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Efficient use of Satellite Resources through the use of Technical Developments and Regulations

ITU BR Workshop on the Efficient use of the Spectrum/Orbit resource

Session II: Technical Options to Improve Access to, and the Efficient use of the Spectrum /Orbit resource

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Background – History of Satellite communications

- **1945**
  - **Arthur C. Clarke Article**: proposes a station in geosynchronous orbit to relay communications and broadcast television
- **1957**
  - **Sputnik 1**: First satellite to orbit the earth
- **1965**
  - **EARLY BIRD**: First commercial communications satellite
- **1972**
  - **ANIK-1**: First Domestic Communications Satellite (Canada)

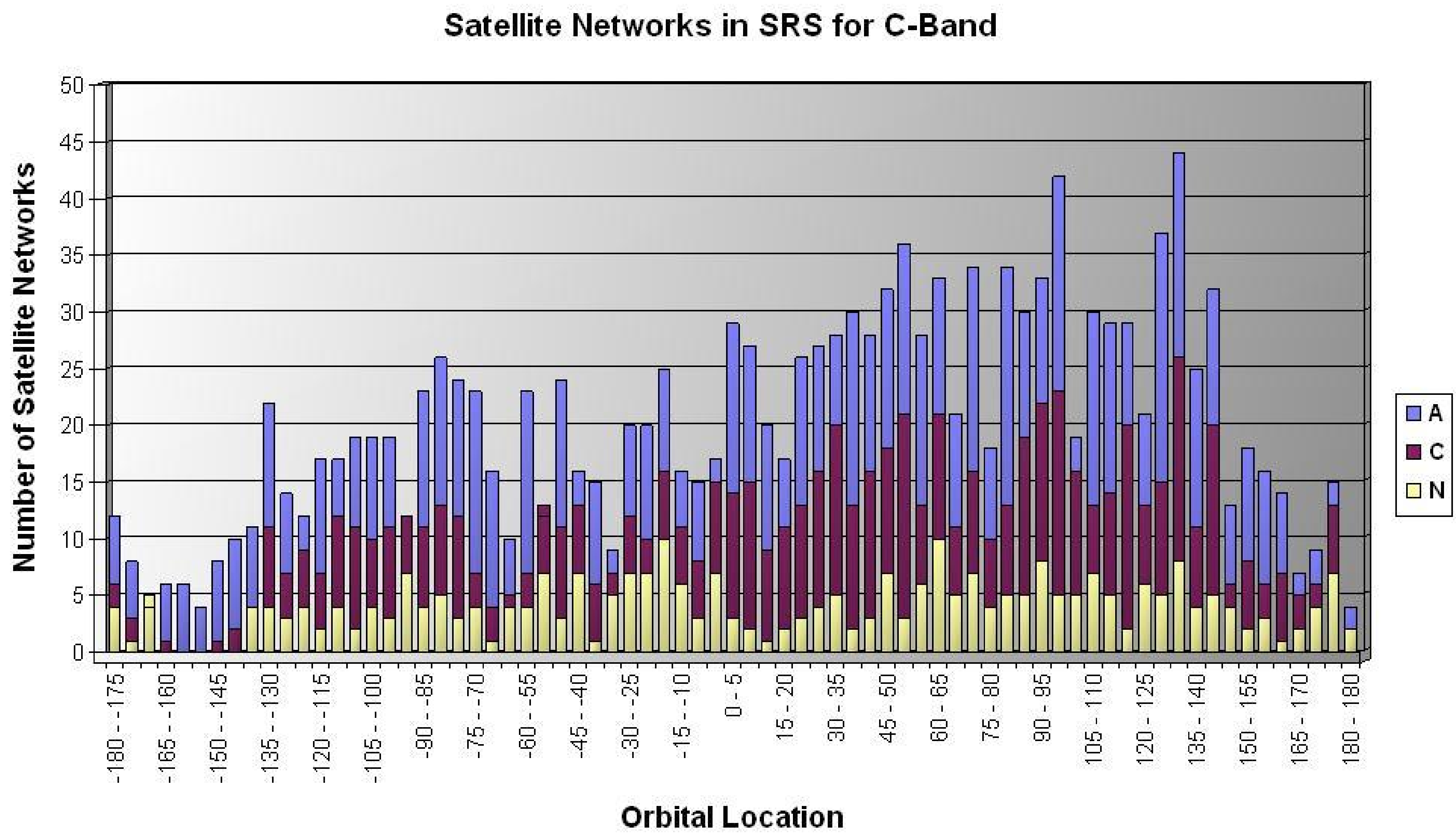
Today - Spectrum/orbit congestion

- **Developments in satellite communications lead to an increased use of spectrum and orbital locations**

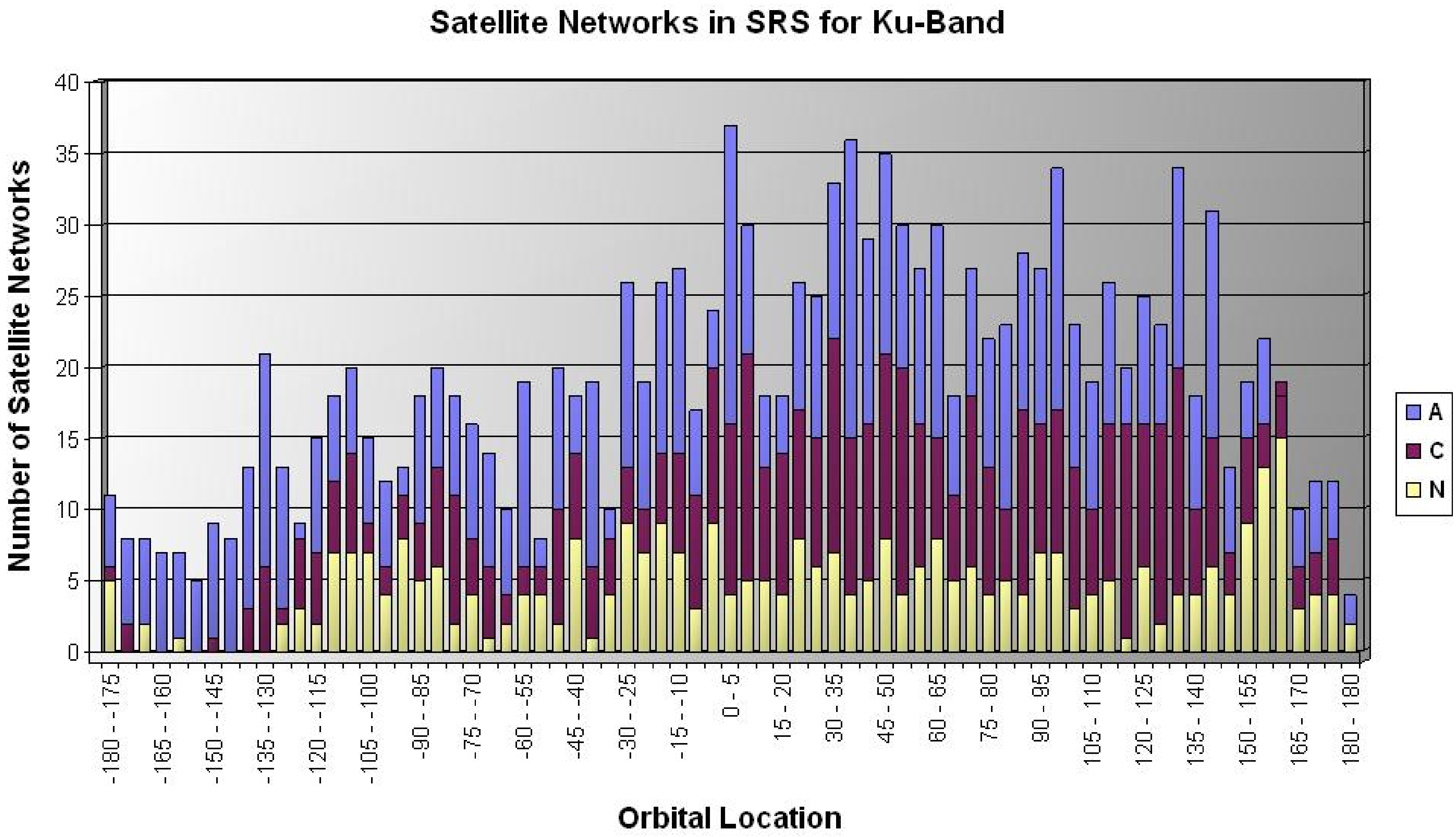
- **Since Dec 2007, the BR has received approximately:**
  – 730 new Advance Publication of Information (API)
  – 320 new Coordination requests (CR/C)
  – 70 new Notification requests (Part I-S)

- **ITU SRS database contains approximately:**
  – 3500 APIs, 2100 CR/Cs, 1200 Notifications

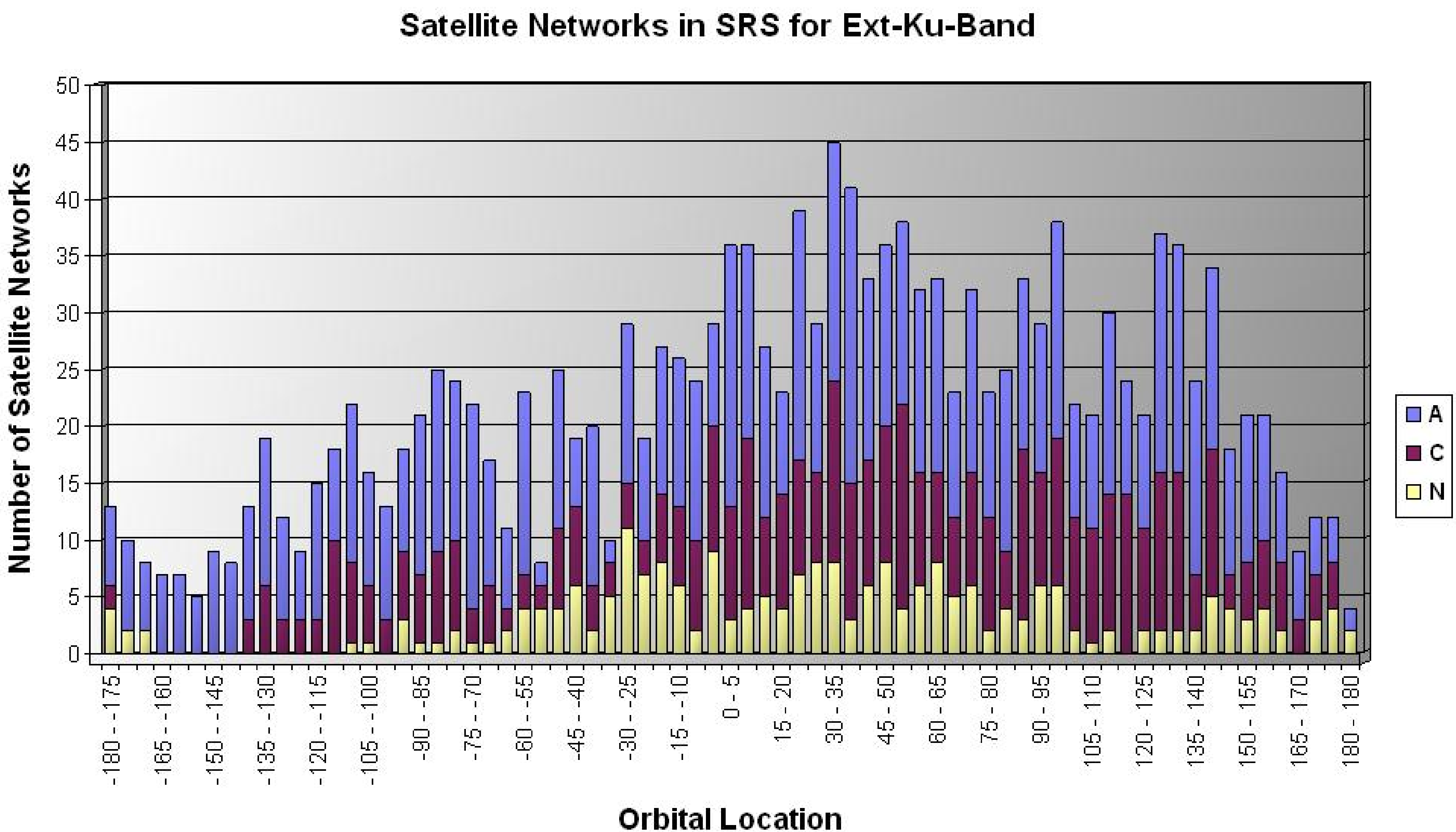
Spectrum/orbit congestion (cont'd)



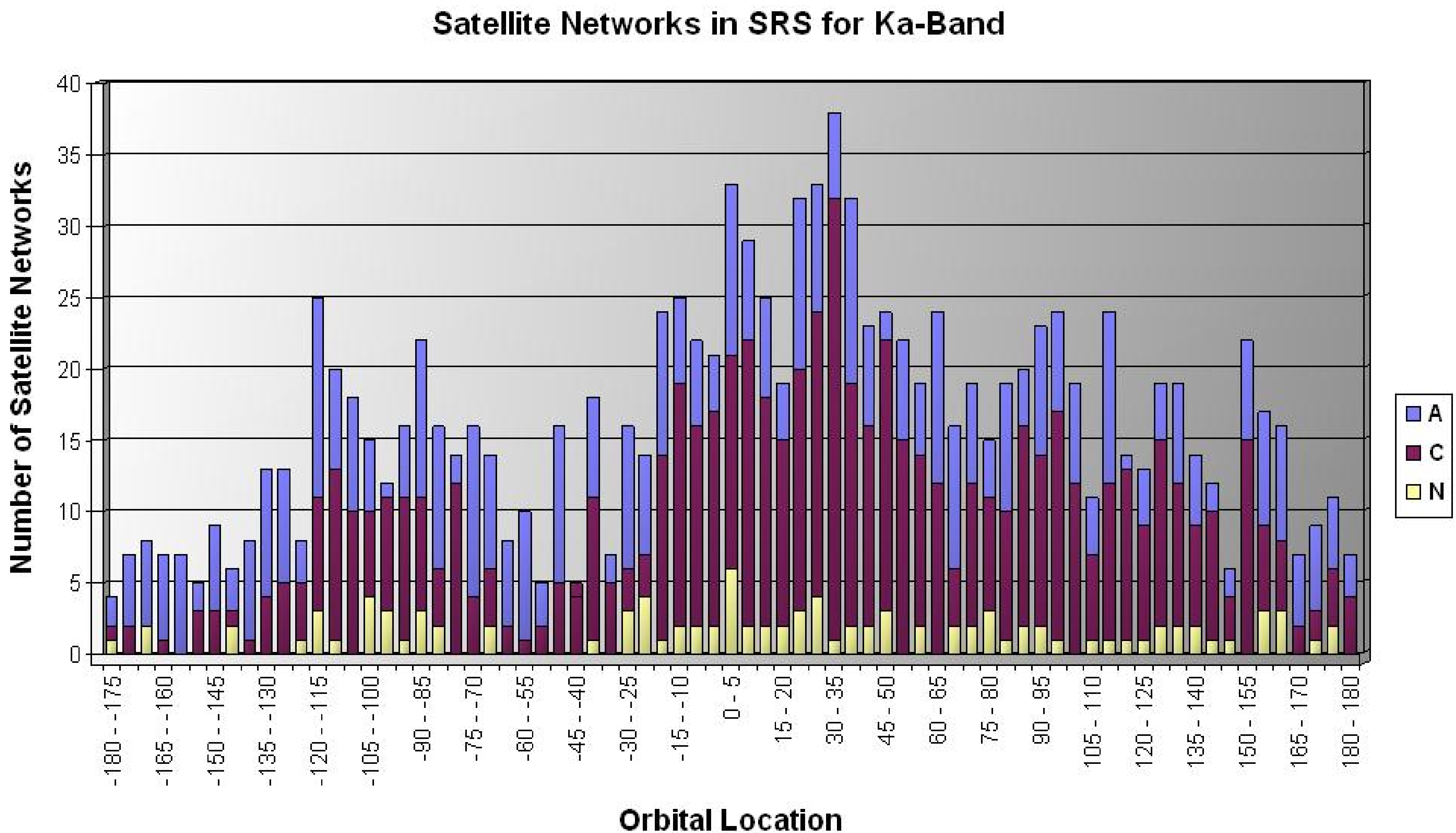
Spectrum/orbit congestion (cont'd)



Spectrum/orbit congestion (cont'd)



Spectrum/orbit congestion (cont'd)



Spectrum/orbit congestion (cont'd)

- **Planned satellite networks sent to the BR for notification and brought into use**

BSS

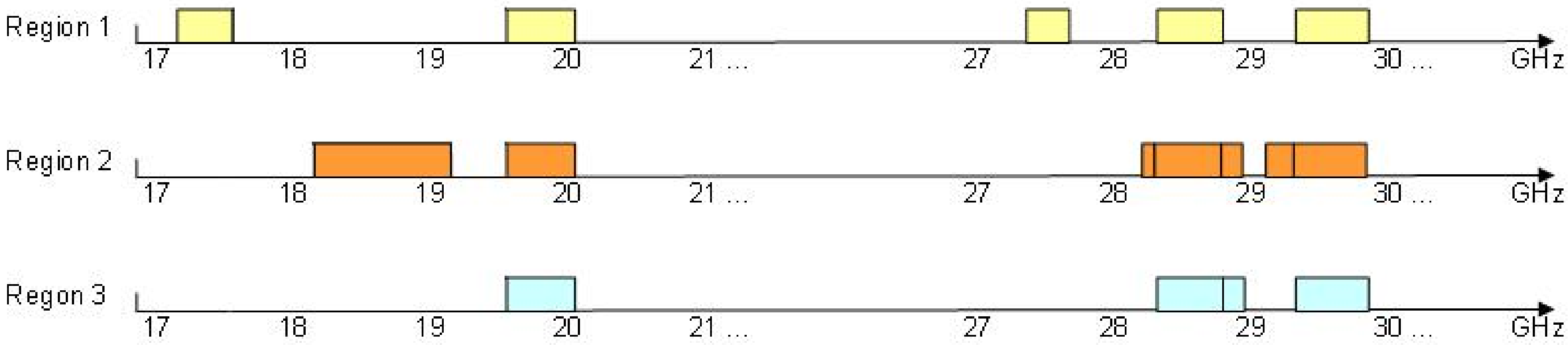
- Appendix 30, Region 1 & 3
  - 73 satellite networks
- Appendix 30A, Region 1 & 3 feeder-links
  - 61 satellite networks
- Appendices 30 & 30A, Region 2
  - 22 satellite networks

FSS

- Appendix 30B
  - 56 satellite networks

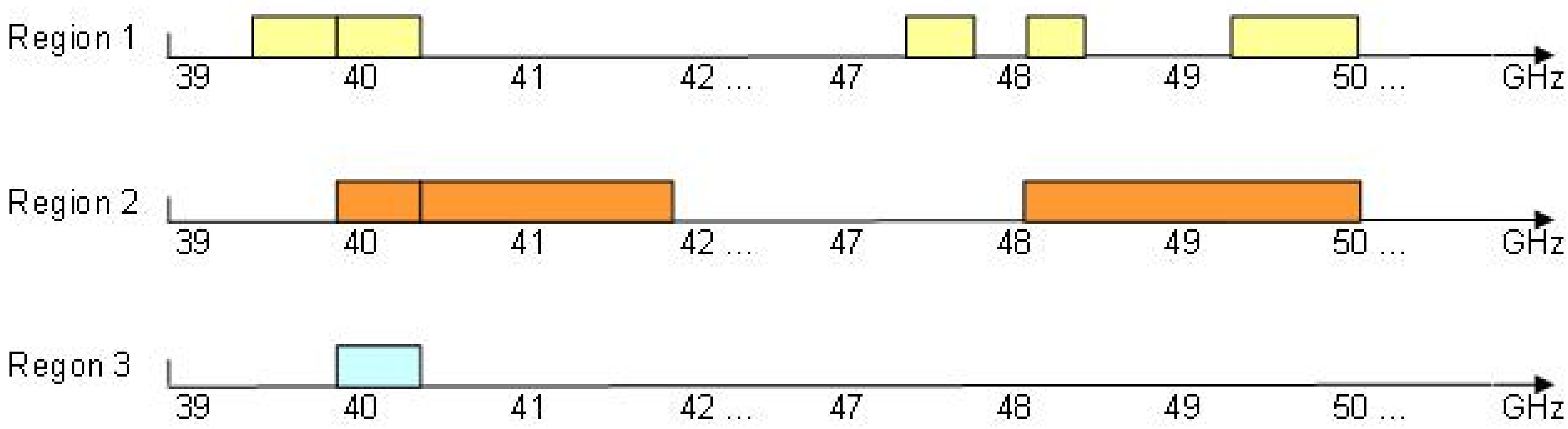
High-Density FSS Applications

- **HD FSS spreads the cost of a satellite network over a large number of subscribers using smaller less expensive terminals**
- **Frequency bands identified for high-density applications in the FSS**
  - No. 5.516B of the ITU-RR



High-Density Applications (cont'd)

- **Frequency bands identified for high-density applications in the FSS**
  – No. 5.516B of the ITU-RR



Spectrum Management

- **Link Budget Basics**
  - Ability of a satellite link to deliver information from a transmitting earth station at one location over a satellite to a receiving earth station in another location is dependent upon the link margin
  - Propagation conditions on the wanted signal path will determine the percentage of the time that the received signal is above the receiving system's (C/N_{Total}) threshold

Spectrum Management (cont'd)

- **Link Budget Basics (cont'd)**
  - This percentage of the time is referred to as the end-to-end link availability

$$M = \left(\frac{C}{N+I}\right)_{Total\ Link,CS} - \left(\frac{C}{N_{Total}}\right)_{Threshold}$$

  - Regardless of what levels of interference are present in a satellite link, all that really matters in terms of the satellite link performance is the link margin and the propagation conditions on the wanted signal path

Spectrum Management (cont'd)

- **Mechanisms to share the spectrum among space users**
  - Coordination procedures
  - Unplanned frequency bands
    - First come, first served
  - Planning approach
    - Equitable access to spectrum
    - Provide national coverage
    - Reservation of spectrum for future use
    - Specified notification procedures for FSS Plan and BSS Plans
  - Allocations
  - Technical limits (for protection of Space Plans)

Coordination Procedures

- **Article 9 of the ITU Radio Regulations**
  - No. **9.6** : “Before an administration notifies to the Bureau or brings into use a frequency assignment … it shall effect coordination, as required, with other administrations”
  - Lengthy and complex procedures

- **Coordination requirements**
  - First come, first served
    - Process
      - Article 9 of the ITU Radio Regulations
        - API
        - Coordination
      - Article 11 of the ITU Radio Regulations
        - Notification

Planning Approach

- **Planned Frequency bands**
  - Identified in Article 5 of ITU-RR, Article 2 of Appendices 30 & 30A, and Article 3 of Appendix 30B

- **Appendix 30 & 30A of the ITU Radio Regulations**
  - Compatibility with assignments in the Plan and List
    - EPM, PFD, or Coordination Arc in Region 1 & 3
    - OEPM in Region 2
  - Compatibility between Plan/List and unplanned services or other Regions
    - PFD & Δ T/T

Planning Approach (cont'd)

- **Appendix 30B of the ITU Radio Regulations**
  - Compatibility with assignments in the Plan and List
    - C/I & Coordination Arc
    - Outside Coordination Arc → PFD hard limit
  - Compatibility with terrestrial service
    - PFD limit in Article 21

Improving Utilization of Space Assets

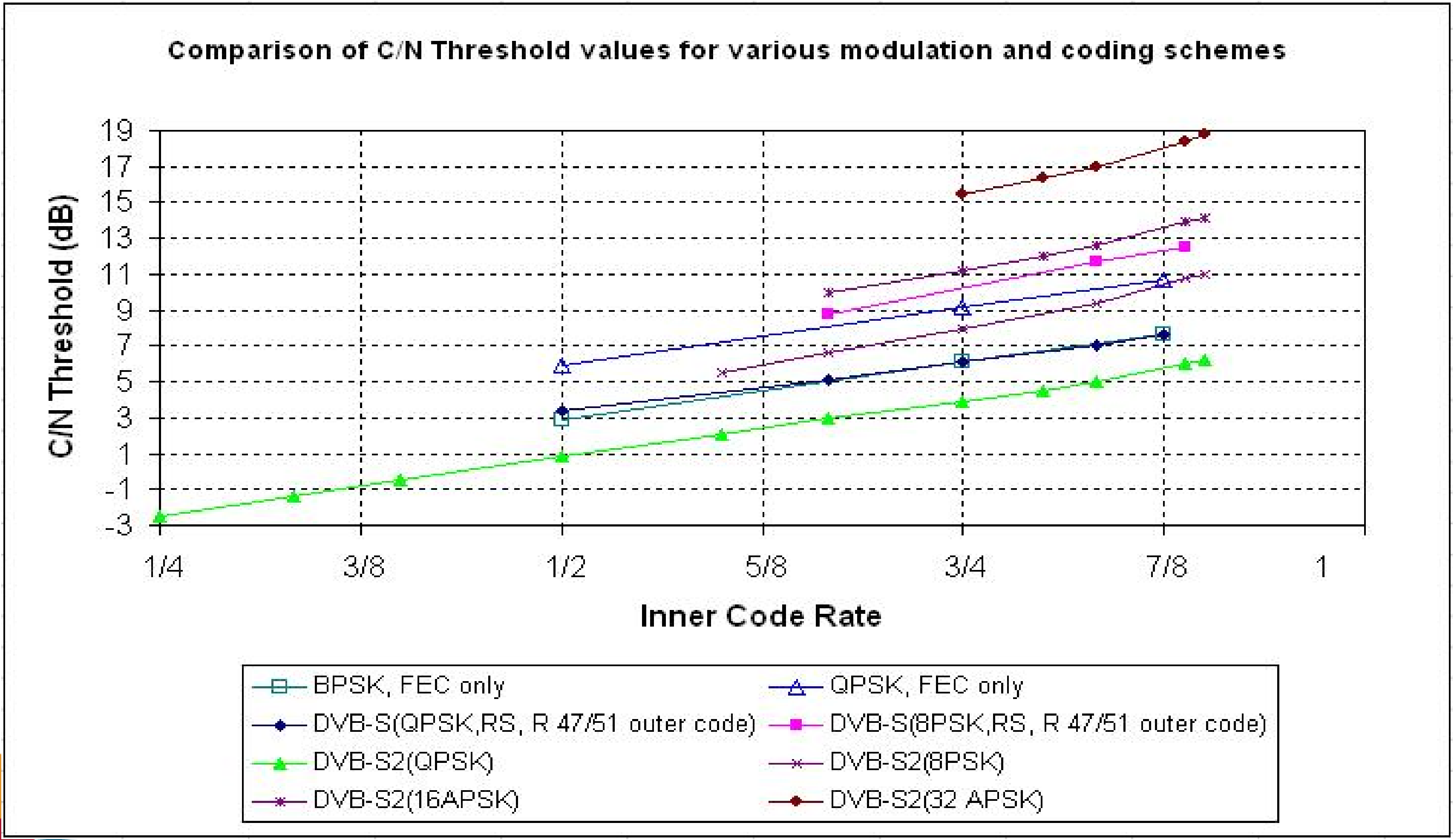
- **Due to spectrum/orbital congestion, coordination process is increasingly more difficult**
  - Constant increase in spectrum/orbit use and demand
  - limited access to ideal spectrum and orbital location
  - Solution?

- **Technological developments**
  - DVB-S2, “2nd generation” standard for satellite communications
    - Improved Forward Error Correction (FEC) performance
    - Option to use higher order modulation schemes
    - Adaptive ability to dynamically change modulation and coding schemes can be used to advantage in some applications

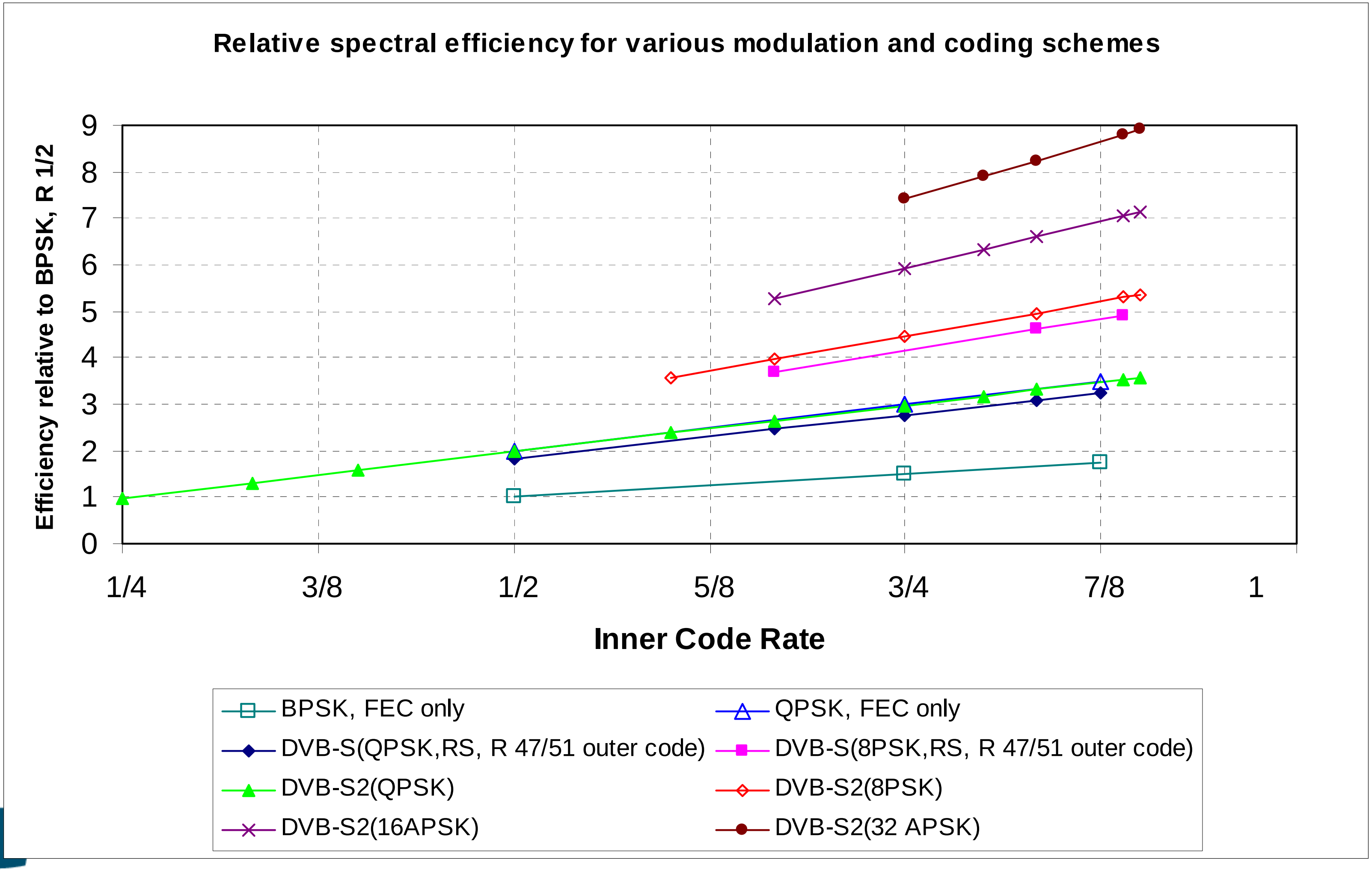
Improving Utilization of Space Assets (cont'd)

- DVB-S2 compared to DVB-S
  - Average E_b/N_o margin increase of 2.7dB
  - Average bandwidth reduction of 25%
  - Average power spectral density reduction of 46%
  - Average throughput increase of 33%
- Potential use for DVB-S2
  - Where limited by Article 21 PFD Hard Limit
    - Possible to provide services with national coverage using smaller antennas without increasing satellite EIRP
  - Cost reduction
    - Option to decrease receive antenna size
  - Option to increase the number of HDTV channels per transponder

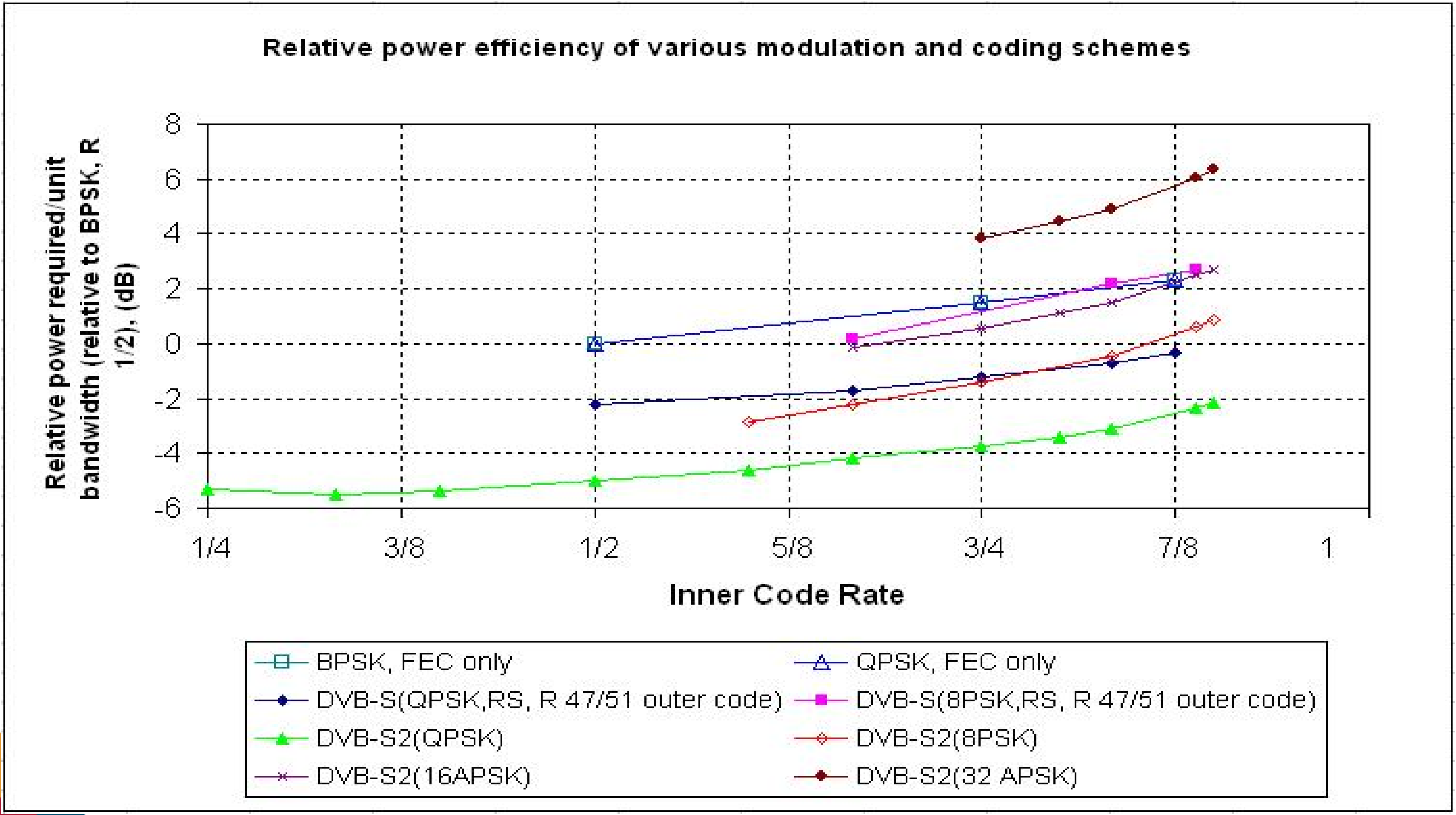
Improving Utilization of Space Assets (cont'd)



Improving Utilization of Space Assets (cont'd)



Improving Utilization of Space Assets (cont'd)



Improving Utilization of Space Assets (cont'd)

- Statistical Multiplexing
  - As capacity of broadcasting signals vary with time, not all signals require constant maximum information rate
  - Statistical multiplexing benefits from sharing the baseband capacity among the channels
    - by giving the most bandwidth at to the most demanding channel at any given moment
  - Can increase the capacity by more than 20%
    - transponder with an aggregate information rate of 44 Mb/s can increase its capacity from 8 channels to 10 channels

Improving Utilization of Space Assets (cont'd)

- Video coding standard: H.264/AVC (MPEG-4 part-10)
  - Improved image quality at same compressed bit rate
  - Same image quality at lower compressed bit rate
  - Bit-rate savings compared to MPEG-2
    - Reduction average of 64% for equivalent quality
  - Satellite employing DVB-S system using MPEG-2 can triple its number of programmes by switching to:
    - 8-PSK with turbo coding or equivalent
    - DVB-S2
    - H.264/AVC
  - Compared to MPEG-2 video compression, required information rate reduced by a factor of 2.25 to 2.5

Advances in Technology

- **High Mass / High Power Payloads**
  - Use of multiple frequency bands and high power satellites
  - Reliability of launch and in-orbit operations paramount
- **Satellite Solar Panel Technology**
  - Fewer solar panels required to supply same bus power
- **Modulation and Coding**
  - Higher information rates with less spectrum
  - Use adaptive modulation and coding to combat rain fading
- **Improved earth station radiation pattern envelopes**
  - Compliant with improved off-axis radiation pattern envelope of 29-25log ϕ instead of the more familiar 32-25log ϕ envelope
    - Reduces the susceptibility to adjacent satellite interference and interference caused to adjacent satellites

Advances in Technology (cont'd)

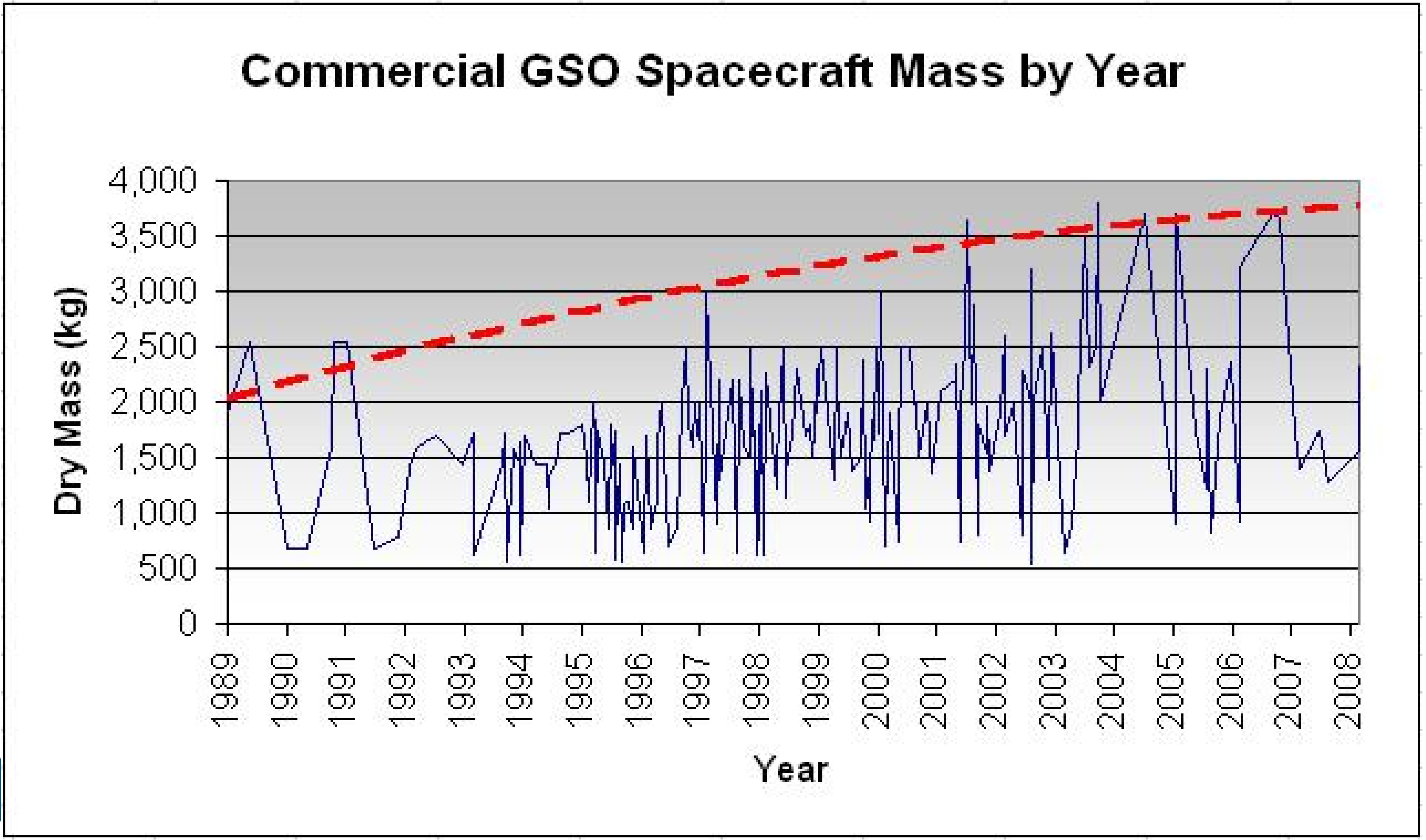
- **Digital compression and replacement of analogue technology**
  - Enable more TV channels per transponders
  - Smaller antennas make TV reception by satellite more accessible to greater numbers of subscribers
- **Rain fade countermeasures**
  - Make more efficient use of spectrum at all times
    - Higher information rates using less power per unit of bandwidth under clear sky conditions (most of the time)
    - Lower information rates using more power per unit of bandwidth only during fading events
- **Satellite antenna advancements**
  - Large shaped mesh reflectors (25 m+) at C-band can be used to provide multiple spot beam coverage are in development

Limits of Technology

- **High mass/High power payloads**
  - Increased complexity and integration of time with multiple band payloads
  - Heavy lift launch vehicle have their limits
  - Use of new, heavier lift payload launchers carries additional risk
  - Insurance costs
    - Choose overall launch and hardware reliability over payload size

- **Satellite Solar Panel Technology**
  - Limits to efficiency – difficult to achieve on wide scale commercially
    - 27% to 40% (in Lab) for triple junction cells, potentially twice that of current of Silicon cells.
  - Higher efficiency dual and triple junction solar cells are more costly and currently produced in lower volumes
  - Most efficient triple junction solar cells require 100's of suns illumination for peak efficiency adding weight and mechanical complexity of concentrators

Limits of Technology (cont'd)



Limits of Technology (cont'd)

- **Modulation and Coding**
  - DVB-S2 has "higher" modulation and coding schemes that are more spectrally efficient but at the expense of additional power (refer to slides 19 & 20)
  - Modulation schemes employing 8PSK, 16PSK or 32 APSK require quasi-linear transponders to minimize non-linear distortions driving up the size and mass of TWTA's to achieve appropriate output power back-off's

Limits of Technology (cont'd)

- **Digital compression and replacement of analogue technology**
  - H.264 uses a more efficient digital video compression algorithm
  - H.264 takes significantly more processing power and memory to compress and decompress video
- **Rain fade countermeasures**
  - Use of hydrophobic coatings and other techniques to reduce/eliminate "antenna wetting" losses
  - Automatic Level Control (ALC) and Uplink Power Control (UPC) widely employed by feeder link uplinks to the Broadcasting Satellite Service
  - Adaptive coding/modulation techniques for increasing throughput best suited to applications where there is feedback from the receiving ES to the transmitting ES to control the level of modulation and/or coding employed while optimizing end-to-end link performance

Limits of Technology (cont'd)

- **Satellite antenna advancements**
  - Use of large antennas employing multi-beam spot beams at C-band can be used to greatly increase capacity, increase flexibility and reduce frequency coordination problems with satellite networks covering adjacent administrations.

Impact of Modern Technology

- **Provide new or additional satellite applications over limited spectrum/orbit resources**
  - More robust
    - Reduced susceptibility to adjacent satellite interference
    - Increased throughput through employment of rain fade counter-measures
    - Increased availability with improved link margin
  - Conserve satellite capacity
  - Increased coverage area
  - Use smaller earth station antenna dish

- **All of the above options make satellite technology more accessible and will increase or generate new revenue streams!!!**

Regulatory changes due to technology improvements

- **Changes to Appendix 30B at WRC-07**
- **Regulatory changes**
  - New Coordination Arc
    - 10° / 9° for C/Ku frequency bands
  - Use of updated propagation models
    - ITU-R Rec. P.676-7 and P.618-9
  - Simplified Regulatory procedures
    - Non-sequential processing (Article 6 of Ap30B)
    - Elimination of PDA and Macro Segmentation
    - Revised and improved procedures for addition of new Allotments to the Plan for new Member States

Regulatory changes due to technology improvements (cont'd)

- **Technical changes**
  - 13/10-11 GHz band

Uplink

	Pre-WRC-07	WRC-07	Impact on (C/N)	Min Faded C/N	
ES Antenna	3m	2.7m	-0.9 dB	**Pre-WRC-07**	**WRC-07**
Sat RX Noise Temp	1500 K	550 K	4.4 dB	23 dB	21 dB
Net difference to clear sky uplink (C/N)			3.5 dB		

Downlink

	Pre-WRC-07	WRC-07	Impact on (C/N)	Min Faded C/N	
ES Antenna	3m	2.7m	-0.9 dB	**Pre-WRC-07**	**WRC-07**
ES RX Noise Temp	200 K	125 K	2.0 dB	17 dB	15 dB
Net difference to clear sky uplink (C/N)			1.1 dB		

Regulatory changes due to technology improvements (cont'd)

- **Changes to Appendix 30B at WRC-07 (cont'd)**
  - 6/4 GHz band

Uplink

	Pre-WRC-07	WRC-07	Impact on (C/N)	Min Faded C/N	
ES Antenna	7m	5.5m	-2.1 dB	**Pre-WRC-07**	**WRC-07**
Sat RX Noise Temp	1000 K	500 K	3.0 dB	23 dB	21 dB
Net difference to clear sky uplink (C/N)			0.9 dB		

Downlink

	Pre-WRC-07	WRC-07	Impact on (C/N)	Min Faded C/N	
ES Antenna	7m	5.5m	-2.1 dB	**Pre-WRC-07**	**WRC-07**
ES RX Noise Temp	140 K	95 K	1.7 dB	17 dB	15 dB
Net difference to clear sky uplink (C/N)			-0.4 dB		

Future Technical & Regulatory Options for Increasing Capacity of Spectrum

- **Increased utilization of geostationary orbit**
  - Larger earth stations (impractical)
  - Improved earth station antenna standards
    - Earth stations with improved performance in the direction of the GSO plane
  - Implementation of coordination arcs in additional frequency bands
  - Homogeneous networks (similar levels and parameters eases coordination difficulties)

Future Technical & Regulatory Options for Increasing Capacity of Spectrum (cont'd)

- **Backlog in the number of satellite filings**
  - Use of ITU-RR provisions to request assistance from the BR increases burden on BR
  - Decrease burden on the BR
    - Eliminate ALL paper: make it mandatory to file satellite antenna patterns electronically
    - Improve mechanism for coordination "opt-in" provision (example, No. 9.41) other than $\Delta T/T > 6\%$
    - Administrations conduct its due diligence before requesting assistance from the BR
      - Develop guidelines for procedures to contact BR
        - Study methods to streamline this process with objective of accelerating problem resolution from time of request

Future Technical & Regulatory Options for Increasing Capacity of Spectrum (cont'd)

- **Competition with co-primary services for the same spectrum (e.g., space based services (FSS or BSS) sharing with fixed service)**
  - Do not rely on simple worst-case interference calculations when developing regulatory conditions (e.g., Art. 21) for sharing
  - Rely less on I/N calculations and more on impact to service availability
  - Study quantitative inter and intra-service burden sharing methodologies with other that will help achieve overall spectrum utilization
  - Use more complex statistical methodologies for developing sharing conditions
  - Incorporate more imaginative solutions for sharing that are more than a single globally applied pfd limit (explore non-uniform pfd limits linked to climatic parameters and/or operational constraints)

Questions

?

ITU References

- ITU Radio Regulations
- ITU Recommendations
- Radiocommunication Bureau Seminar
- Space Network List (SNL)
- Space Network Systems Online (SNS)
- ITU BR Space Networks software

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