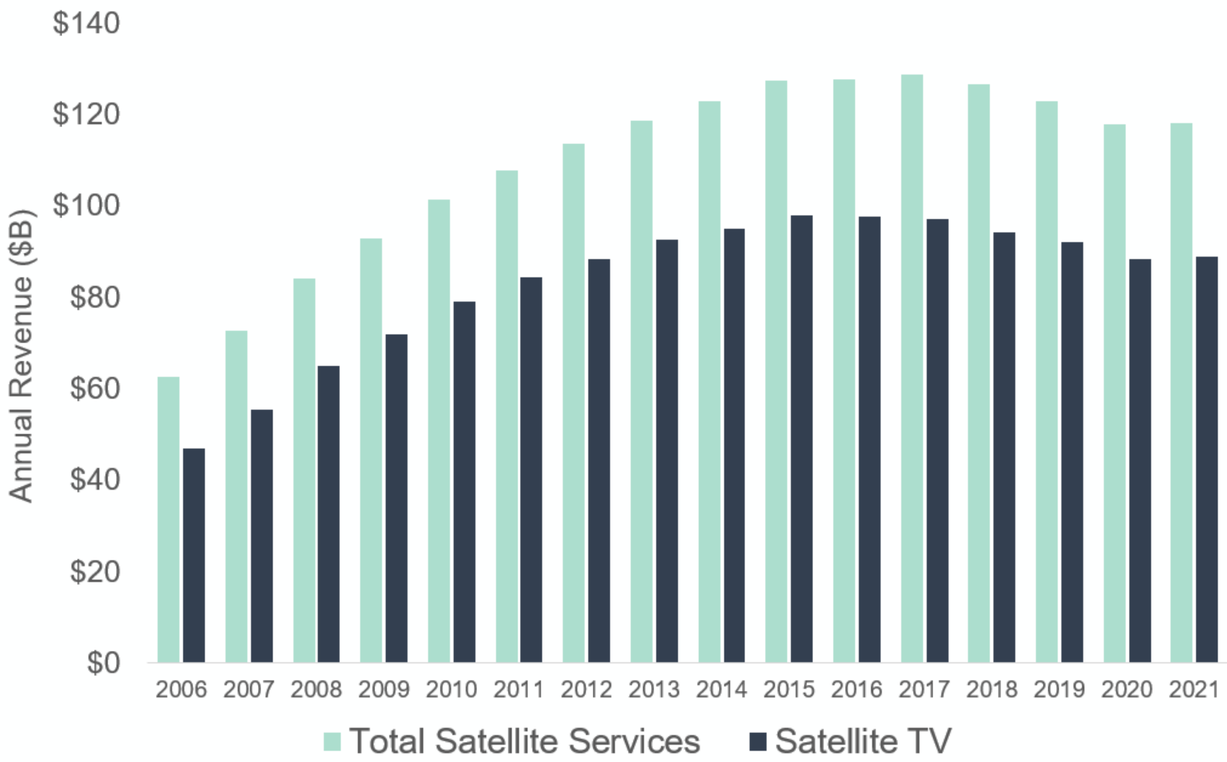
- **The riskiest business is where there are less revenues:**
  - Satellite manufacturing 15.8 B US$
  - Launch industry 7 B US$
  - Heavily subsided sector as large innovation required, and volumes often limited
  - Europe facing heavy competition from USA, India and China

The Satellite Market Evolution



Source: Bryce SIA reports

The Satellite Market Evolution



Source: Bryce SIA reports

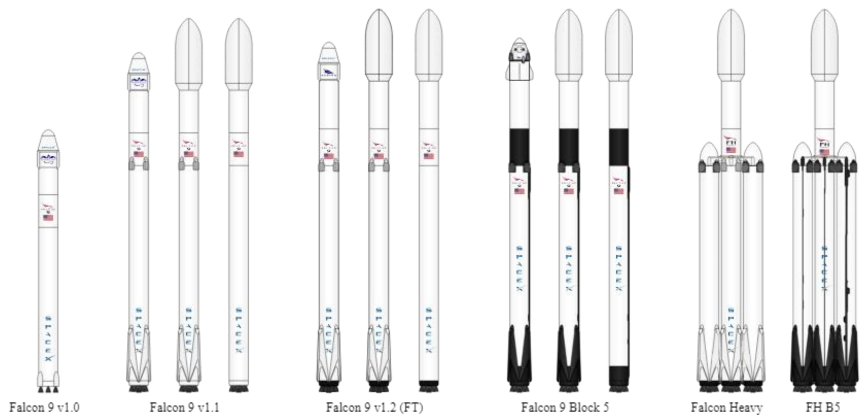
- **Satellite services revenue peaked** in 2017, pulled down by falling satellite TV revenue.
- **Inflection point expected in 2022** when revenue for other services grow more quickly than satellite TV slowly declines.
- **New SatCom markets required** to offset decline in Satellite TV and to sustain and grow the SatCom market.

The Launcher Market Evolution

- Europe leadership with Ariane 4-5 launchers has been taken over by SpaceX in US thanks to its unprecedented growth in terms of Falcon 9 launch rates and launch cost reduction also due to booster reuse
- ESA's Ariane 6 has been launched in July 9 2024 with 4 years delay – 50% less expensive

ESA Ariane 1-5 family

ESA Ariane 6 family

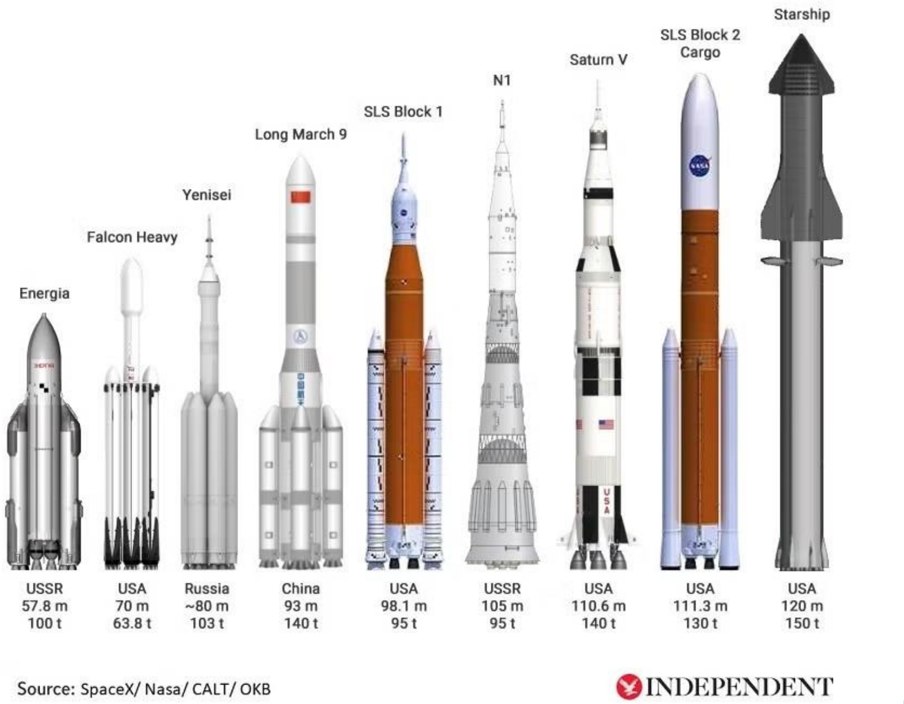


SpaceX Falcon family

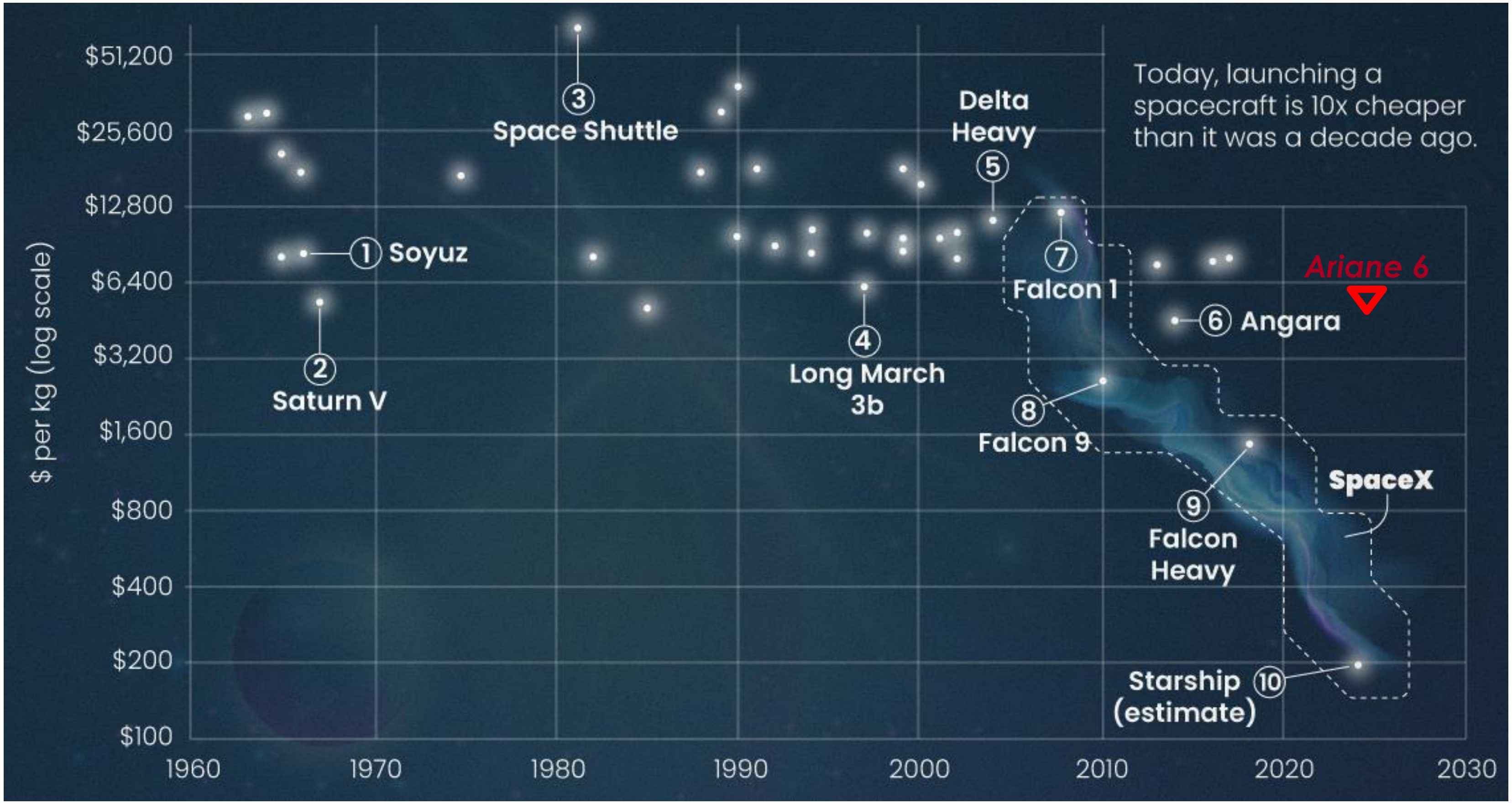
The Launcher Market Evolution

- **The development of SpaceX Starship launcher is opening up a new era in terms of single launch capabilities and cost – target is to also bring human on Mars**
- **Planned full reusability and launch rate every 2 days**

(Ariane 6 is planning 9 launches/year)

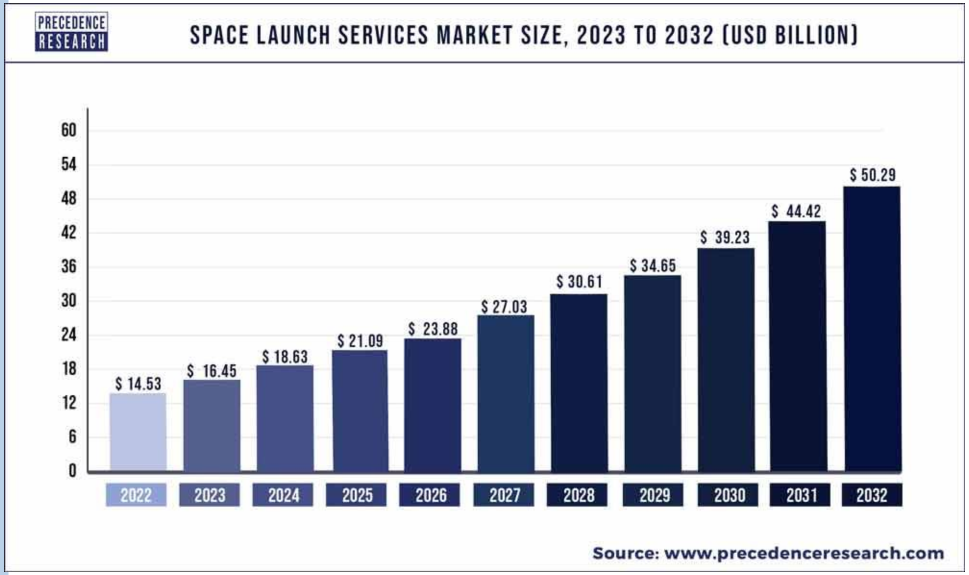


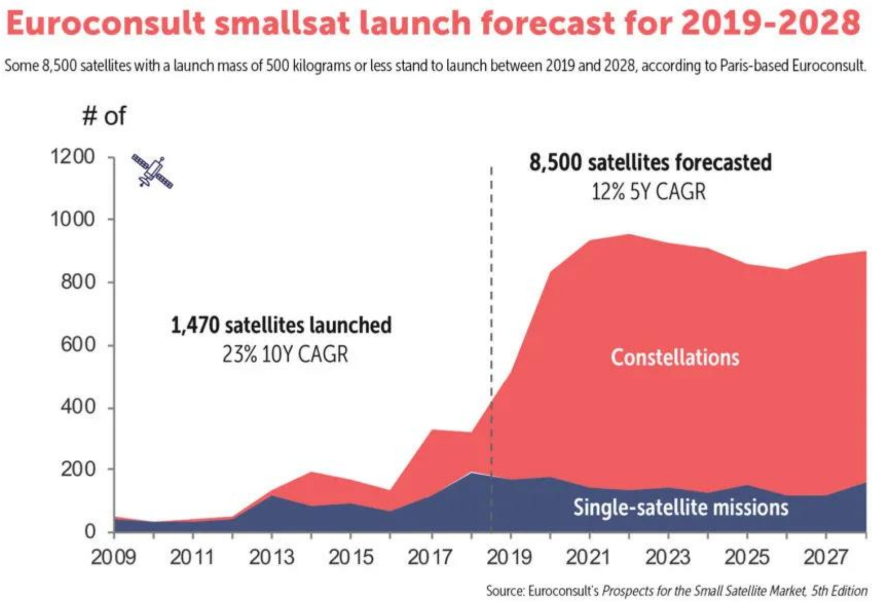
The Launcher Market Evolution



The Launcher Market Evolution

- **Large growth of the small satellites launch market mainly related to constellations**
- **GEO launch market steady or declining**





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PART 2 - SATELLITE SERVICES

Classification of Commercial Satcom Services

- **Broadcast services**
  - Television and radio broadcasting to home or cable head ends
  - The most successful commercial satellite application currently declining
- **Fixed services**
  - Point-to-point communication partly overcome by terrestrial fiber
  - Satellite News Gathering
- **Broadband fixed access**
  - Covering digital divide areas (no terrestrial Internet access) or private networks
  - Increasing market share
- **Mobile access to individual users and large platforms**
  - Complementing terrestrial network coverage at regional or global level (rural areas, emergency, military forces, airplanes, ships, trains)
  - Market with up and downs

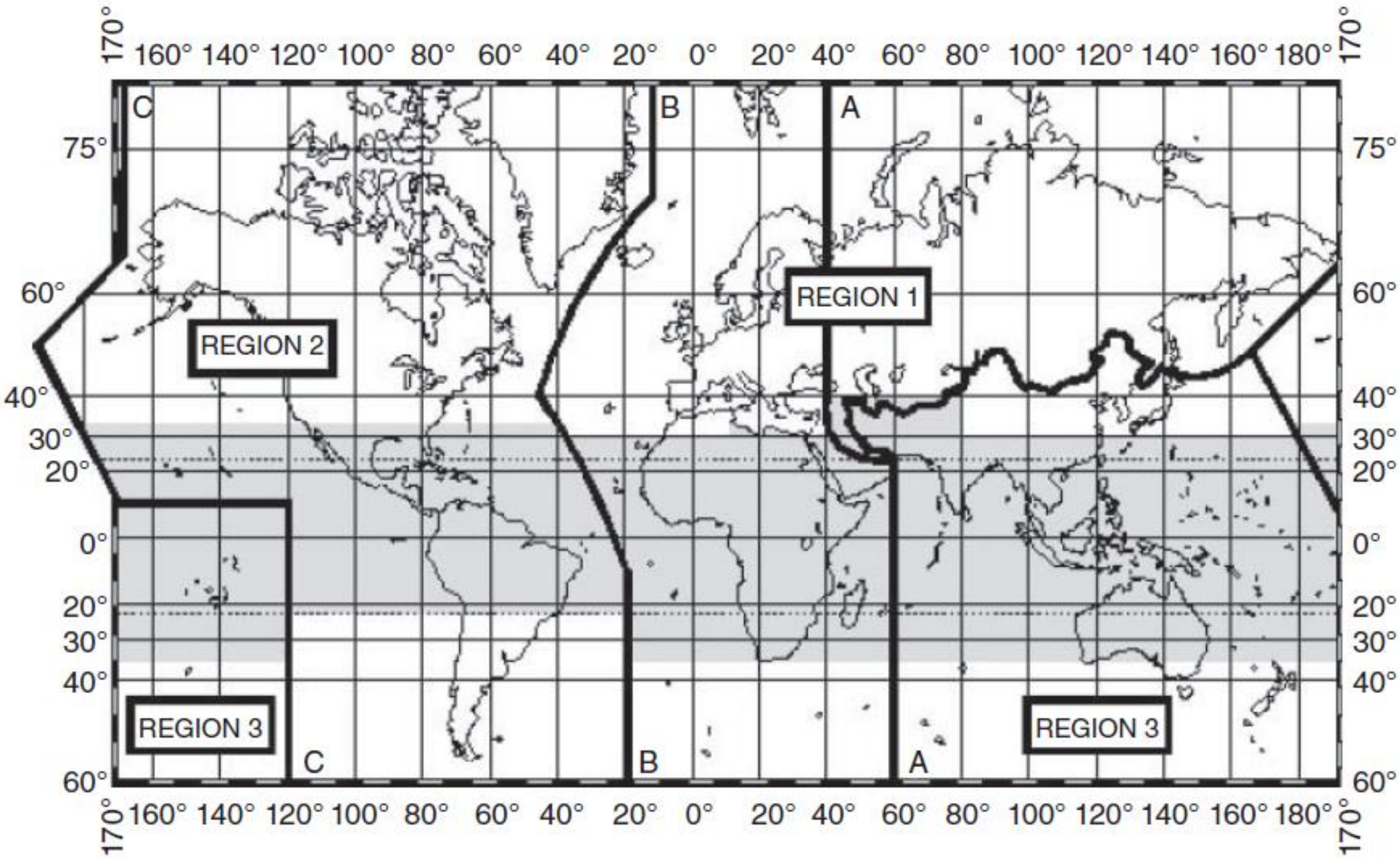
Satellite Frequency Bands and Regulations

- The Radio Regulations (RR) are by the ITU, a UN organization based in Geneva
- RR defines the rules to be applied in using the spectrum, as well as the rights and obligations resulting from this use
- Periodically reviewed by the ITU World Radio Conferences/Regional Radio Conferences
- RR can be downloaded from https://www.itu.int/pub/R-REG-RR
- Official ITU space radiocommunication services covered by the RR are:
  - Fixed-satellite service (FSS)
  - Mobile satellite service (MSS)
  - Broadcasting satellite service (BSS)
  - Earth exploration satellite service (EES)
  - Space research service (SRS)
  - Space operation service (SOS)
  - Radiodetermination satellite service (RSS)
  - Inter-satellite service (ISS)
  - Amateur satellite service (ASS)

Frequency (GHz)	Band
1–2	L
2–4	S
4–8	C
8–12	X
12–18	Ku
18–27	K
27–40	Ka

Satellite Frequency Bands and Regulations

- The ITU RR regions – frequency allocations are region dependent



Satellite Frequency Bands and Regulations

- Simplified ITU RR frequency bands mapping on services

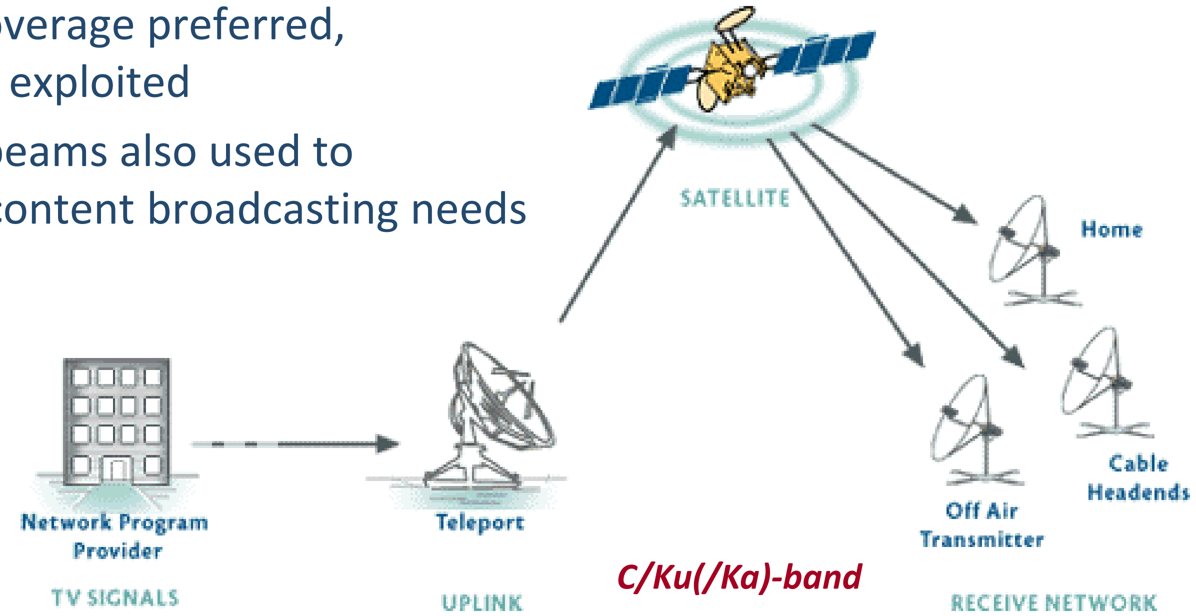
Radiocommunications service	Typical frequency bands for uplink/downlink (GHz)	Usual terminology
Fixed-satellite service (FSS)	6/4	C band
	8/7	X band
	14/12–11	Ku band
	30/20	Ka band
	50/40	V band
Mobile satellite service (MSS)	1.6/ 1.5 and 2.0-2.2	L band S band
	30/20	Ka band
Broadcasting satellite service (BSS)	2/2.2	S band
	12	Ku band
	2.6/2.5	S band

GSO Systems Architecture: Broadcasting Satellite System

Satellite Broadcasting System Architecture:

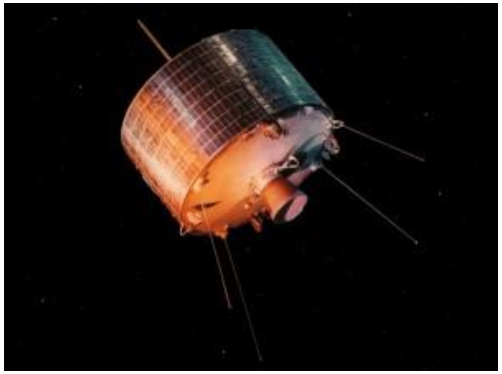
- Gateway connected to the network program provider(s)
- Feeder uplink connecting the terrestrial gateway to the satellite
- User downlink connecting the satellite to the users
- Satellite acting as a bent pipe transponder from the gateway to users (home, head-ends)
- Typically, wide area coverage preferred, and C or Ku(Ka)-bands exploited
- Regional or linguistic beams also used to best match linguistic/content broadcasting needs

The acronym DTH applies (also) to similar services transmitted over a wider range of frequencies (including Ku- and Ka-band) not specifically designated for BSS



GSO Systems: Broadcasting Satellite System

INTELSAT 1 (Early Bird)
April 6, 1965 by Hughes (USA)



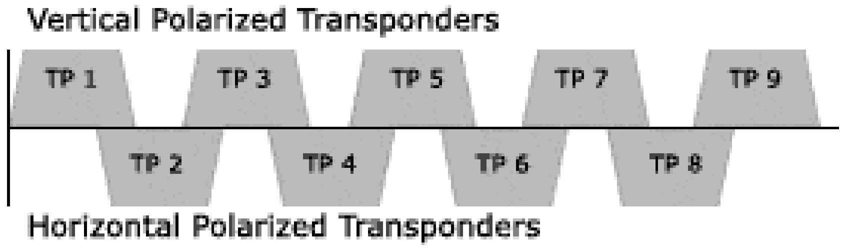
The Europe dawn: ESA OTS-2 (1977)
first GEO sat with six Ku-band transponders by British Aerospace - Few analogue TV channels

Satellite broadcasting evolution 1965-2023

Today: Aribus Eutelsat Hot Bird 12F/FG AD 2023
7 premium TV platforms, over 600 pay-TV channels, 300 free-to-air channels, and 500 HDTV and UHD channels. With its unique pan-European coverage, in Europe alone, Hotbird reaches 130 million homes

DTH services in Ku-band

Europe:

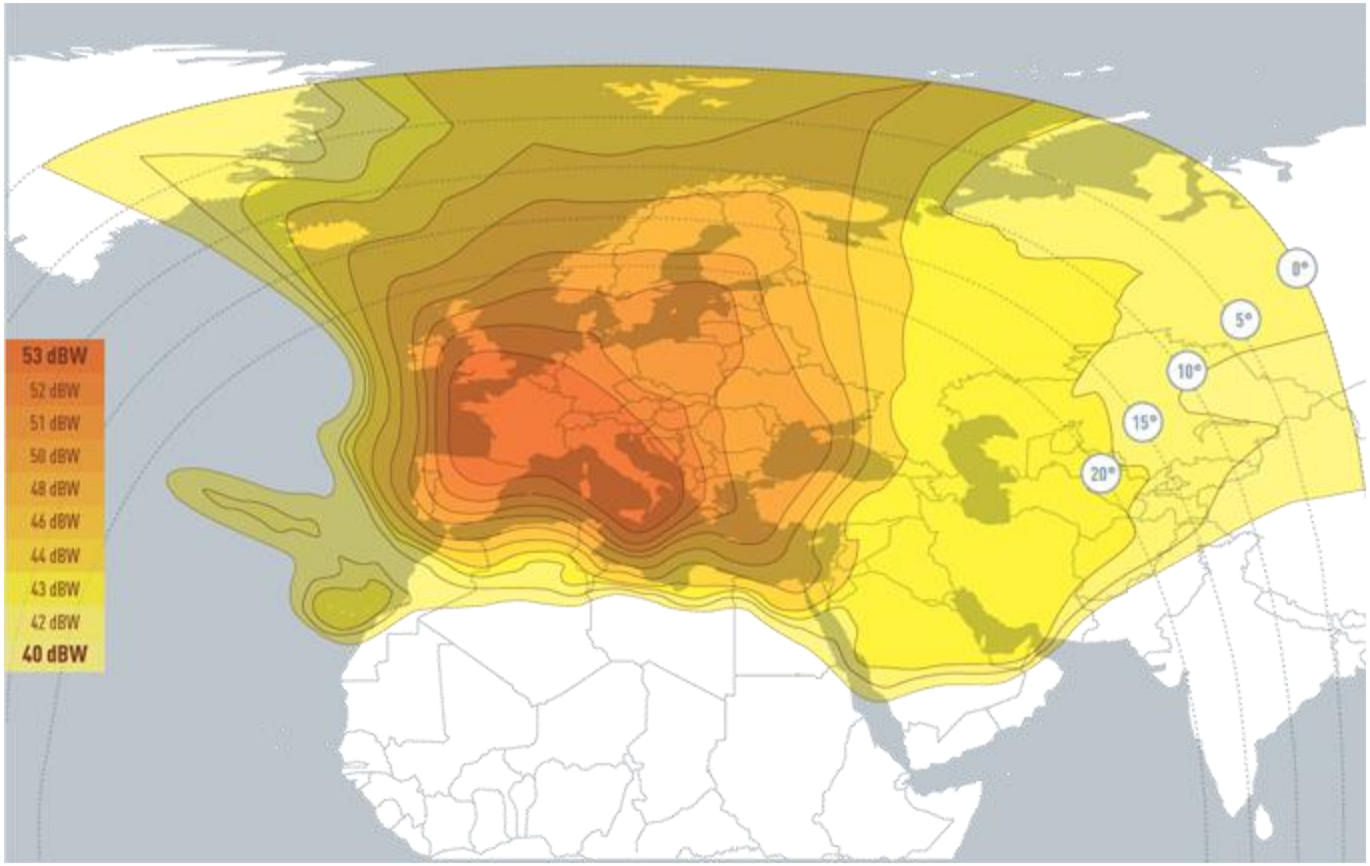


- Downlink frequencies: 10.7-12.75 GHz
- Uplink frequencies: 12.75-14.5 GHz

- Adjacent transponders may be transmitted with alternate polarity (to increase channel isolation with reduced carrier spacing). The user terminal LNB is capable of switching between signal polarity
- Typical DTH transponder bandwidth is 36 MHz but also 27, 33, 54 and 72 MHz
- Number of Ku band transponders per satellite depends on the platform: recent SES-6 satellite (E3000 platform) contains 48 transponders (36 MHz equivalent) – DTH satellites typically take up to ~64 transponders
- Transponder transmit power 100-300 W (typical 150 W)
- Satellite antenna size diameter: 1-2 m – user terminal antenna 40-60 cm
- Single beam DTH satellites covering Europe needs small antenna size (to cope with the large service area). DTH satellites with linguistic beams might use larger antenna size

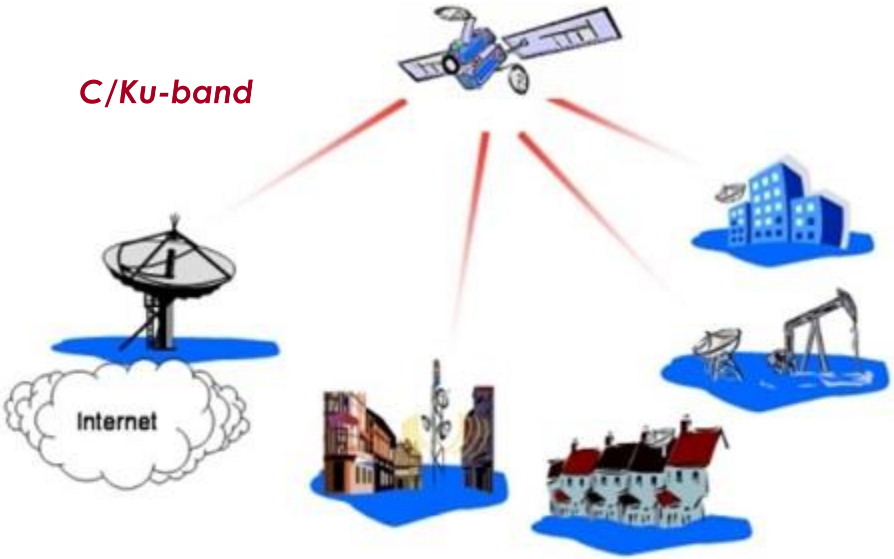
GSO Systems: Broadcasting Satellite System

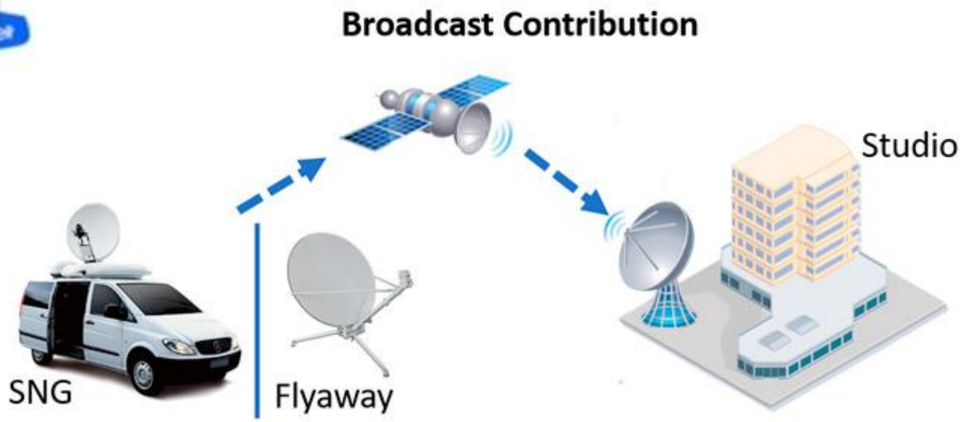
Typical Eutelsat Hot Bird BSS coverage



GSO Systems: Fixed Services Satellite System

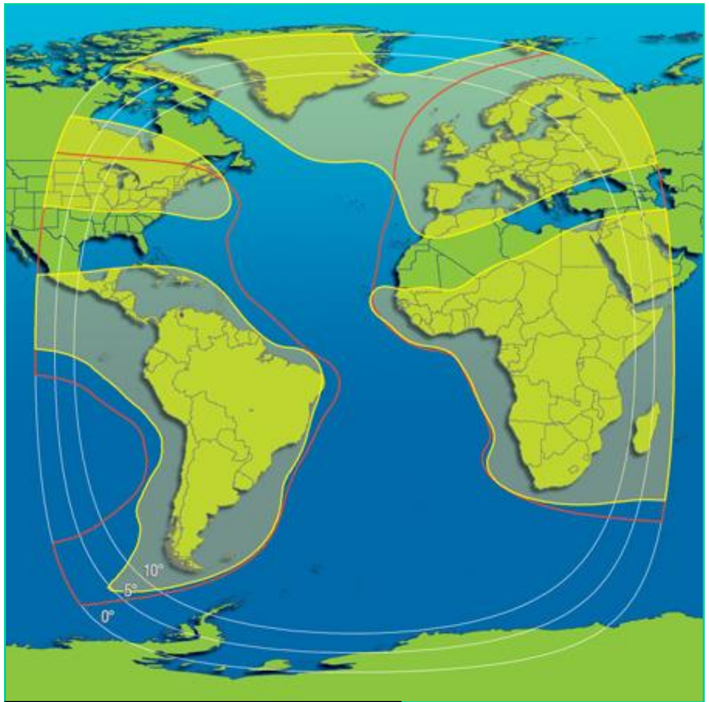
Satellite Fixed Satellite Services System Architecture:





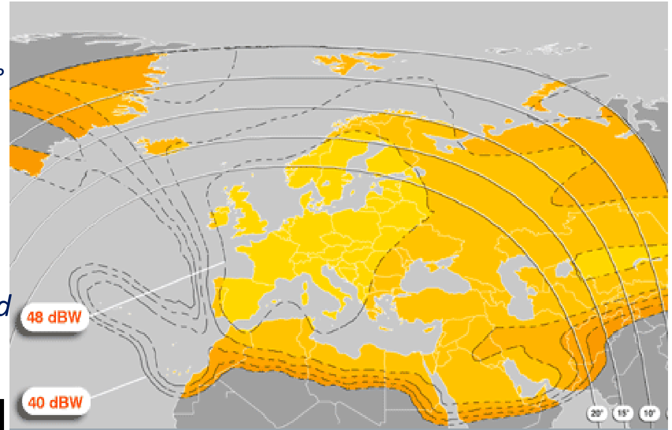
GSO Systems: Fixed Services Satellite System

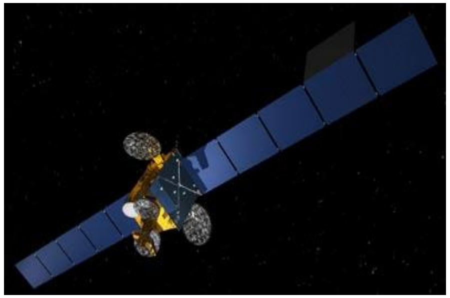
Typical regional and multi-regional FSS coverage

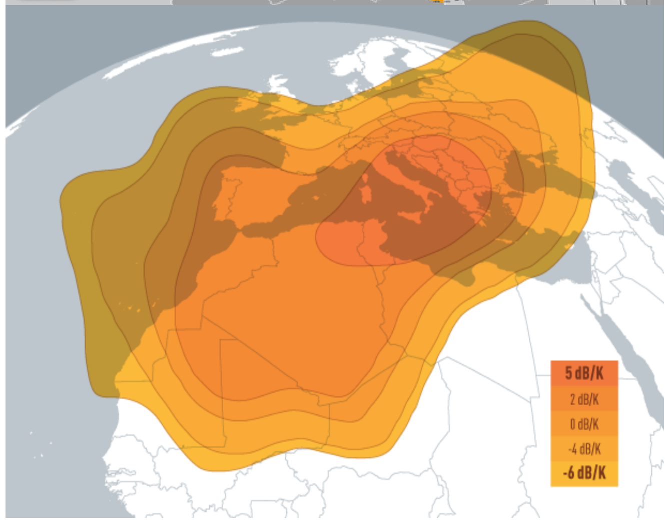


EUTELSAT 3A, deployed at 3° East, delivers users coverage of Europe and North Africa for services that include mobile backhaul, data networks, IP backbone connectivity and maritime applications.

Launched on 1/5/2007. 24 C band transponders

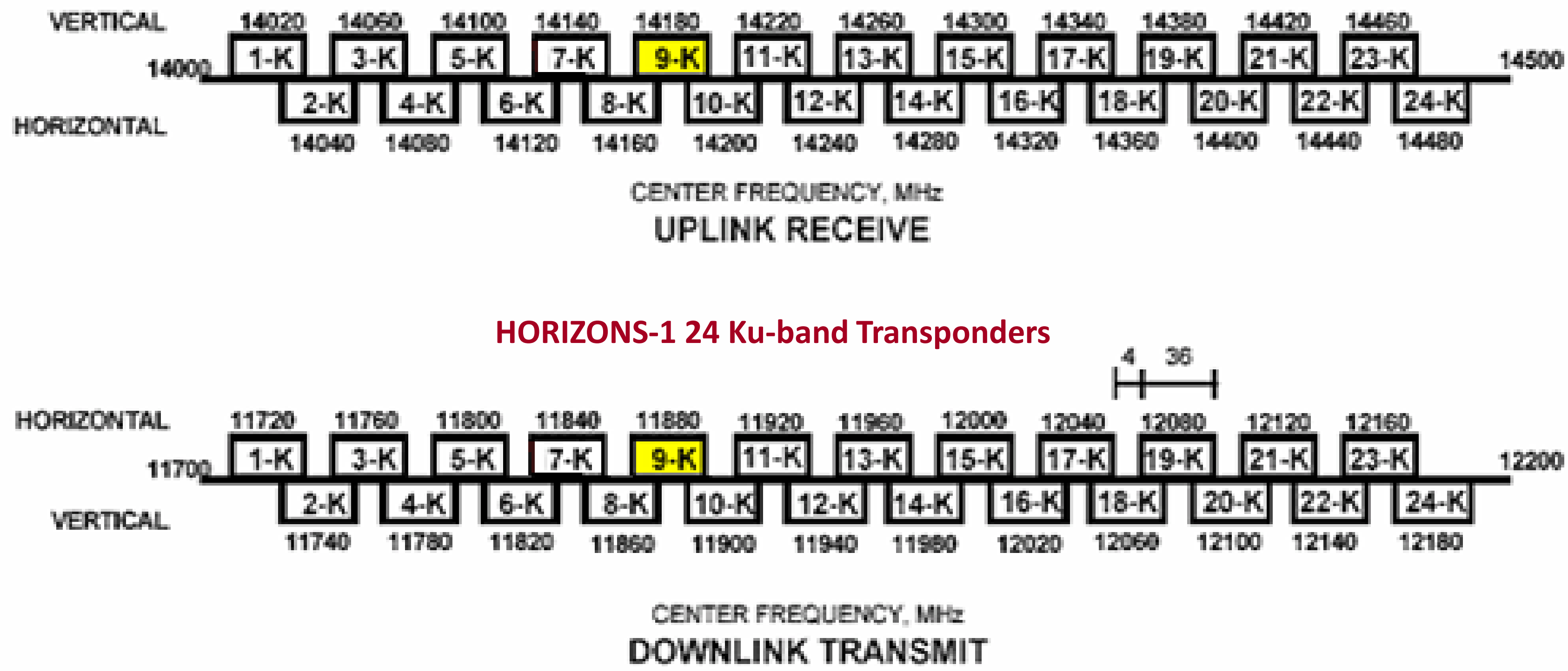






- *INTELSAT 907 Launched on February 17th, 2003 carries 22 Ku-band and up to 76 C-band transponders (in 36 MHz equivalents),*
- *Data connectivity and voice communication for passengers and operational purposes in the cruise, ferry and offshore sectors.*
- *Ku-band services: DBS, VSAT, Maritime connectivity, backhauling for DTH*

FSS Typical frequency plan /satellite transponder layout



- Dual use of polarization, different frequency bands for uplink and downlink, 40 MHz spacing (transparent payload)

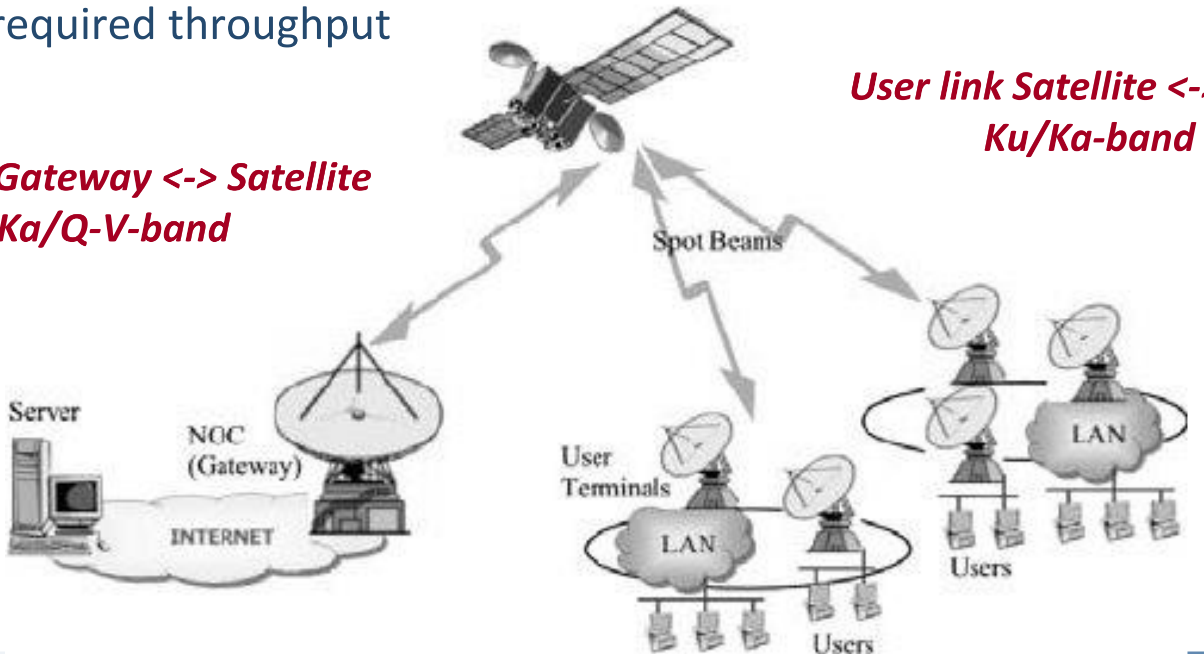
- A single channel can relay up to hundreds of Mbps, if a suitable antenna, power amplifier and modulation equipment is used on the ground.

GSO Systems Architecture – Broadband Access System

- Gateway(s) connected to terrestrial high-speed backbone
- Feeder link connecting the satellite to the terrestrial gateway
- User link connecting the users to the satellite
- Satellite acting as a bent pipe transponder from/to gateway to/from users
- Multiple beams to increase the frequency reuse and satellite antenna gain
- For high throughput satellites multiple gateways spatially separated are required to support the required throughput

User link Satellite <-> Users
Ku/Ka-band

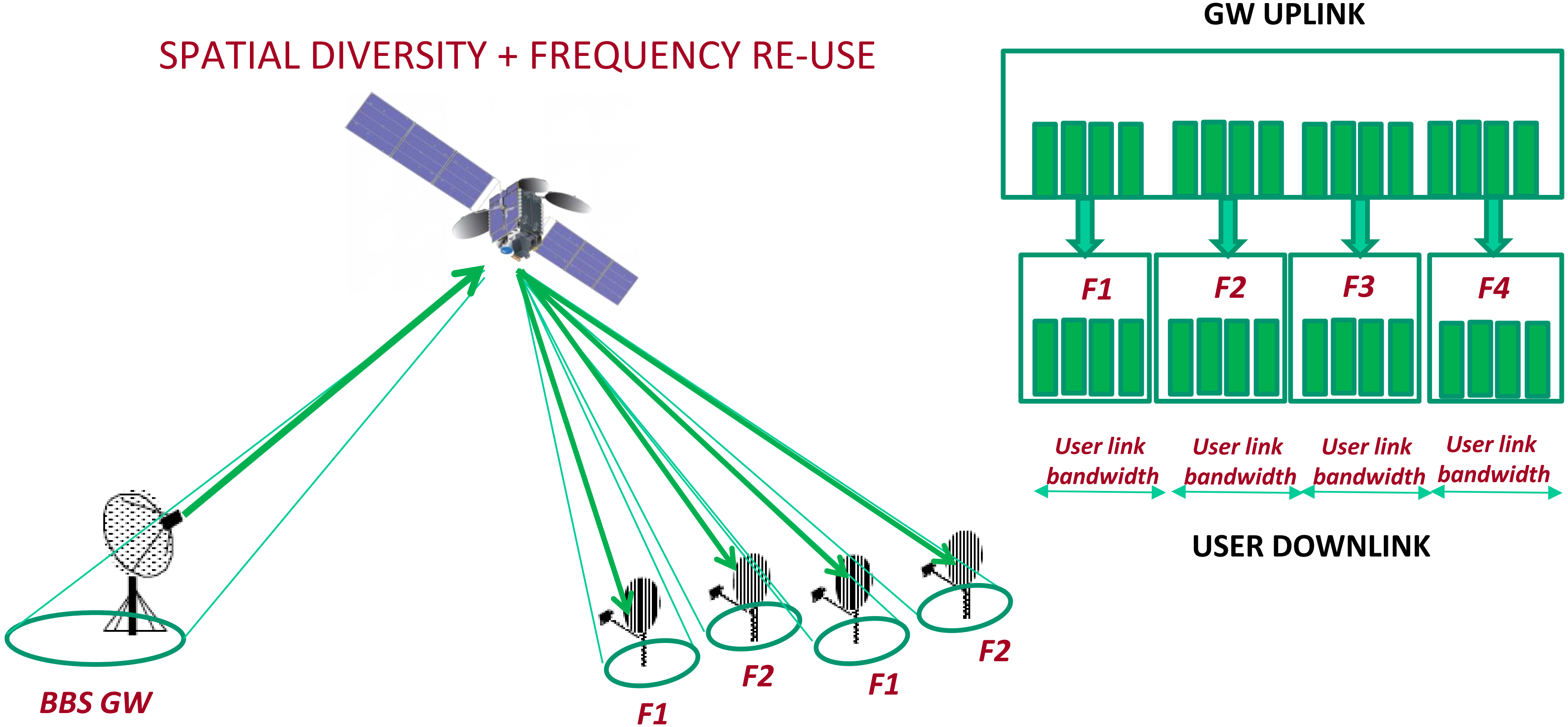
Feeder link Gateway <-> Satellite
Ku/Ka/Q-V-band



GSO Systems Architecture – Broadband Access System

Solution borrowed from terrestrial wireless cellular networks:

SPATIAL DIVERSITY + FREQUENCY RE-USE



The user link bandwidth is re-used several times within the service area=> network capacity increase

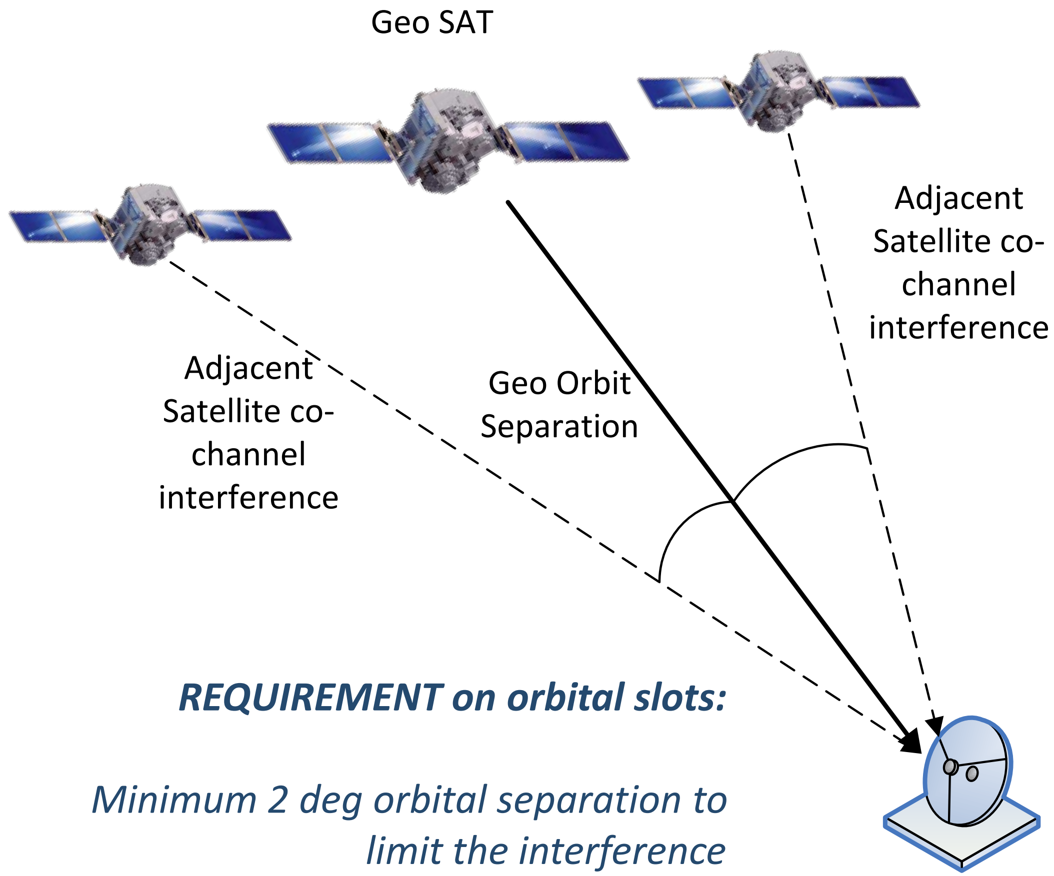
GSO - Inter-Satellite (external-system) Interference

REQUIREMENT on emission:

No coordination policy required if external interference < 6% of system noise level: considering the two nearest interferers, for the victim satellite we should have

$I_0 < 0.12\, N_0$ *or* $I_0/N_0 < -9.2$ dB

> ***Example:***
>
> $C/N_0 = 81$ dBHz
>
> **How much is the external interference degradation?**



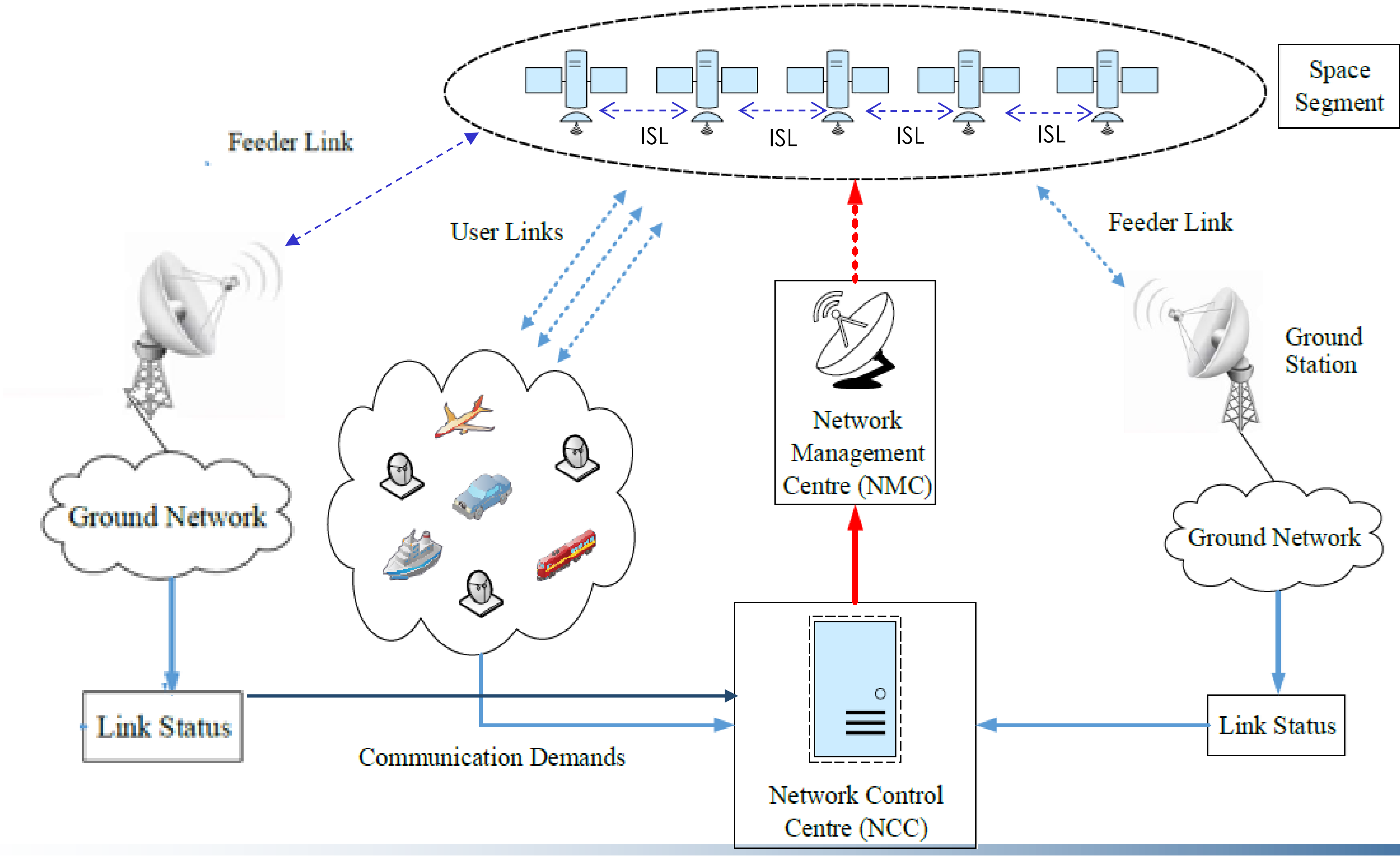
REQUIREMENT on orbital slots:

Minimum 2 deg orbital separation to limit the interference
For Ku-Band services in Europe the minimum is 3 degrees

NGSO System Architecture

- Service provided:
  - Mobile voice/data links (e.g. Iridium, Globalstar)
  - Broadband access (O3B, Starlink, Kuiper)
- Gateway(s) connected to terrestrial high-speed backbone (for non real time services e.g. IoT one may be enough)
- Feeder link connecting the satellite to the terrestrial gateways
- User link connecting the users to the satellite
- Satellite acting as a regenerative or bent pipe transponder from/to gateway to/from users
- Multiple beams to increase the frequency reuse and satellite antenna gain
- Multiple gateways required to achieve the required throughput
- ISL to reduce the number of gateways

High level architecture of an NGSO system



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PART 3 - SATELLITE STANDARDS: A SUCCESFUL CASE STUDY

Satellite Standards - DVB-S2: History

DEFINIGN A STANDARD is not an easy task. All started with:

- US interest to include 8PSK on top of QPSK already present in the DVB-S standard
- Possible FEC enhancement wrt the concatenated convolutional + Reed Solomon
- The DVB group issued in 2002 a call for proposals in two rounds: 1) FEC contest; 2) PHY and framing

FEC Proposals Performance Comparison

Proponent	Average loss from capacity (dB)	Performance figure	Ranking
COMTECH (USA)	1.49	1.507	6
CONNEXTANT (USA)	1.38	1.284	5
ESA (NL)	1.00	0.995	2
HNS (USA)	0.73	0.727	1
PHILIPS (F)	1.28	1.276	4
SPACE BRIDGE (CDN)	0.81	0.817 (discarded for excessive complexity)	N/A
TURBO CONCEPT (F)	0.97	0.973	2

Satellite Standards - DVB-S2: History

- HNS (USA) won the FEC contest: ESA+Polito runner-up with Turbo concept (F)
- HNS LDPC FEC allowed higher parallelization than European Turbo Codes ☹
- ESA proposal for Amplitude Phase Shift Keying (16 and 32-APSK), Adaptive Coding and Modulation (ACM) and pilot-aided synch accepted by DVB TM ☺

The Modulation/Framing Winner

- QPSK for efficiencies < 2 b/s/Hz
- 8PSK for efficiencies < 3 b/s/Hz
- 16APSK for efficiencies < 4 b/s/Hz [ESA]
- 32APSK for efficiencies < 5 b/s/Hz [ESA]
- Pilot-aided carrier synchronization and channel estimation optional as suggested by ESA
- Physical layer I-Q scrambling as suggested by ESA
- Framing structure as proposed by RAI
- Preamble coding as proposed by HNS
- Pre-distortion techniques proposed by Tandberg and ESA

Satellite Standards - DVB-S2: History

- ESA provided the reference model for assessing end-to-end performance
- The hard work was completed in 2003 with celebration in Turin and standard publication in 2004
- Lessons learned on FEC: look at the implementation on top of performance aspects!

ETSI EN 302 307 V1.1.1 (2004-01)

European Standard (Telecommunications series)

Digital Video Broadcasting (DVB)
Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications

Satellite Standards - DVB-S2: Features

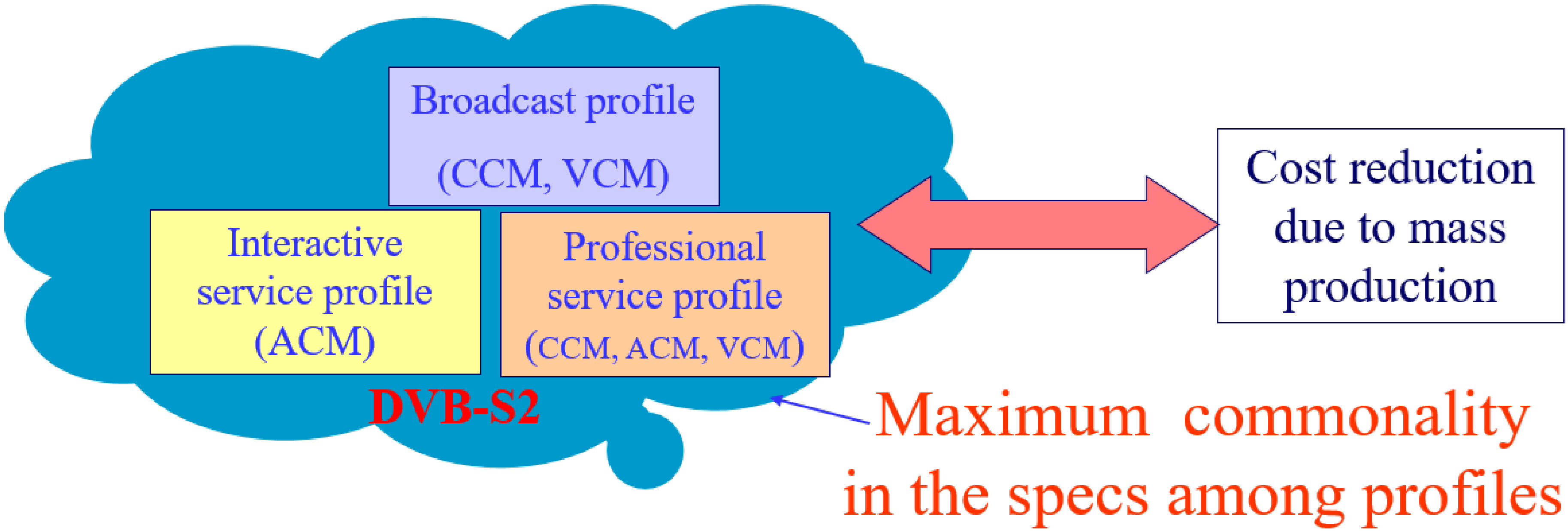
Applications

- Broadcasting of standard definition and high-definition TV (SDTV and HDTV)
- Interactive services, including Internet access, for consumer applications
- Professional applications, such as digital TV contribution and news gathering
- Data content distribution and Internet trunking

Key features

- Near-Shannon physical layer performance thanks to powerful LDPC FEC
- Wide range of power and spectral efficiencies with CCM/VCM/ACM
- Satellite channel optimized modulation formats (APSK) suitable to pre-distortion
- Pilot-aided channel synchronization
- Optional channel bonding
- Super-framing allowing support for beam-hopping and pre-coding

DVB-S2 is a single system for the various application scenarios



Satellite Standards - DVB-S2: Features

Much more extended for DVB-S2X

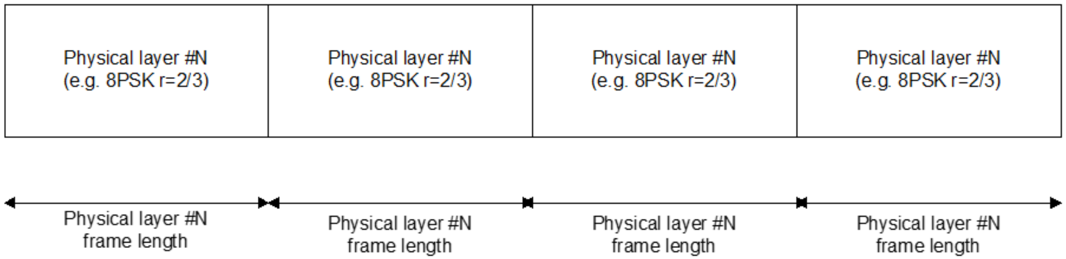
Table 1: System Configurations and Application Areas

System configurations		**Broadcast Services**	**Interactive Services**	**DSNG**	**Professional Services**
QPSK	1/4 ;1/3; 2/5 ; 1/2,3/5,2/3,3/4,4/5,5/6, 8/9, 9/10	O N	N N	N N	N N
8PSK	3/5, 2/3,3/4,5/6, 8/9, 9/10	N	N	N	N
16APSK	2/3, 3/4,4/5,5/6, 8/9, 9/10	O	N	N	N
32APSK	3/4, 4/5,5/6, 8/9; 9/10	O	N	N	N
CCM		N	N (*)	N	N
VCM		O	O	O	O
ACM		NA	N(**)	O	O
FECFRAME (normal)	64800 (bits)	N	N	N	N
FECFRAME (short)	16200 (bits)	NA	N	O	N
Single Transport Stream		N	N(*)	N	N
Multiple Transport Streams		O	O(**)	O	O
Single Generic Stream		NA	O(**)	NA	O
Multiple Generic Streams		NA	O(**)	NA	O
Roll-off 0.35, 0.25 and 0.20		N	N	N	N
Input Stream Synchroniser		NA (***)	O(***)	O(***)	O(***)
Null Packet Deletion		NA	O(***)	O(***)	O(***)
Dummy Frame insertion		NA(***)	N	N	N
N=normative, O=optional, NA=not applicable					

* Interactive Service receivers shall implement CCM and Single Transport Stream
** Interactive Service Receivers shall implement ACM at least in one of the two options: Multiple Transport Streams or Generic Stream (single / multiple input)
*** Normative for ACM/VCM or for multiple TS input stream(s) combined with CCM

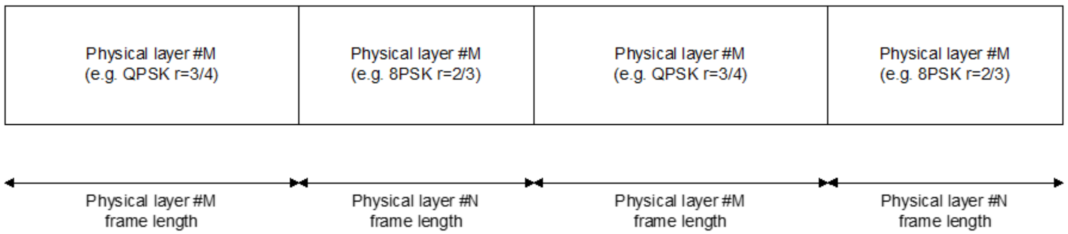
Satellite Standards - DVB-S2: Features

– Constant Coding and Modulation (CCM) – repeating frame configuration



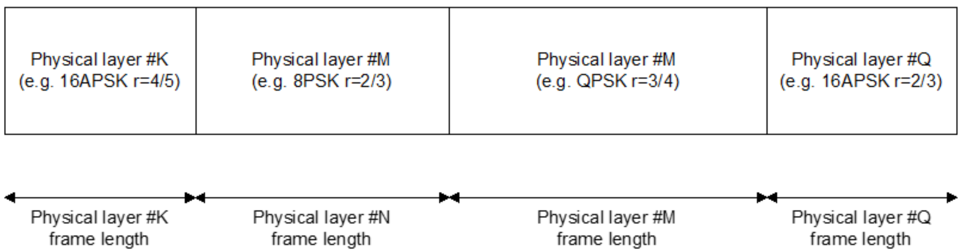
Typically used for broadcasting systems

– Variable Coding and Modulation (VCM) – periodic frame configuration



Broadcasting systems with different QoS (e.g. SDTV+HDTV with different FEC)

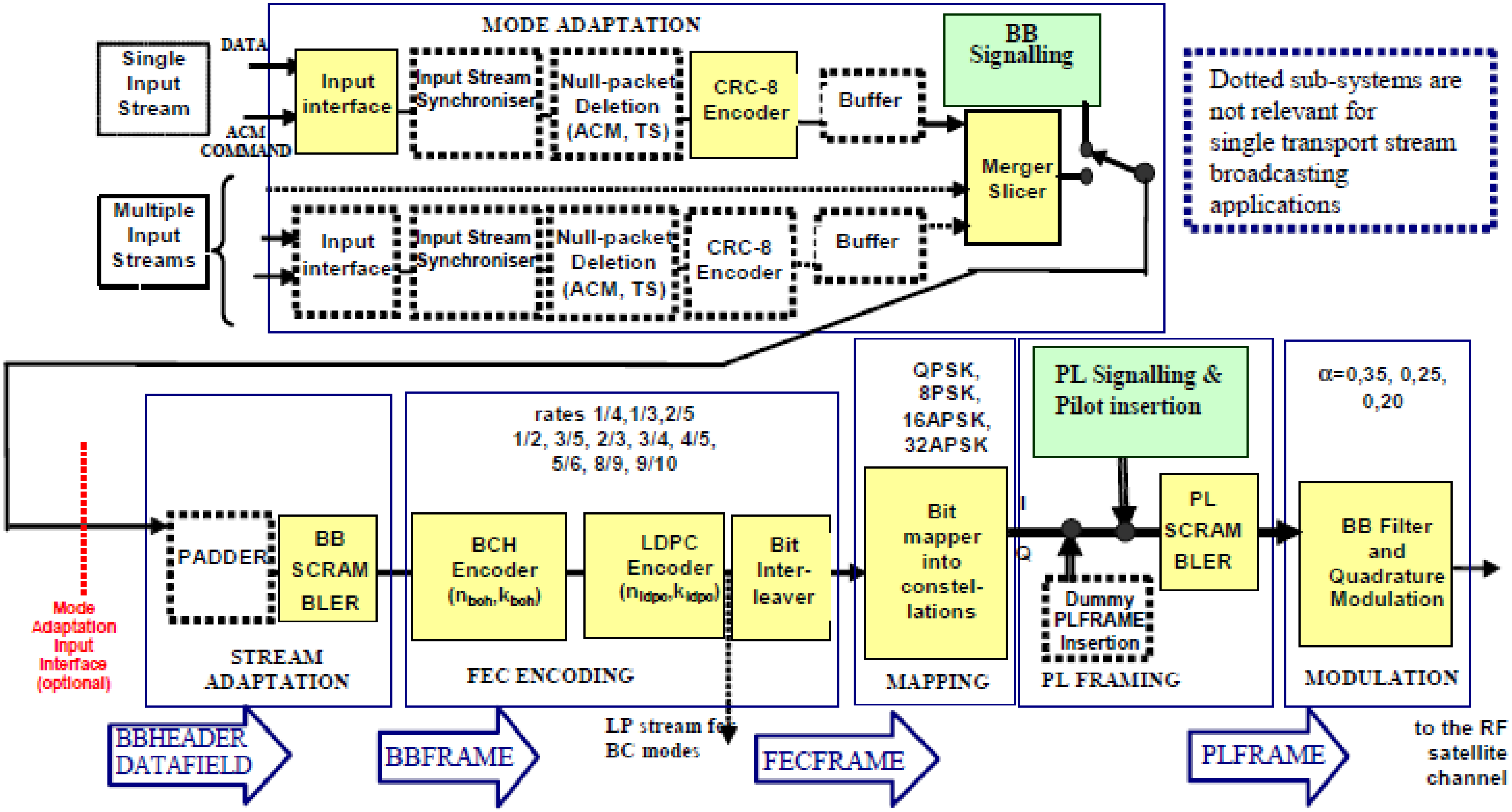
– Adaptive Coding and Modulation (ACM) – irregular frame configuration



Interactive systems, trunking etc..

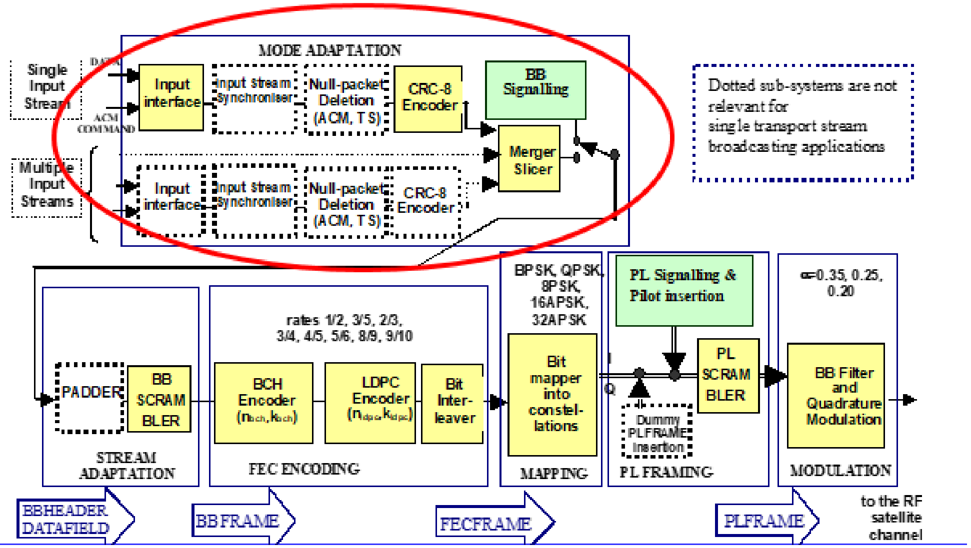
Satellite Standards - DVB-S2: Physical Layer

DVB-S2 modulator architecture



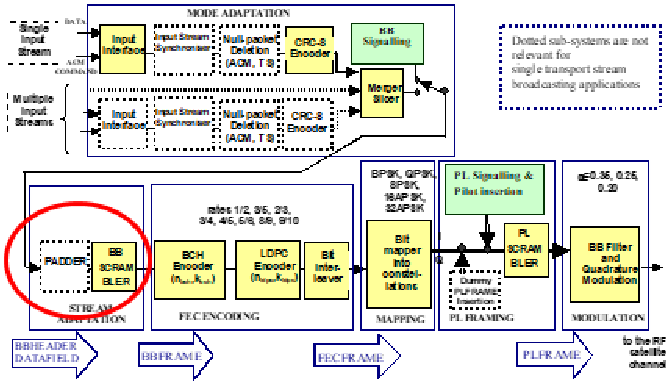
MODE ADAPTATION

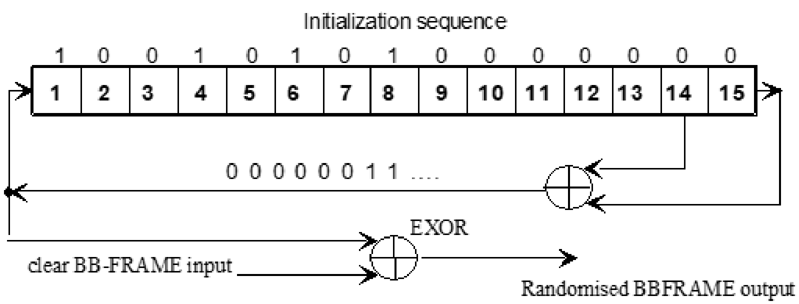
- Input stream interfacing
- Input stream synchronization (TS optional)
- CRC encoding (for packetised TS input only)
- Merging of input streams (for multiple input streams)
- Slicing in data fields

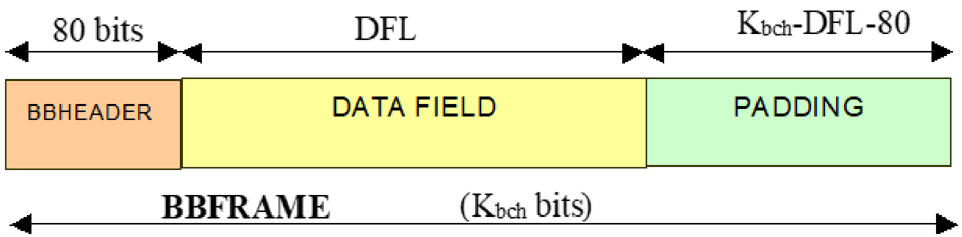


STREAM ADAPTATION

- Padding is required when data is not sufficient to fill the BBFRAME [unicast mode only]
- Stream adaptation provides padding to complete a constant length (K_{bch} bits) BBFRAME and scrambling
- K_{bch} is coding rate dependent (see Table 5-a)
- BB scrambler to randomize information bits at the encoder input







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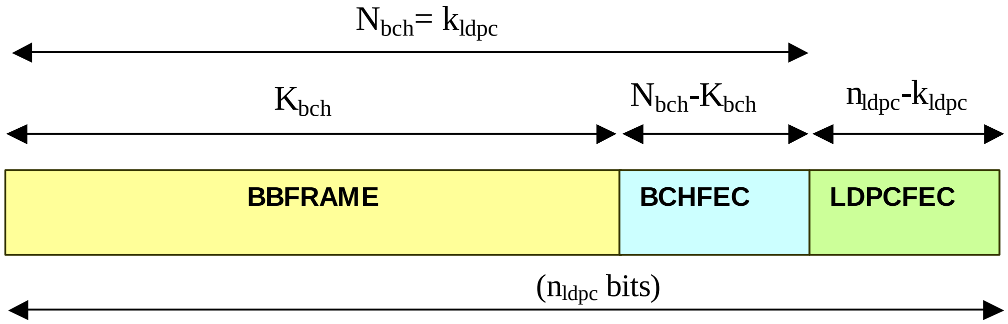
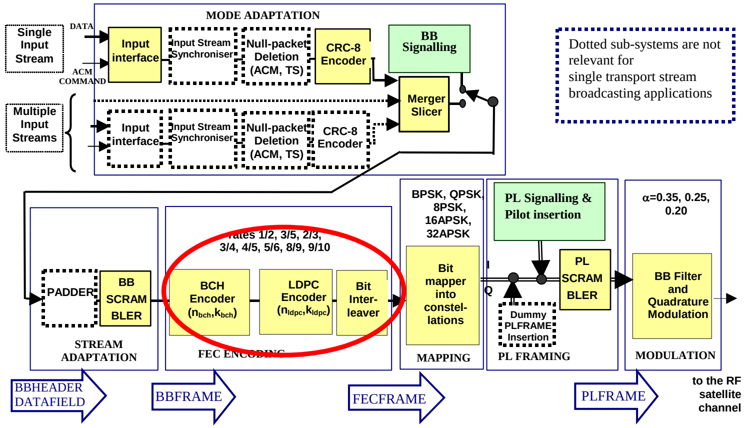
Satellite Standards - DVB-S2: Physical Layer

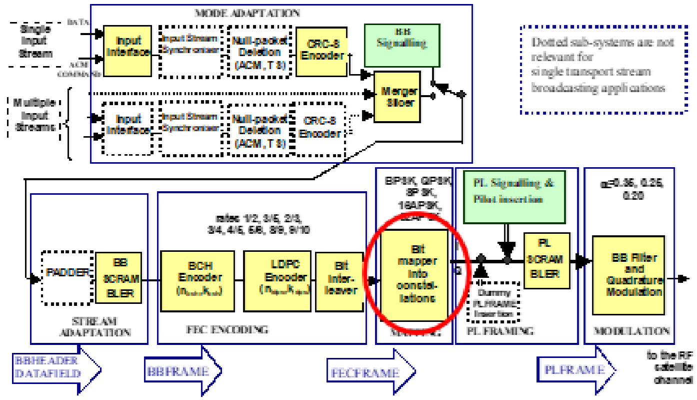
FEC encoding



- This block performs:
  - BCH outer encoding
  - LDPC inner encoding
  - Bit interleaving before M-ary modulator (Bit Interleaved Coded Modulation)
- FEC Encoding operations
  - Each BBFRAME (K_{bch} bits) is processed by the FEC coding subsystem, to generate a FECFRAME (n_{LDPC} bits).
  - The parity check bits (BCHFEC) of the systematic BCH outer code shall be appended after the BBFRAME, and the parity check bits (LDPCFEC) of the inner LDPC encoder shall be appended after the BCHFEC field

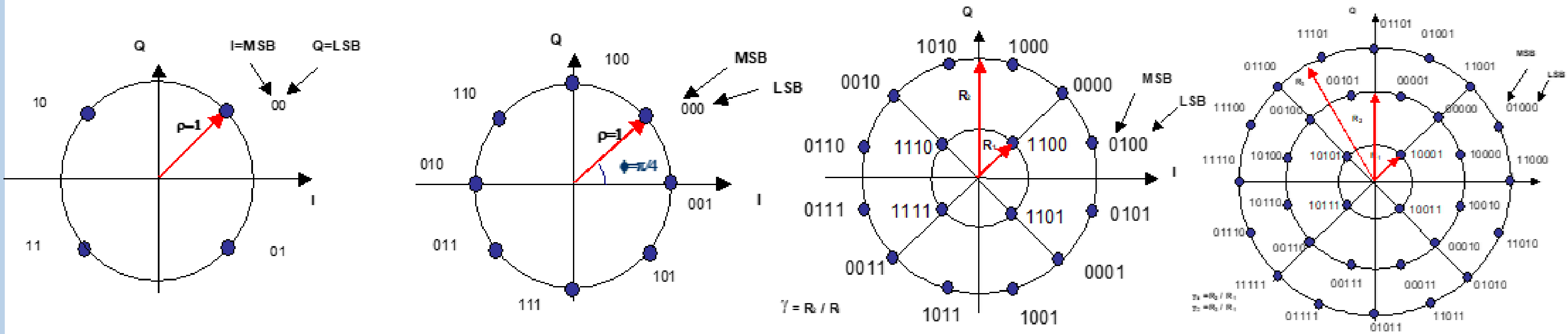


MAPPING & MODULATION



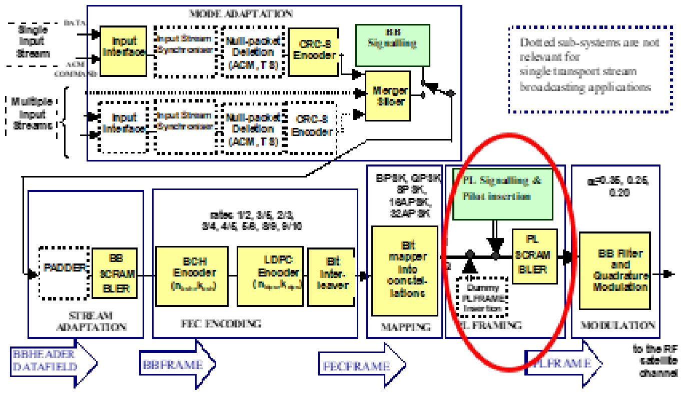
- Four modulation formats, all optimised to operate over non-linear transponders (external points over circles):
  - **QPSK (2 bit/s/Hz)**
  - **8PSK (3 bit/s/Hz)**
  - **16APSK (4 bit/s/Hz): 4-12-APSK**
  - **32APSK (5 bit/s/Hz): 4-12-16 APSK**
- Gray mapping

More modulation formats in DVB-S2X



PHYSICAL LAYER FRAMING

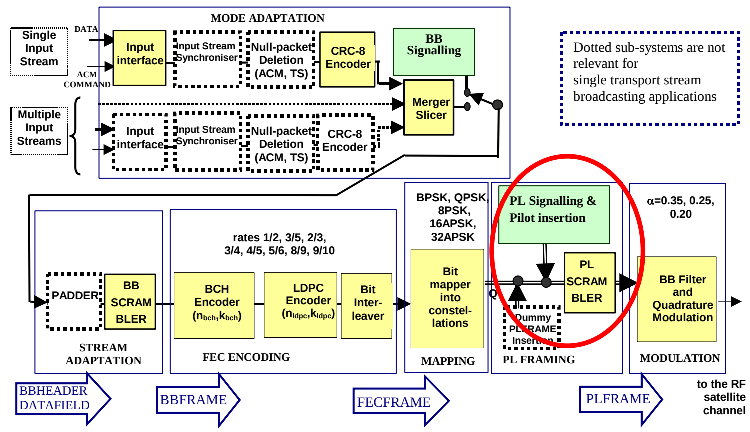
- Inclusion of physical layer signalling
- Generation of dummy PLFRAMEs
- Generation of physical layer scrambling
- Optional introduction of pilot symbols



Satellite Standards - DVB-S2: Physical Layer

Why pilot symbols?

- Phase recovery for 8PSK and higher modulation order in the presence of the specified phase noise appears impossible without pilot symbols
- Allows for frequency/phase recovery independently from the current frame physical layer configuration [ACM]
- No need for frame re-acquisition for users not able to decode the current frame (due to fading and/or bad C/I) [ACM]
- Allows for accurate data–aided channel estimation which is a must for ACM
- Solution: Optional pilot symbols at regular interval after the PLHEADER (36 pilot symbols every 1440 symbols)

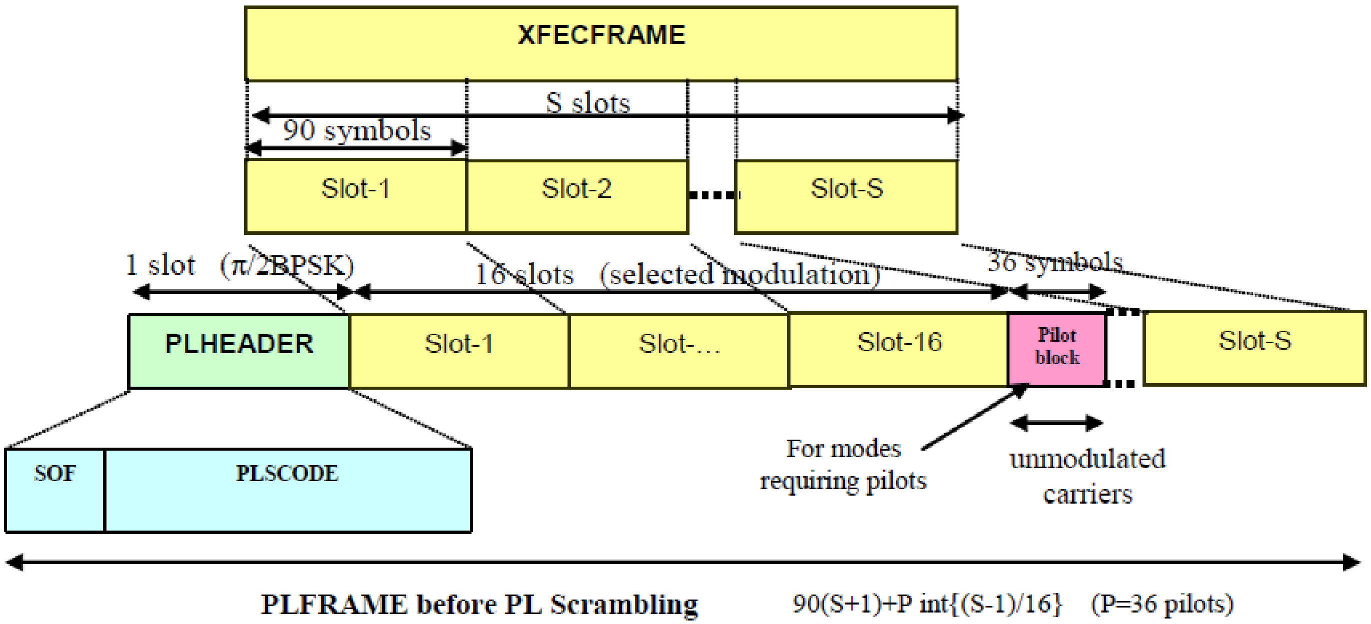


Why pilot scrambling?

- To identify the transponder
- To avoid correlated interference from other beams interference

Satellite Standards - DVB-S2: Physical Layer

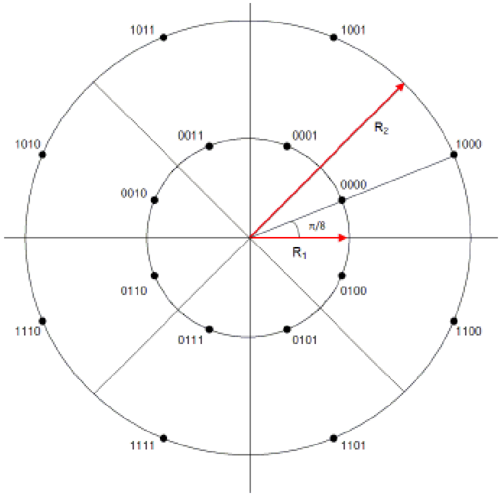
- The PL frame payload is composed of a different number of modulated symbols depending on the FEC length (64 800 or 16 200) and the modulation constellation
- Excluding the optional pilots, the payload length is always a multiple of a slot of 90 symbols
- PLFRAME periodicity can be exploited by the frame synchronizer in the receiver

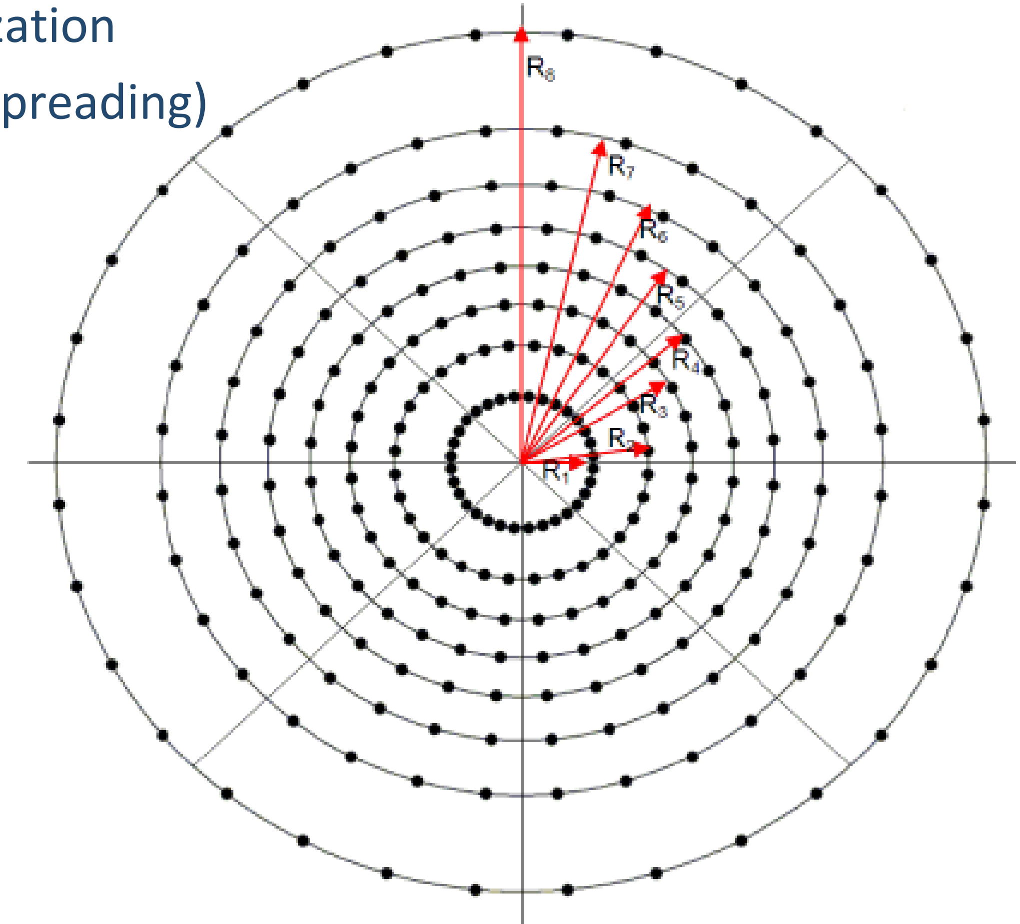


Satellite Standards - DVB-S2X: Physical Layer

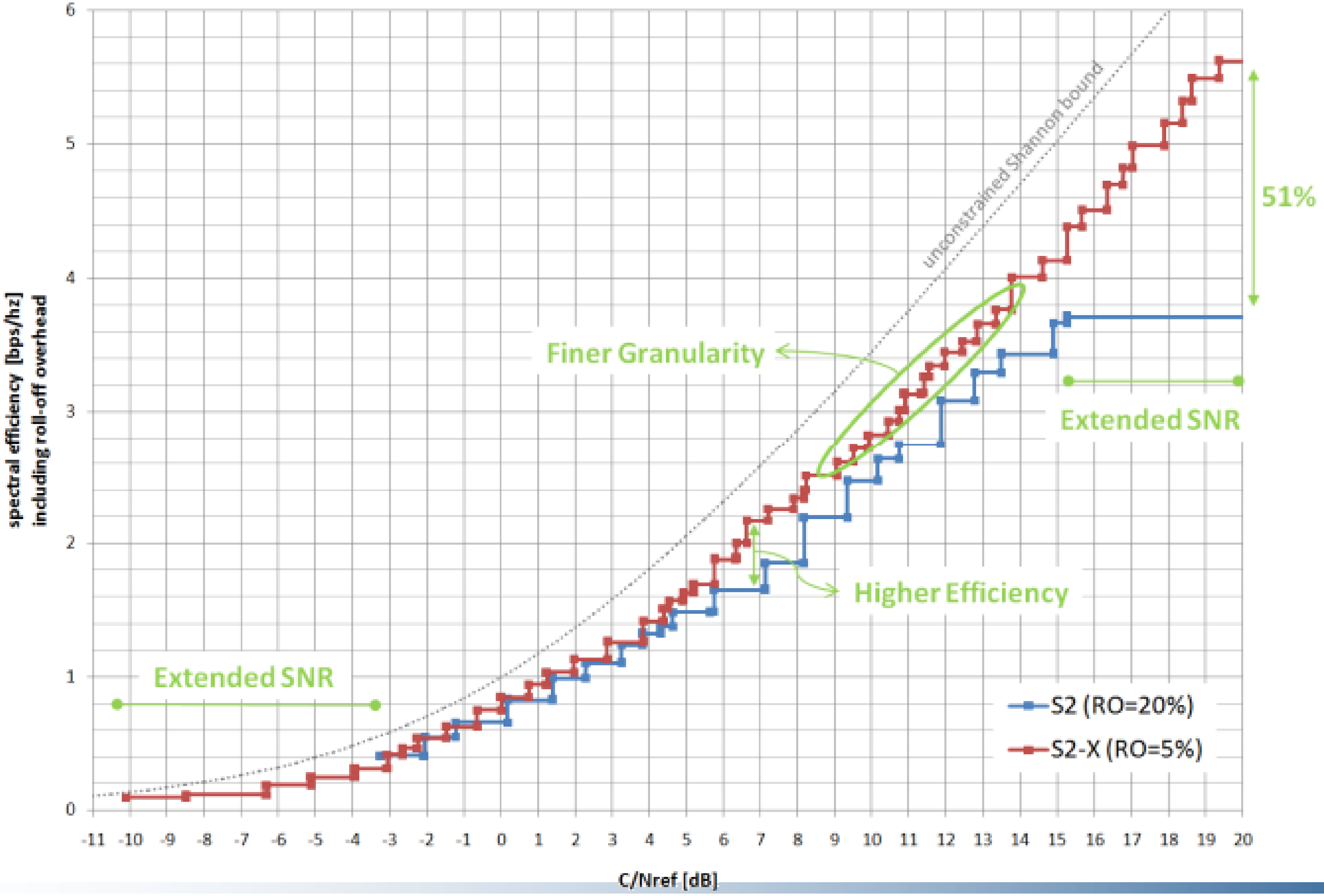
ACM

- Powerful LDPC FEC with BICM mapping onto constellations
- Joint FEC and constellation optimization
- Modulation formats from BPSK (+spreading) to 256APSK
- Extended SNR range and finer MODCODs granularity
- SRRC roll-off factor down to 0.05



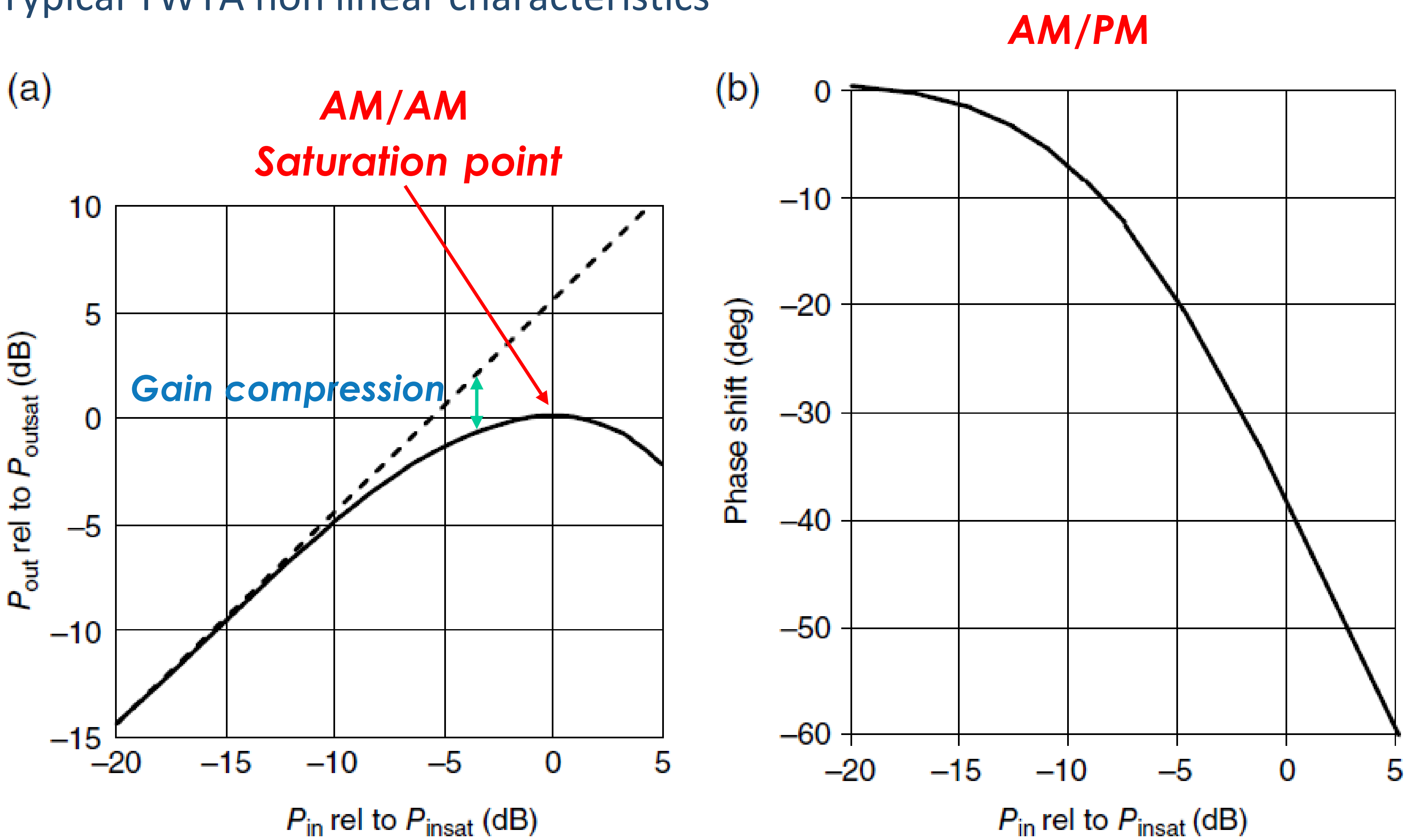


Satellite Standards - DVB-S2X: Physical Layer



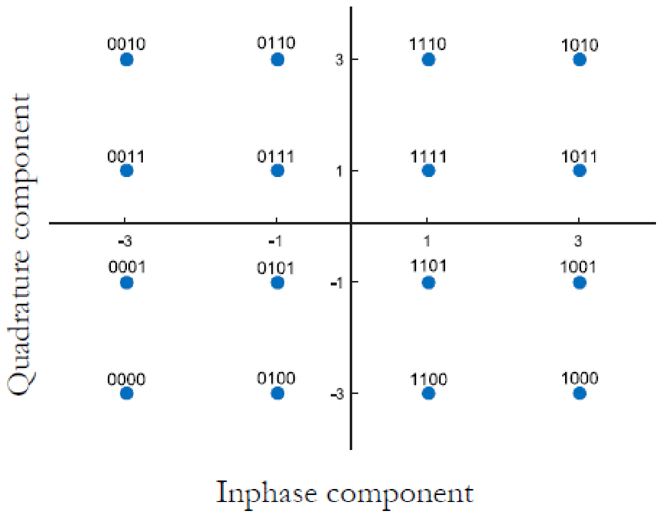
The satellite nonlinear channel challenge

- Typical TWTA non linear characteristics

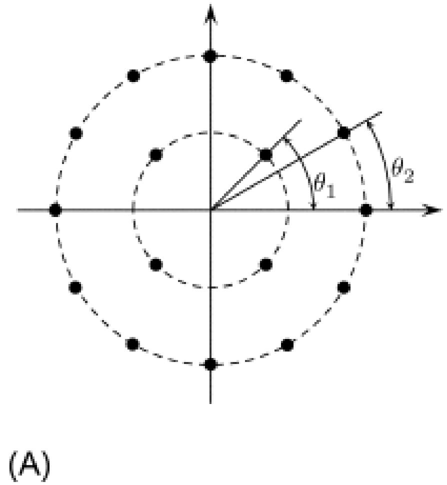


Satellite Standards - DVB-S2X: Physical Layer

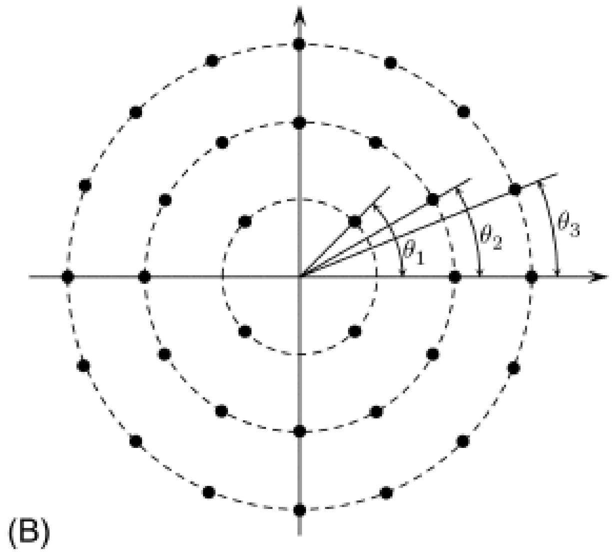
- SRRC pulse shaping is causing envelope fluctuations even for QPSK, PAPR grows with higher order modulations
- APSK although not constant envelope is easier to pre-compensate than QAM: high-amplitude “corner” points are missing



16-QAM

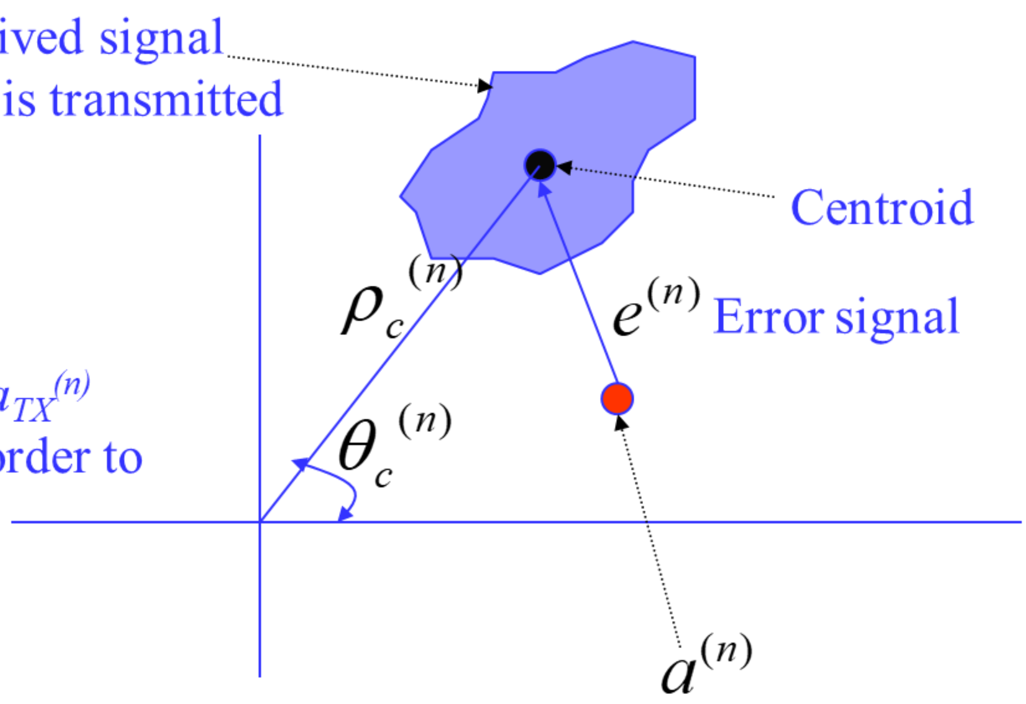


16-APSK



32-APSK

Static pre-distortion technique:



If the centroid is estimated the transmit constellation point $a_{TX}^{(n)}$ could be adjusted iteratively in order to reduce the error signal $e^{(n)}$:

$$\rho_{a_{TX}}^{(n)}(m+1) = \rho_{a_{TX}}^{(n)}(m) - \gamma_\rho \left| e^{(n)}(m) \right|$$

$$\theta_{a_{TX}}^{(n)}(m+1) = \theta_{a_{TX}}^{(n)}(m) - \gamma_\theta \arg\{e^{(n)}(m)\}$$

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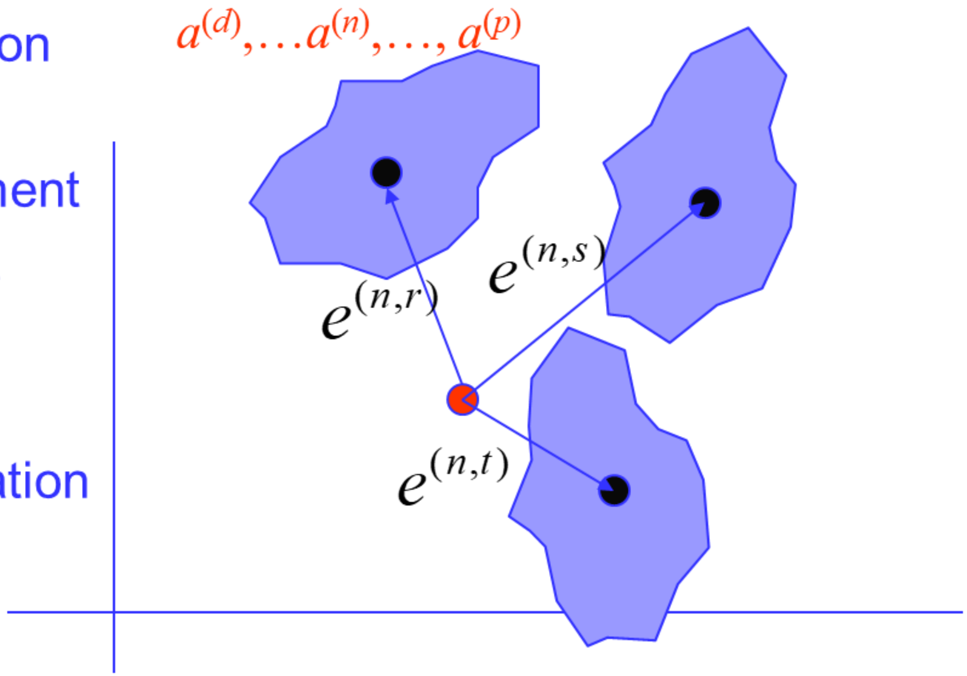
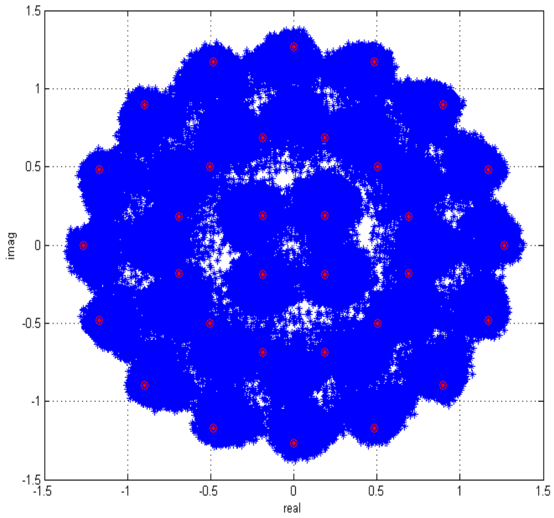
Satellite Communications

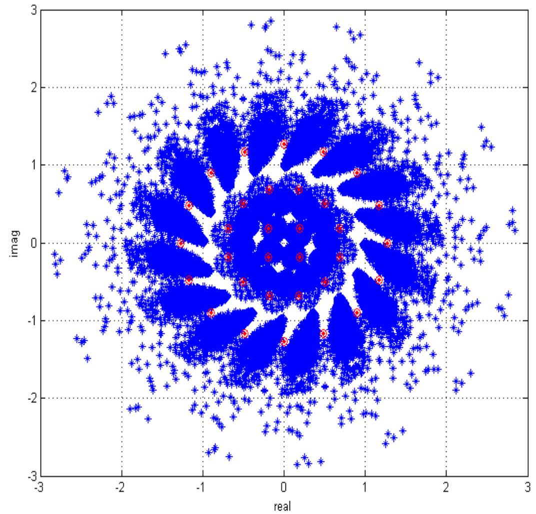
Dynamic pre-distortion technique:

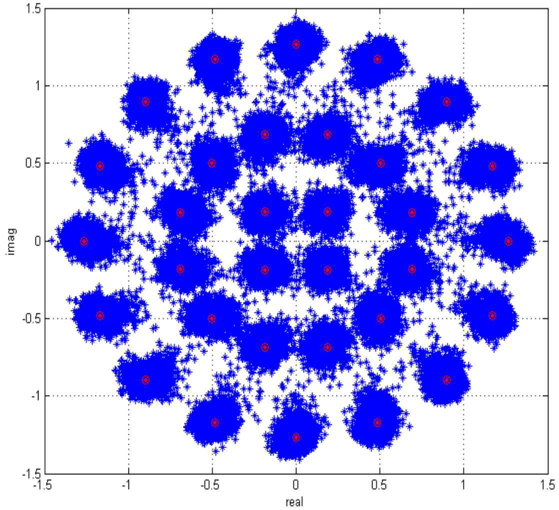
- The same technique as the static pre-distortion is applied but here the centroids are computed over clouds belonging to a given pattern of L symbols
- L is the memory of the pre-distortion technique
- The iterative constellation adjustment is performed over the $a^{(n)}$ transmit symbol, but there are in total $M^{(L-1)}$ adjustments and eventually $M^{(L-1)}$ transmit constellation points



Dynamic pre-distortion technique







Received constellation without pre-distortion

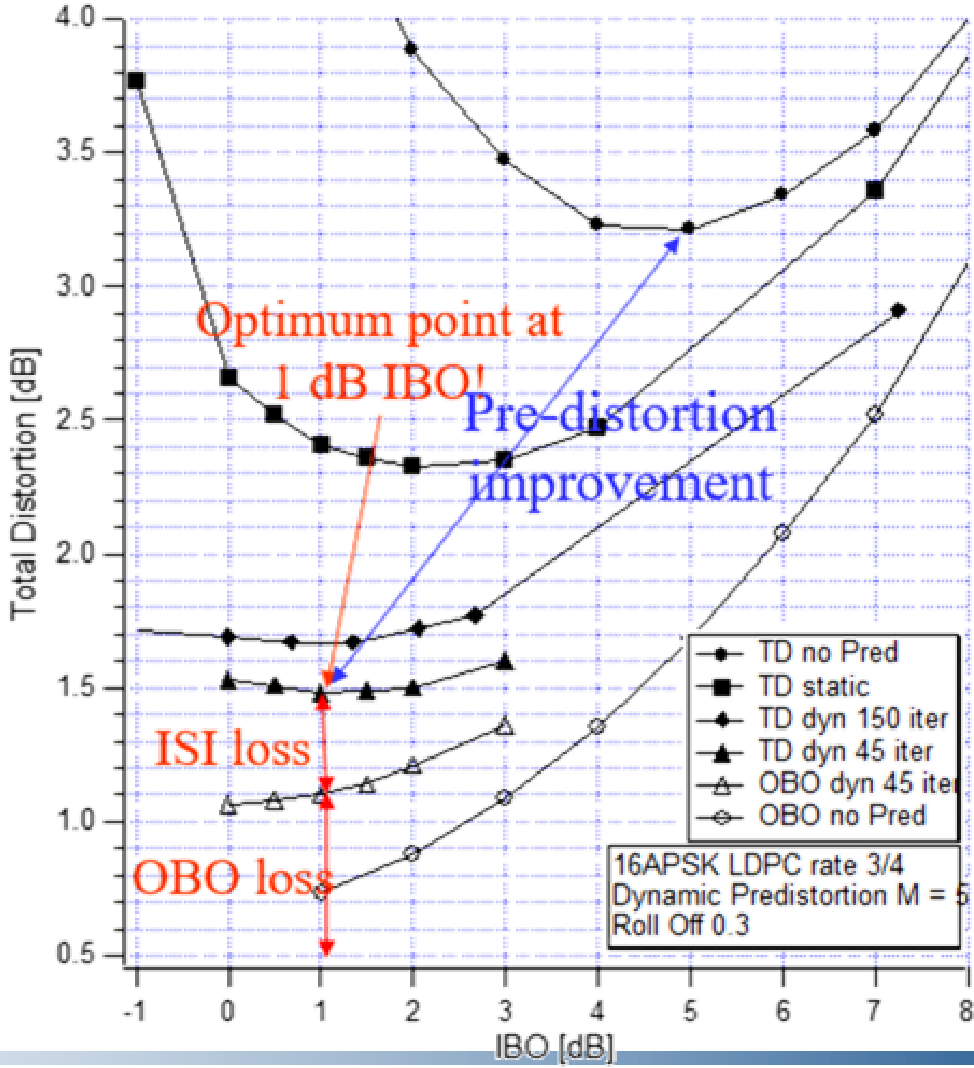
Pre-distorted TX constellations

Received constellation with pre-distortion

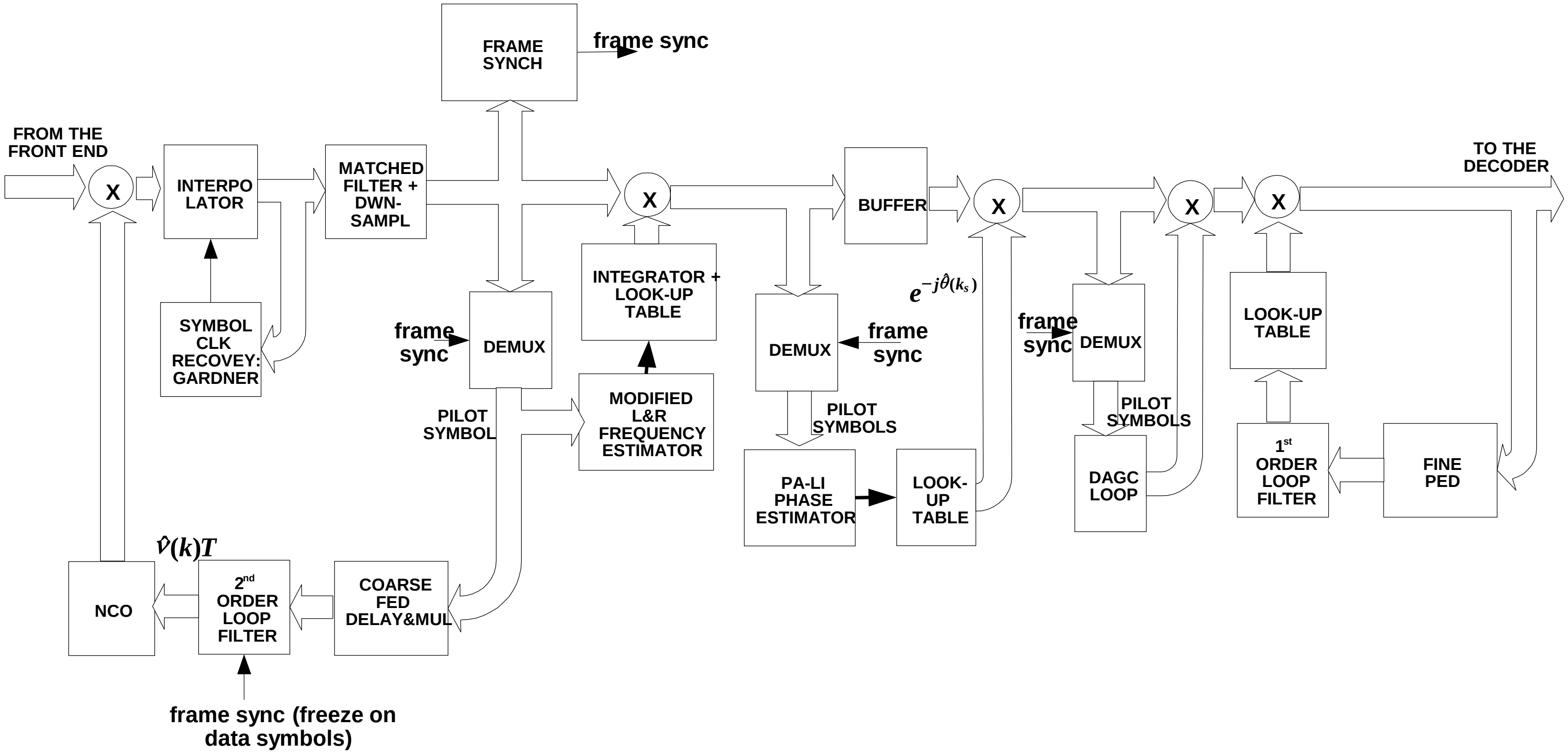
Satellite Standards - DVB-S2X: Physical Layer

- Optimization of Total Degradation (OBO+Distortion Loss)
- Reduction of the IBO operating point
- Improvement in the HPA DC to RF conversion efficiency

$$D_{TOT}(s)[dB] = \left[\frac{E_s}{N_0}\right]_{req}^{NL}(s)[dB] - \left[\frac{E_s}{N_0}\right]_{req}^{AWGN}(s)[dB] + OBO(s)[dB]$$



DVB-S2 demodulator block diagram



Satellite Standards - DVB-S2X: Physical Layer

DVB-S2 mass-market chipset – overall hundreds of millions of chips sold in the world!

STV6110A

8PSK/QPSK low-power 3.3 V satellite tuner IC

Data Brief

Features

- RF to baseband 8PSK/QPSK direct conversion
- Single 3.3 V DC supply
- Input frequency range 950 MHz to 2150 MHz
- Supports 1 to 45 Msymbol/s
- On-chip RF loop-through
- Fully integrated PLL frequency synthesizer for DVB-S2 (including loop filter)
- Extremely low phase noise compliant with DVB-S2 requirements
- Low external component count
- Low power consumption
- Flexible crystal frequency output to drive the demodulator IC
- Continuously variable gain: 0 to 65 dB
- Additional and programmable gain on baseband amplifier: 0 to 16 dB
- Programmable 5- to 36-MHz cut-off frequency (butterworth 5th-order baseband filters)
- Compatible with 5-V and 3.3 V I^2C bus

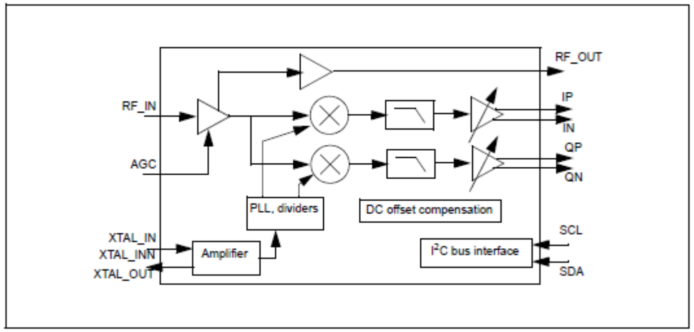
Description

The STV6110A satellite tuner is a direct-conversion (zero IF) receiver dedicated to digital TV broadcasting.

On the RF input is a low noise amplifier (LNA), with buffer to supply the RF output for loop-through, and a continuously variable gain LNA to ensure an optimal signal level for the two mixers. Each mixer, which down-converts the signal to baseband, is followed by a low-pass filter and amplifier. The baseband gain can be varied by programming a register via the I^2C bus.

The LO signals are provided by an integrated PLL which contains an on-chip voltage controlled oscillator (VCO) meeting stringent phase noise requirements. The PLL loop filter is integrated. The LO frequencies are programmable.

The comparison frequency for the phase-frequency detector (PFD) is generated by dividing the crystal oscillator reference frequency. The crystal frequency can be from 16 MHz to 32 MHz depending on application.



STV0910

Multi-standard advanced dual demodulator for satellite digital TV broadcast set-top boxes

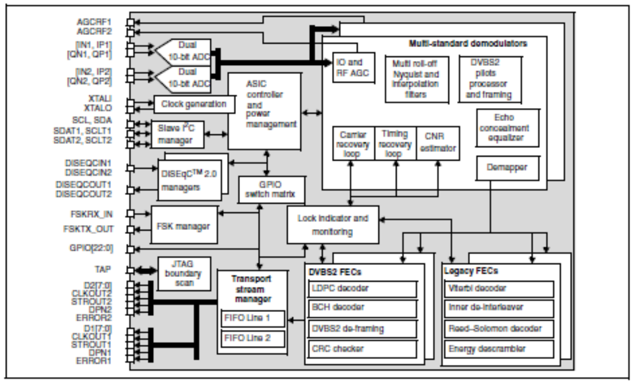
Data brief

Features

- Dual multi-standard demodulation for broadcast applications
  - DVBS2 QPSK, 8PSK, CCM, VCM
  - Legacy DVBS and DirecTV™ QPSK with SuperFEC™ for enhanced reception
  - Multi-tap equalizer for RF reflection removal
  - Wide range carrier frequency tracking loop for offset recovery
- Advanced version for DVBS2 16APSK, 32APSK, low QPSK code rates and ACM
- Dual multi-standard decoding
  - DVBS2 FEC and framing
  - Up to 270 Mbit/s channel bit rate
  - DVBS or DirecTV™ legacy
- Interfaces
  - Dual data to MPEG decoder
  - DVB common interface compliant
  - I^2C serial bus interface, including two private repeaters for tuners
  - JTAG interface for boundary scan
  - 2 DiSEqC 2.x 22-kHz interfaces
  - FSK interface
  - Flexible GPIOs and interrupts
  - Bit error rate monitoring and reporting
- Technology
  - Multi supply: 1.1-V core, 2.5-V analog, 3.3-V digital interfaces
  - Fine-grained power management
  - LFBGA-168 12x12 mm² package, RoHS

Description

The STV0910 is a cost effective, high-performance dual demodulator/decoder for advanced DVB satellite reception.



December 2012 Doc ID 024009 Rev 1 1/4

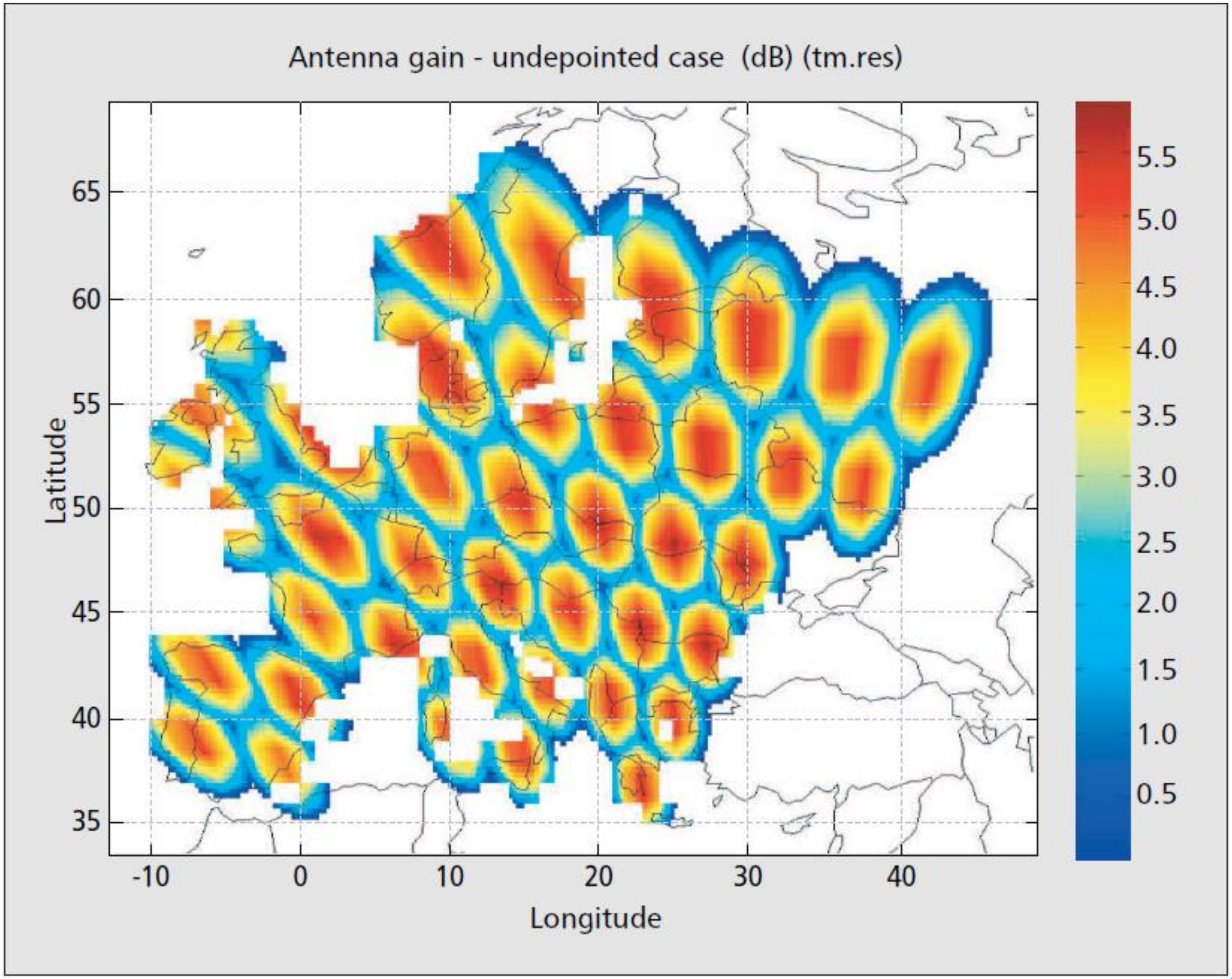
For further information contact your local STMicroelectronics sales office. www.st.com

Satellite Standards - DVB-S2X: Physical Layer

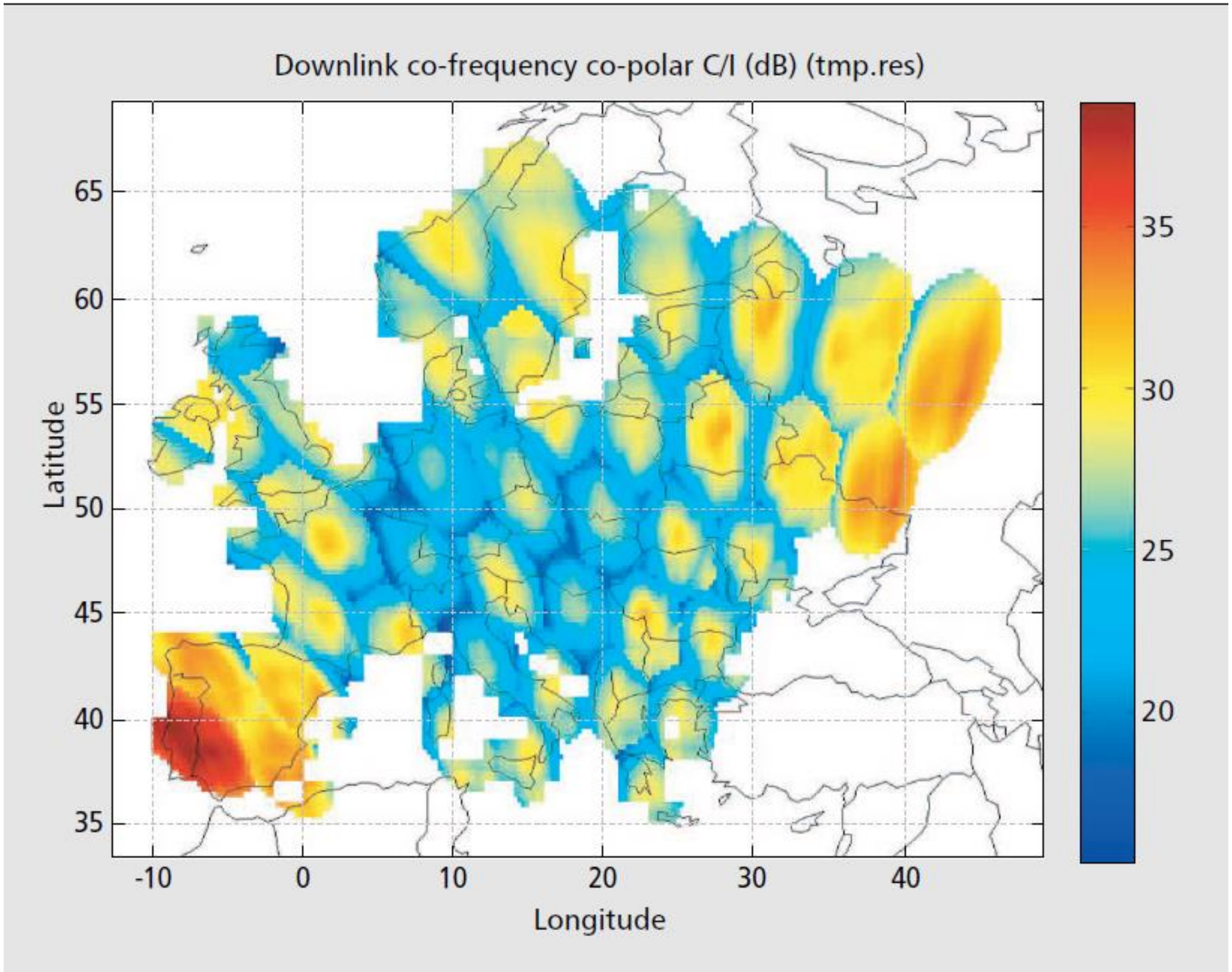
Why Adaptive Coding and Modulation in Satellite Broadband Networks?

- Broadband applications are one-to-one service (not one-to-many as broadcasting)
- The user SNIR (FWD example) is dependent on the satellite antenna gain and path losses (location dependent), the atmospheric losses (weather thus time dependent) and the co-channel and adjacent channel interference
- The physical layer configuration (MODCOD = FEC code rate and modulation) can be locally optimized to get the maximum throughput for each user considering the current SNIR

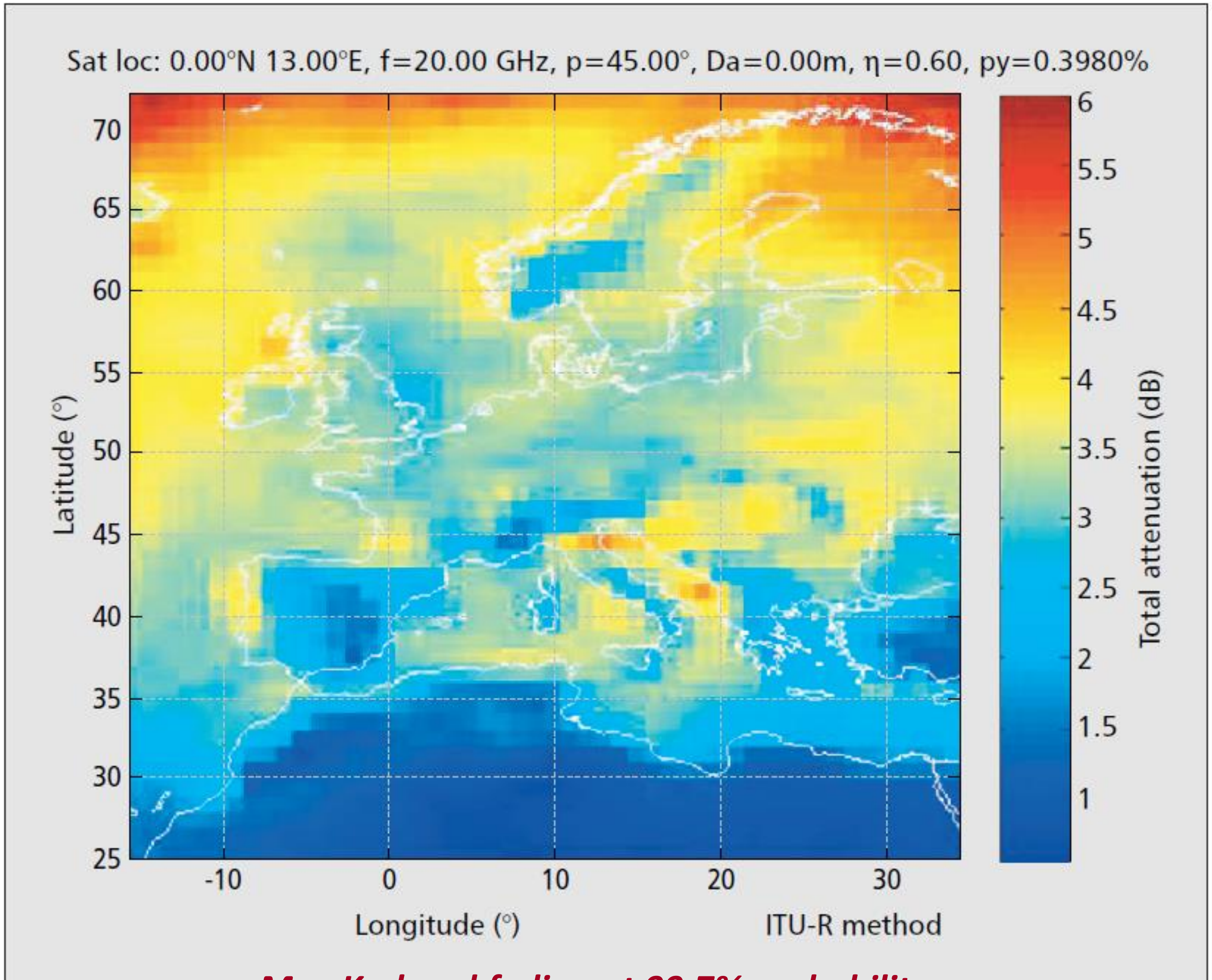
Satellite Standards - DVB-S2X: Physical Layer



Satellite Standards - DVB-S2X: Physical Layer



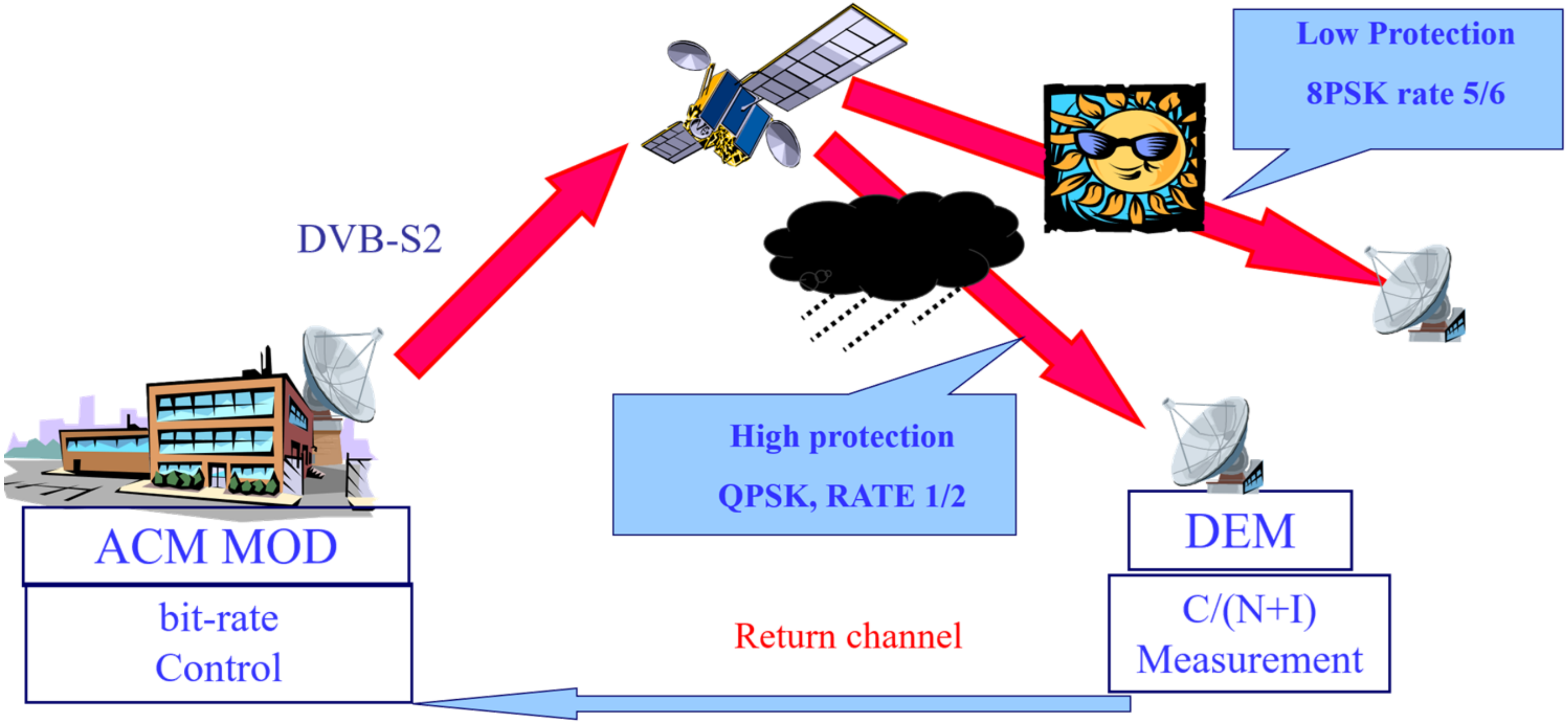
Satellite Standards - DVB-S2X: Physical Layer



Max Ka-band fading at 99.7% probability

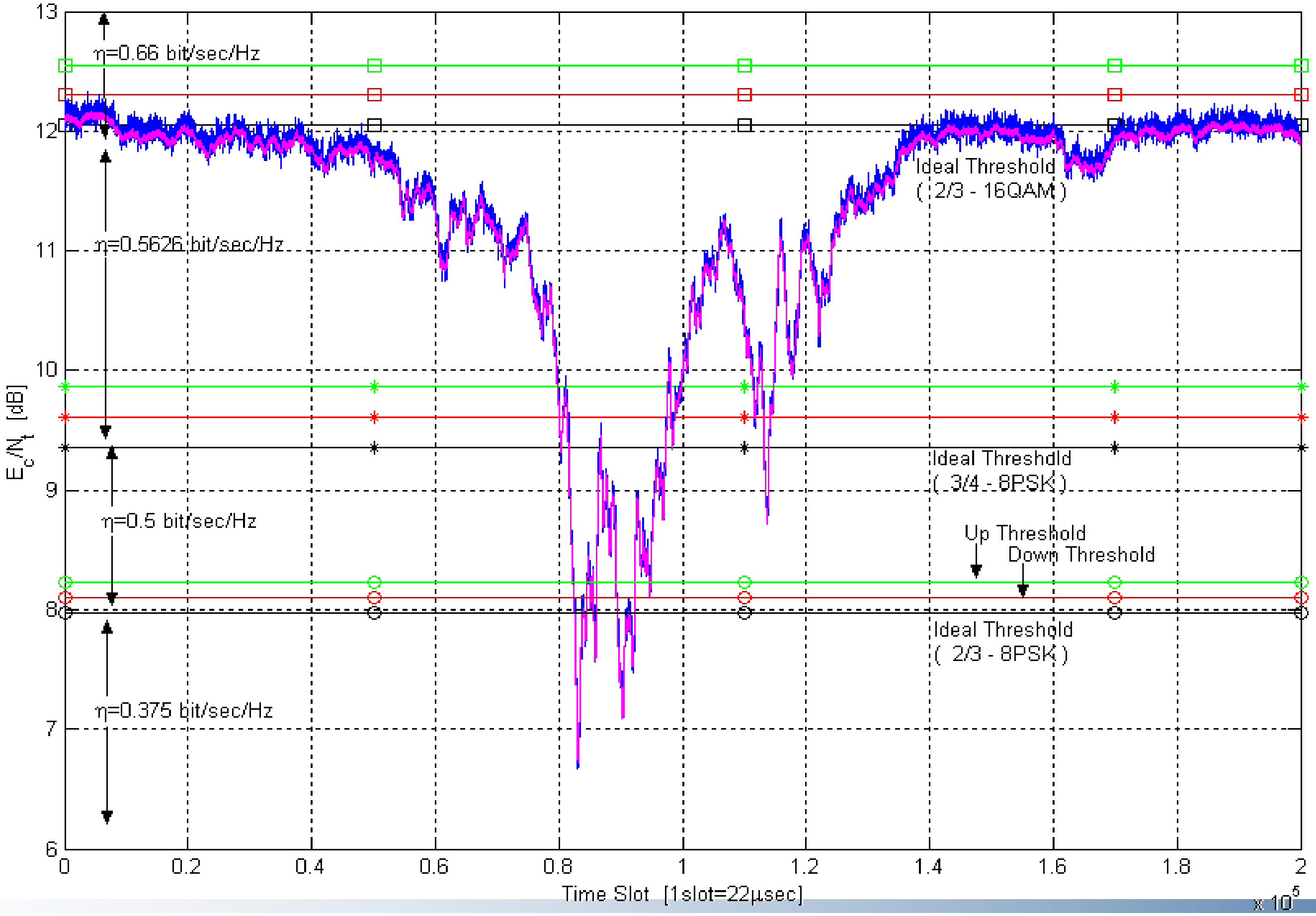
How does ACM work in DVB-S2(X)?

- Quasi-real-time adaptation based on the C/(N+I) estimation at the user terminal
- Minimization of link margins required for a given link availability
- User throughput reduction (instantaneous bit rate) can be compensated by RRM



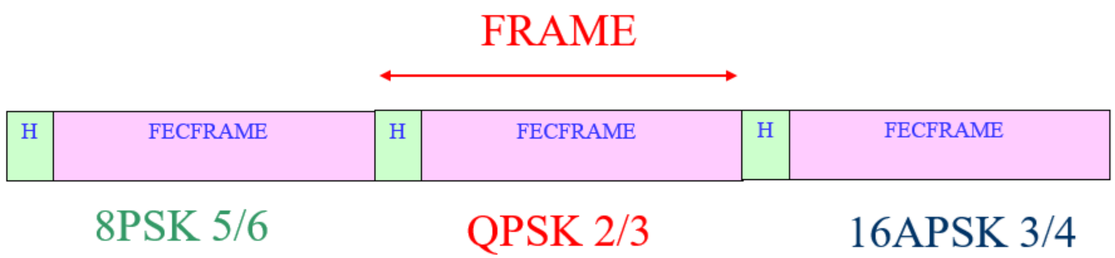
Satellite Standards - DVB-S2X: Physical Layer

- ACM based on real-time SNIR estimate by each user terminal
- Hysteresis required to avoid MODCODs ping-pong effects



RESULTS

- Ka-band multibeam forward link example using DVB-S2 and ACM
- The majority of users are adopting 8PSK or 16APSK depending on their location and/or channel conditions
- More protected MODCODs (QPSK) used with limited probability
- The impact on the throughput corresponds to **190% increase** compared to a classical CCM approach!
- The TDM frame allows to mix different MODCODs on the same carrier



- Deep fading is rare and limited in the coverage area => negligible impact on the system throughput!

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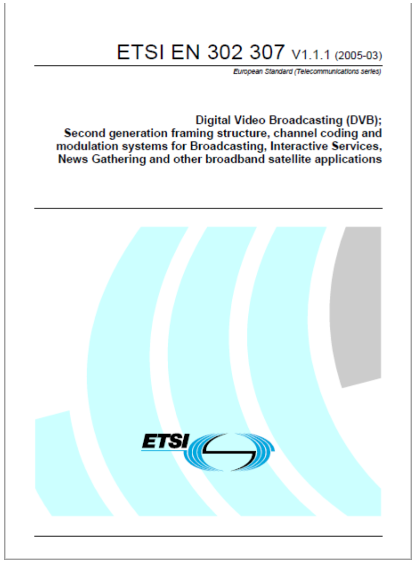
DVB-S2 in the Commercial Market


ETSI EN 302 307 V1.1.1 (2005-03)

European Standard (Telecommunications series)

Digital Video Broadcasting (DVB);
Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications

ETSI

Satellite Standards - DVB-S2X: Physical Layer

Multi-beam system throughput estimation with ACM:

AVERAGE EFFICIENCY

BEAM AREA

$$\eta_s^{\max} = \max_{N_p, f_R} \left\{ \frac{1}{N_b} \sum_{n=1}^{N_b} \frac{1}{\mathcal{S}(B_n)} \iint_{(x,y)\in B_n} \hat{\eta}_s(x,y,N_p,f_R)\, dxdy \right\}$$

BEAM AVERAGING

PUNCTUAL EFFICIENCY (x,y) AVERAGED OVER FADING

$$\hat{\eta}_s(x,y,N_p,f_R) = \int_0^1 \hat{\hat{\eta}}_s(x,y,a(x,y),N_p,f_R) p_A(a) da$$

PUNCTUAL EFFICIENCY (x,y) CONDITIONED ON FADING

LINK CLOSURE CONDITION

$$\hat{\hat{\eta}}_s(x,y,a(x,y),N_p,f_R) = \max_{r,M,L,\eta_R} \left\{ \frac{R_b N_p}{f_R R_c} \;\middle|\; \left[\frac{E_b}{N_t}\right](x,y,a(x,y),N_p,f_R) \geq \rho_{\text{req}}(r,M) \right\}$$

PHYSICAL LAYER OPTIMIZATION

REQUIRED E_b/N_t

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Satellite Standards - DVB-S2X: Physical Layer

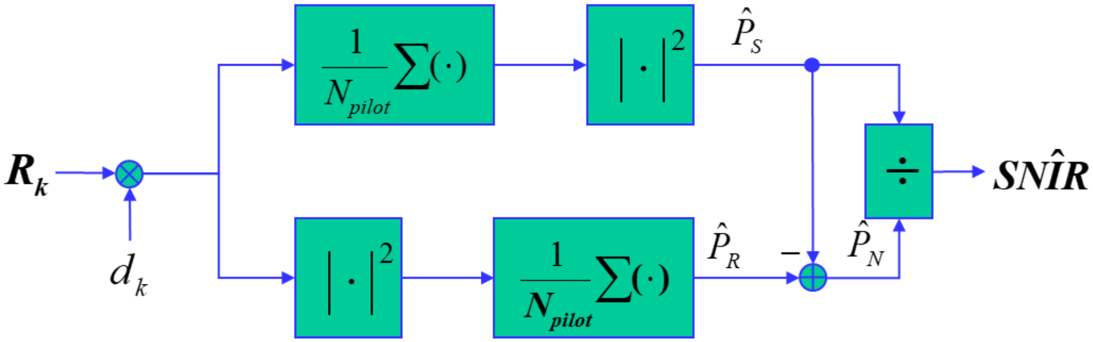
Multi-beam system throughput estimation with ACM:

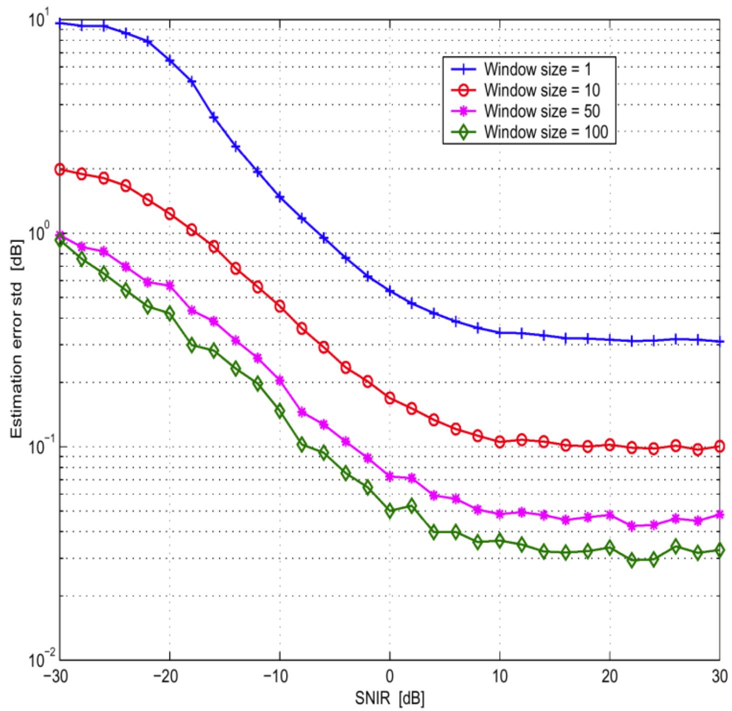
- In practice neither the fading pdf nor the spectral efficiency are available in closed form.
- Previous equation are then solved with a semi-analytical approach
- The satellite coverage region is approximated by a discrete grid of points (equi-spaced on Earth). The equations can be solved numerically by:
  - Generating the random variable (rv) $a(x,y)$ according to its pdf for each grid point (x,y) belonging to the satellite coverage region
  - Computing the spectral efficiency for each grid location
- Repeating steps 1-2 until a sufficiently large number of fading statistics is accumulated
- Averaging efficiency results over the fading rv a and the coverage region points (x,y) thus approximating the integral equations

Satellite Standards - DVB-S2X: Physical Layer

ACM implementation aspects – SNIR estimation:

- DA-SNORE estimator (made in JPL) able to provide an unbiased E_s/N_t estimate
- Possible coherent averaging over few consecutive pilot sub-slots
- Optimized for accurate estimation and dynamic behavior compatible with channel variations

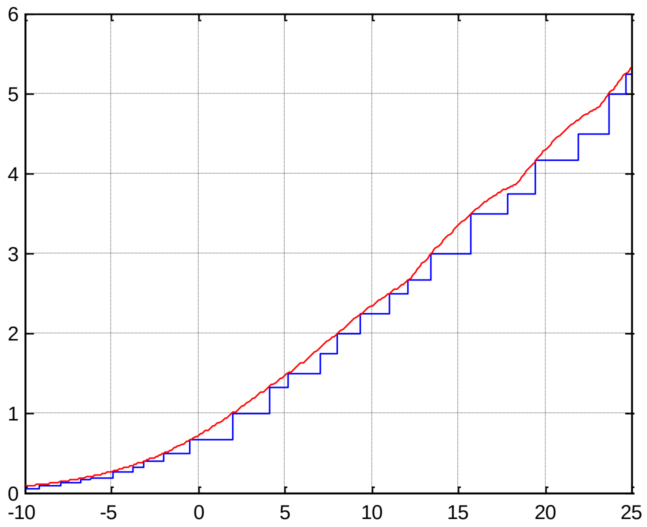


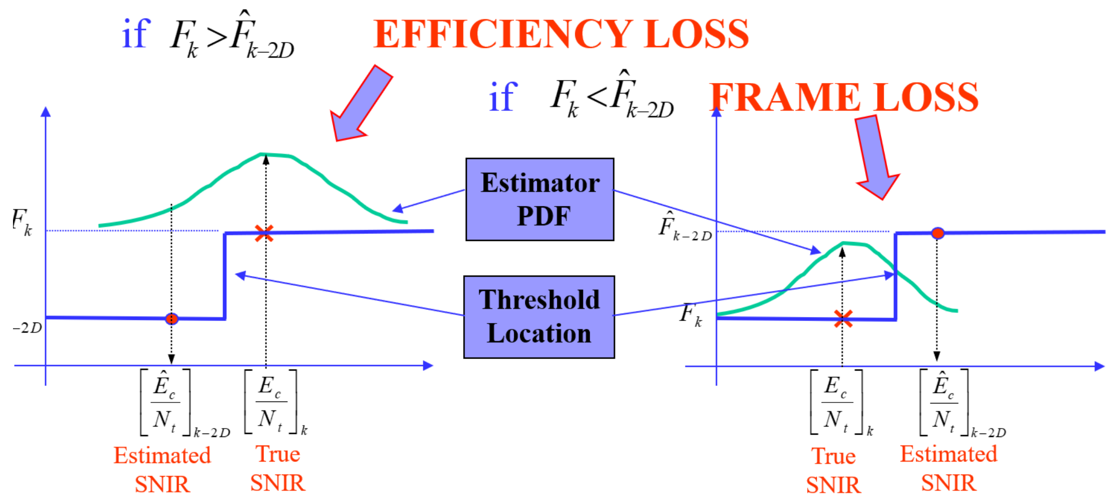


Satellite Standards - DVB-S2X: Physical Layer

ACM implementation aspects – physical layer selector:

- The SNIR estimator is noisy hence MODCOD selection errors are causing:
  - Loss of spectral efficiency if the estimated SNIR is lower than real
  - Frame error if the estimated SNIR is higher than real
  - The SNIR error can be modelled as a Gaussian rv (in dB)

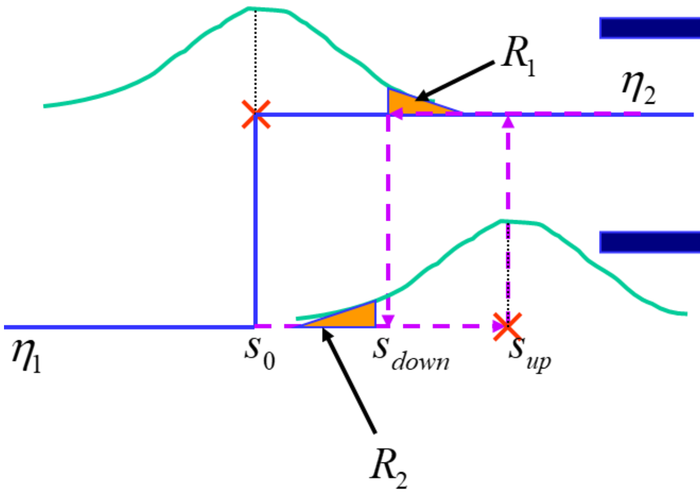




Satellite Standards - DVB-S2X: Physical Layer

ACM implementation aspects – physical layer selector:

- Hysteresis required to avoid ping-pong effects on MODCOD selection and associated signaling overhead
- Hysteresis sizing will be based on the maximum fading slope to be supported



S_{down} is related to the slot loss probability

S_{up} helps to reduce the signalling rate

$$s_{down} = s_0 + \sigma_s \sqrt{2}\,\mathrm{erfc}^{-1}(2R_1)$$
$$s_{up} = s_{down} + \sigma_s \sqrt{2}\,\mathrm{erfc}^{-1}(2R_2)$$

ANY TIME THE PACKET LOSS PROBABILITY IS REDUCED, THE EFFICIENCY LOSS INCREASES

PART 4 - SATELLITE STANDARDS: A LESS SUCCESSFUL CASE STUDY

Satellite Standards: DVB-RCS(2)

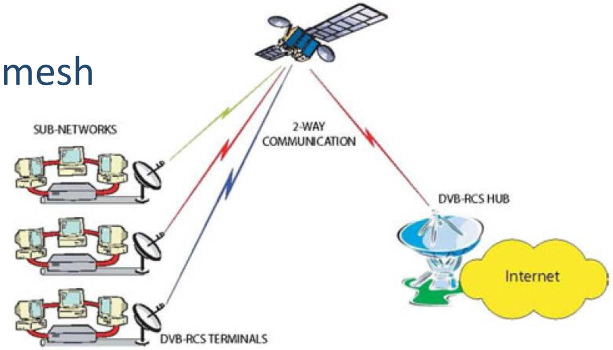
DVB-RCS(2) Short history:

- Triggered in 1999 by European key players desire to reduce the cost for interactive services standardizing their return link leveraging on the DVB-S(2) success
- Standard was adopted in its first version in 2001 and evolved in successive versions
- The last one was including the mobility support (v5, 2008)
- Despite the support to its widespread adoption in particular by Europe (ESA), the market size and the presence of competing proprietary products from USA, Israel inspired by DVB-RCS etc.. made its commercial success modest

- The DVB-RCS2 call for proposals was launched in 2008 by DVB covering all DVB-RCS layers
- 19 proposals received in 2009
- The standard was initiated in 2009 and completed in 2011 with large support by ESA and EU R&D programs as well as more than 10000 working days by worldwide experts
- Despite the many improvements and new features included in DVB-RCS2 the commercial success has been limited due to the proprietary solutions competition and limited market size

Satellite Standards: DVB-RCS(2)

Applications:

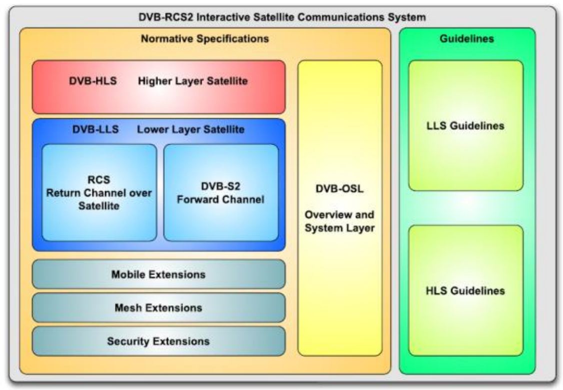


- Consumer and Small Office/Home Office (SOHO): fixed and fixed-mesh
- Multi-dwelling: fixed and fixed-mesh
- Corporate: fixed, mobile, and fixed-mesh
- Military: fixed, transportable, mobile, and fixed-mesh
- Backhaul: fixed, transportable, mobile and fixed-mesh
- Supervisory control and data acquisition (SCADA)/transaction: fixed and fixed-mesh

Key features:

- Support to hub-spoke, mesh and mobile type of networks
- Near-Shannon physical layer performance thanks to powerful turbo-Phi code FEC (University of Bretagne proposal sponsored by ESA)
- Wide range of power and spectral efficiencies with support of ACM
- Linear QAM modulation and CPM supported
- High performance random access (e.g. CRDSA proposed by ESA)
- IP protocols and high layers application specification

  (HLS and IP over sat, encapsulation, QoS management)



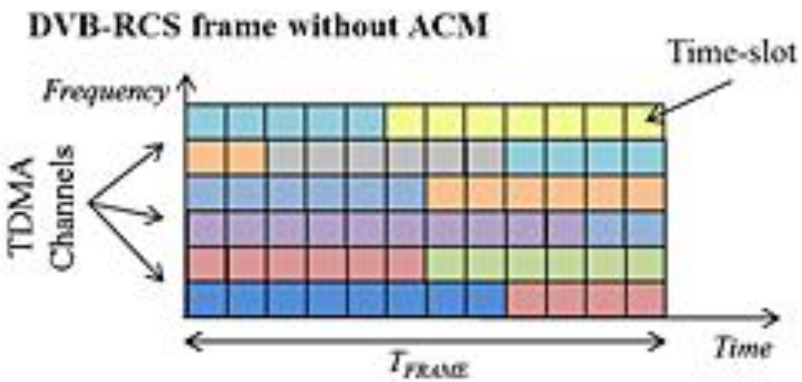
Satellite Standards: DVB-RCS2 vs DVB-RCS

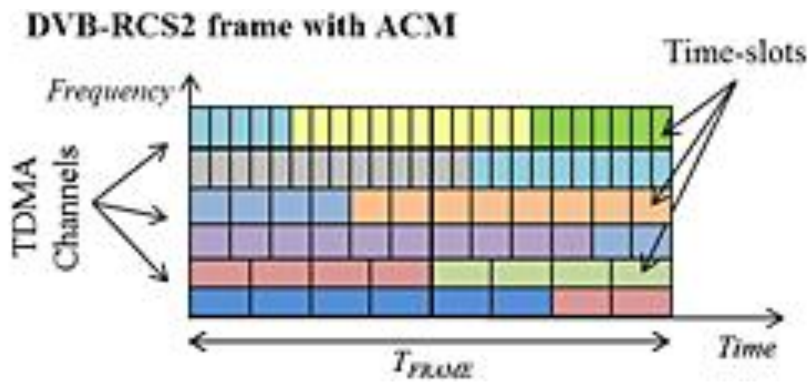
	RCS1	RCS2
Harmonized management and control	None	Yes (optional)
Harmonized IP-level QoS	None	Yes
Multiple virtual network support	None	Yes
Security	Single solution	Support for multiple security systems, for applications with widely different requirements
Return link access scheme for traffic	MF- TDMA, continuous carrier	MF-TDMA, continuous carrier, random access
Modulation schemes	QPSK	Linear: BPSK, QPSK, 8PSK, 16QAM Constant-envelope: CPM
Channel coding	RS/convolutional, 8-state PCCC turbo code	16-state PCCC turbo code (linear modulation), SCCC (CPM)
Burst spread spectrum	Burst repetition	Direct sequence
Return link adaptivity	Limited support	Inherent in air interface (TDMA and continuous carrier)
Bandwidth efficiency	Improved about 30% from DVB-RCS to DVB-RCS2	

BPSK, Binary Phase Shift Keying; QPSK, Quaternary Phase Shift Keying; 8PSK, 8-ary Phase Shift keying; PCCC, Parallel Concatenated Convolutional Codes; SCCC, Serially Concatenated Convolutional Codes.

Satellite Standards: DVB-RCS2 Physical Layer

- Multi-Frequency Time Division Multiple Access (MF-TDMA) is used in DVB-RCS(2)
- This 2D time/frequency resource allocation scheme allows to provide flexible resource allocation for the UE and reducing the peak power required to close the link typical of TDMA
- To each user upon request ACK some time/frequency slot of the MF-TDMA frame is allocated by the control station
- For ACM the time granularity has to be different for the different MODCODs





Satellite Standards: DVB-RCS2 Layers

Key physical/MAC layer enhancements:

- Turbo-Phi 16-states FEC to improve the power efficiency
- Higher order modulations 8PSK and 16QAM for higher spectral efficiency
- Low order modulation (BPSK) and spread-spectrum option for robust modes
- Adaptive Code and Modulation for link optimization
- CPM scheme for reduced user terminal HPA backoff
- Contention Resolution Diversity Slotted ALOHA for enhanced RA performance

Key upper layer enhancements:

- New return link encapsulation scheme (RLE)
- Direct IP support with enhanced TCP and IP protocols performance
- Enhanced Quality of Service support
- Enhanced security for providing sufficient confidentially, integrity, availability, and non-repudiation performance

Satellite Standards: DVB-RCS2 Physical Layer

ACM implementation aspects:

- ACM implementation in a multi-beam satellite return link is more challenging because the co-channel interference is time variant on a short-time scale
- This is because the dynamic MF-TDMA resource allocation and the bursty traffic nature makes the spatial interference distribution over the area of coverage rapidly time variant
- Use of negative peak envelope SNIR detector and hysteresis to avoid outages

$$\widetilde{\left[\frac{E_s}{N_t}\right]}(k) = \begin{cases} \left[\frac{\hat{E}_s}{N_t}\right](k) & \text{if } \left[\frac{\hat{E}_s}{N_t}\right](k) \leqslant \widetilde{\left[\frac{E_s}{N_t}\right]}(k-1) \\ \widetilde{\left[\frac{E_s}{N_t}\right]}(k-1)\exp\left(\frac{T_{\mathrm{F}}}{2\beta D}\right) & \text{otherwise} \end{cases}$$

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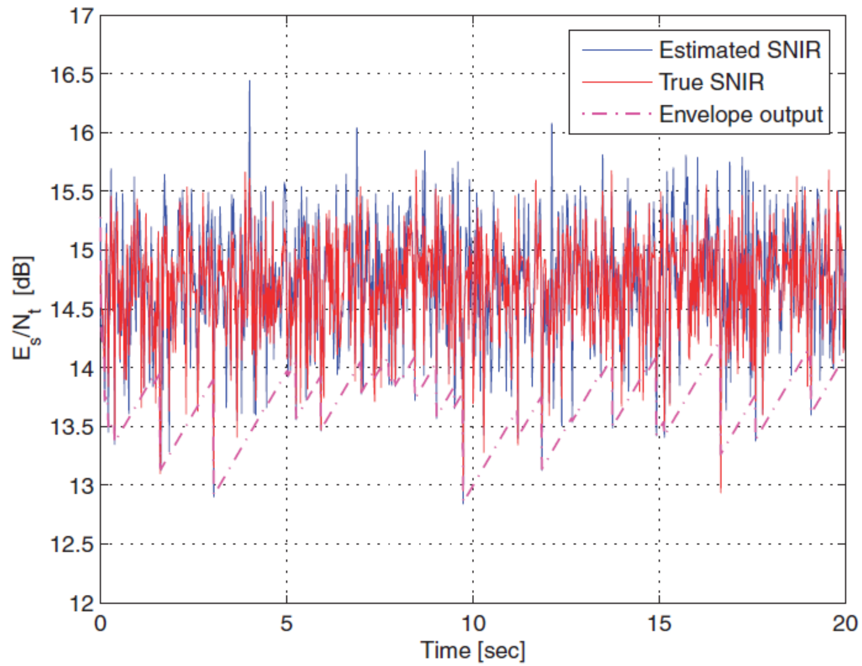
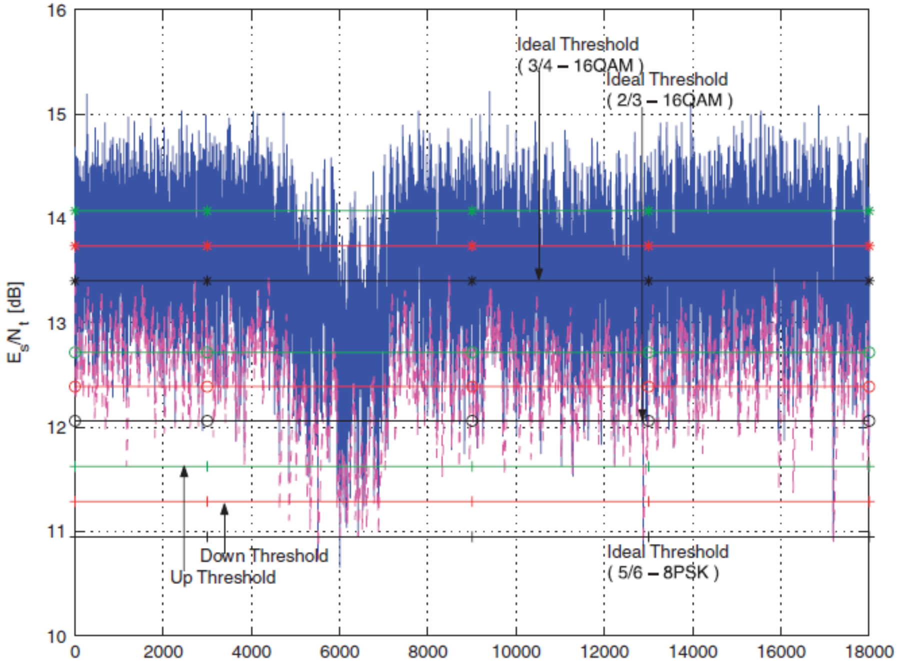


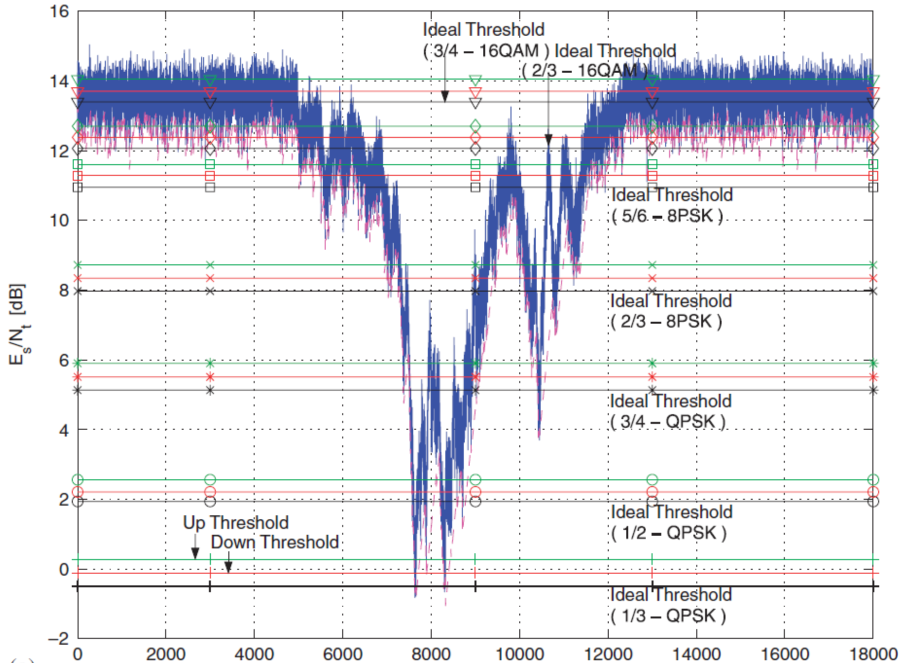
Satellite Standards: DVB-RCS2 Physical Layer

ACM implementation aspects:

- Similarly to the forward link an ACM approach based on hysteresis is required
- Threshold margins are larger as the SNIR estimation is based on the negative peak envelope detector



(a)



(a)

Satellite Standards: DVB-RCS2 Throughput

Reverse link throughput with ACM is cumbersome to compute:

$$\eta_A = \max_{f_R} \{\eta_A(f_R)\}$$

Maximization of the frequency reuse factor

$$\eta_A(f_R) = \frac{1}{N_b} \sum_{n=1}^{N_b} \frac{1}{\mathscr{S}(B_n)} \iint_{(x_n,y_n)\in B_n} \left[\prod_{m=1}^{N_b} \frac{1}{\mathscr{A}(B_n,B_m)} \iint_{(x_1,y_1)\in B_1} \cdots \iint_{(x_{N_b},y_{N_b})\in B_{N_b}} \hat{\eta}_A(x_n,y_n,\bar{x},\bar{y},f_R) \prod_{m=1}^{N_b} f(n,m)\, \mathrm{d}x_1\, \mathrm{d}y_1 \ldots \mathrm{d}x_{N_b}\, \mathrm{d}y_{N_b} \right] \mathrm{d}x_n\, \mathrm{d}y_n$$

System spectral efficiency averaged over the co-channel beams users' location

Reference User spectral efficiency averaged over the co-channel beams and users' fading PDF

$$\hat{\eta}_A(x_n,y_n,\bar{x},\bar{y},f_R) \simeq \int_0^1 \left\{ \int_0^1 \cdots \int_0^1 \hat{\hat{\eta}}_A(x_n,y_n,a(x_n,y_n),\bar{x},\bar{y},\bar{a}(\bar{x},\bar{y}),f_R \times p_{a(1)}(a(x_1,y_1))\, \mathrm{d}a(x_1,y_1) \ldots p_{a(N_b)}(a(x_{N_b},y_{N_b})) \times \mathrm{d}a(a(x_{N_b},y_{N_b})) \right\} p_{a(n)}(a(x_n,y_n))\, \mathrm{d}a(x_n,y_n)$$

Maximization of the reference user PHY conditioned to interfering users' location and fading

$$\hat{\hat{\eta}}_A(x_n,y_n,a(x_n,y_n),\bar{x},\bar{y},\bar{a}(\bar{x},\bar{y}),f_R) = \max_{r,M,L} \left\{ \frac{R_b}{f_R R_c} \middle| \left[\frac{E_b}{N_t}\right](x_n,y_n,a(x_n,y_n),\bar{x},\bar{y},\bar{a}(\bar{x},\bar{y}),f_R) \geqslant \rho_{\mathrm{req}}(r,M) \right\}$$

$$= \max_{r,M,L} \left\{ \frac{R_b}{f_R R_c} \middle| \frac{L}{r \log_2 M} \left[\frac{E_c}{N_t}\right](x_n,y_n,a(x_n,y_n),\bar{x},\bar{y},\bar{a}(\bar{x},\bar{y}),f_R) \geqslant \rho_{\mathrm{req}}(r,M) \right\}$$