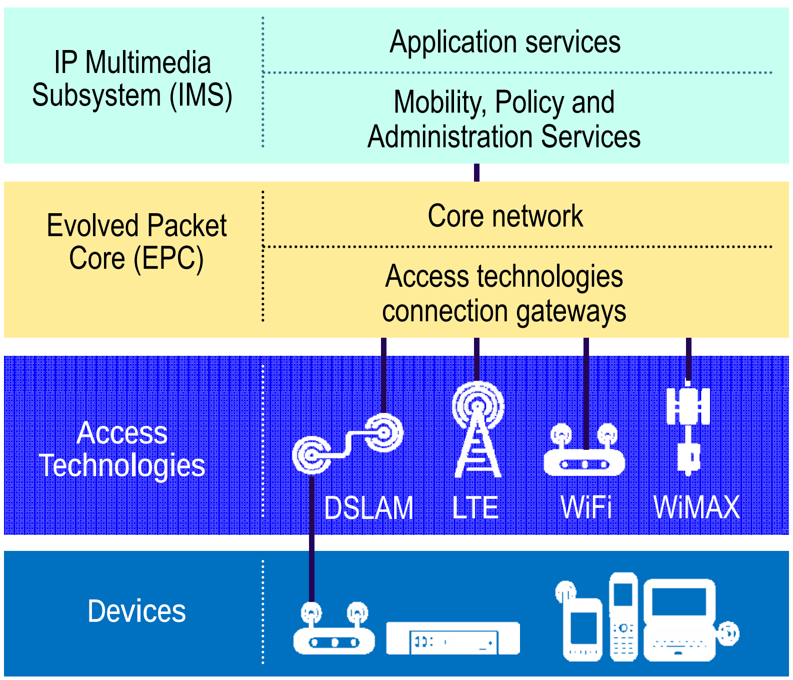
Advances in Broadband Access Communications



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Contents:

- An Overview
- Technical Challenges & Solution Approaches
- Examples in xDSL, wireless communications, and satellite communications

COMMUNICATIONS NEEDS & TRENDS

- **multimedia** services: Voice, Video distribution, Real-time videoconferencing, Data,… for both business and residential customers:
  - Explosive traffic growth
  - Internet growth, VoIP, VideoIP, IPTV
- Cell phone popularity worldwide
- **Ubiquitous** communication for people and devices
- Emerging systems opening new applications
- **Unified** network: Single distributed network, multiple services, packet architecture

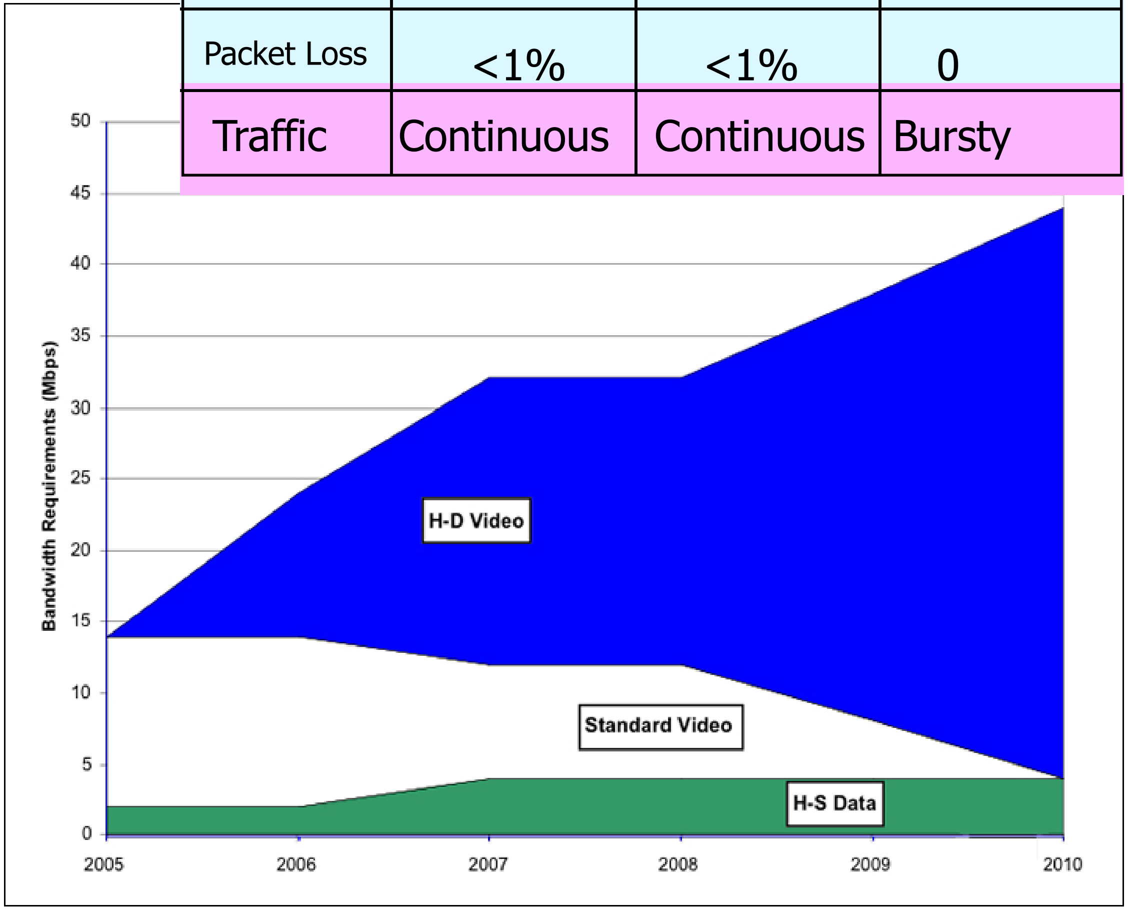
explosive acceptance of the Internet

- The explosive acceptance of the Internet as indicated by the time taken to reach the 10 million customer mark after being introduced to the mass market:
  - 38 years for telephone
  - 25 years for cable TV
  - 9 years for cell phone
  - 6 years for wireless data
  - <2 years for Internet
- Internet users want & demand speed

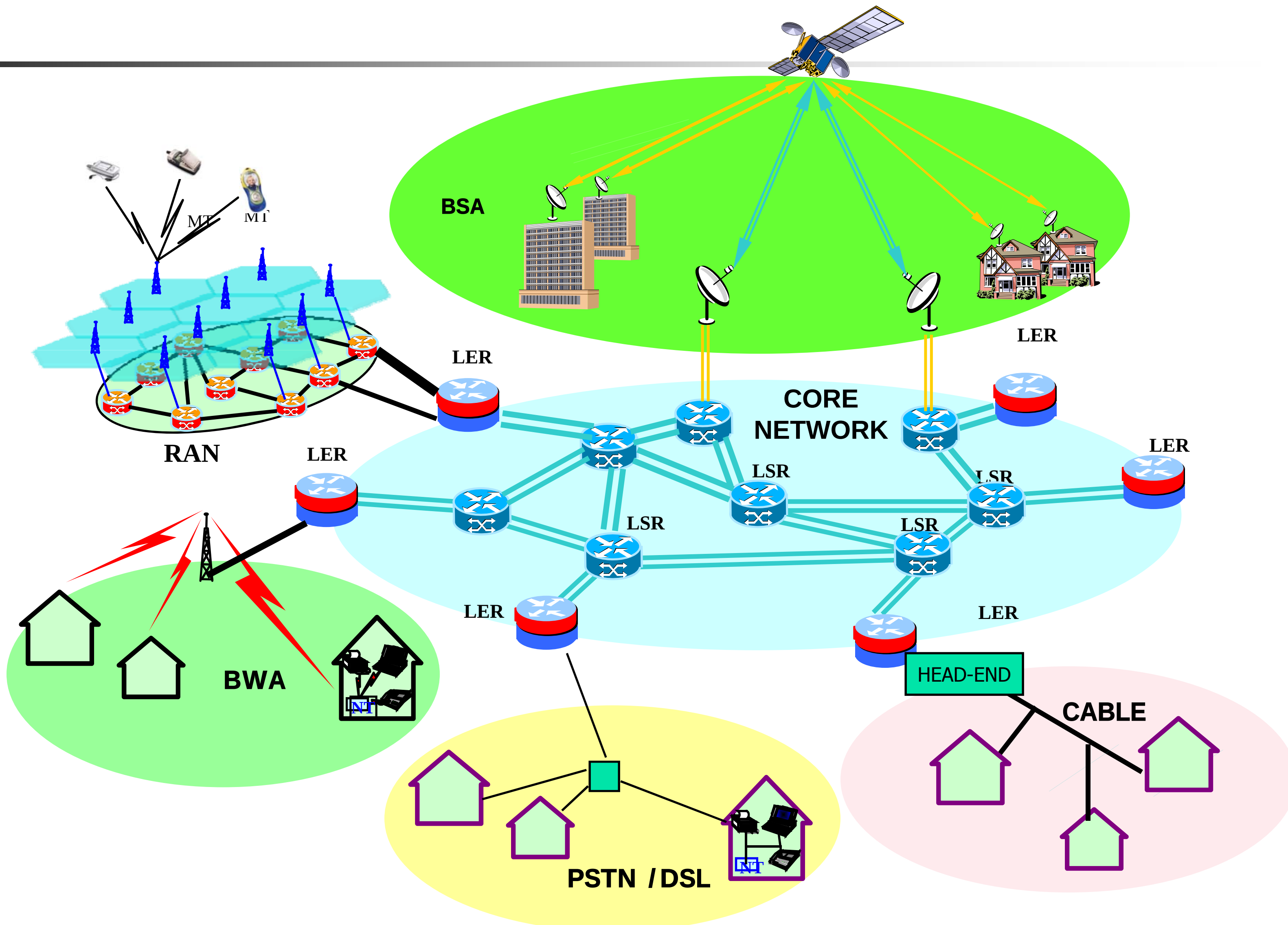
Multimedia Services: Requirements

- attributes: high-speed, bursty traffic, various QoS requirements, mobility
- technical requirements: efficient use of broadband transmission resources
- fiber can provide high capacity but fiber to every user is expensive
- for major areas covered by fiber this is the **last mile** issue.

	Voice	Video	Data
Rate	8-32 Kbps	1-20 Mbps	1-100 Mbps
BER	10^{-3}	10^{-6}	10^{-6}
Delay	<100ms	<100ms	-
Packet Loss	<1%	<1%	0
Traffic	Continuous	Continuous	Bursty



CORE & ACCESS TECHNOLOGIES: EXAMPLES



CONSIDERATIONS:

DEMANDS:

- Users want more capacity at good quality for various applications that need fast response, large volume of information.
- Operator wants more subscribers sharing the network for higher revenue, i.e., more efficient use of resources while offering QoS requirements

ENVIRONMENT & SERVICES:

- Limited resources (bandwidth, power).
- channels: time-varying, (multipath) frequency-selective fading, interference-limited
  - wireline: xDSL
  - wireless Near-LOS, Non-LOS: WiFi, UWB (indoor), WiMax, PCS (outdoor)
- Multimedia services with different QoS requirements.
- Large number of nodes in a dynamic network

TECHNICAL CHALLENGES

- *Higher rates* requires consideration of advanced transmission and signal processing techniques with better performance:
  - new dimensions, e.g., multiple-input multiple-output
  - adaptive to dynamic environmental changes
  - better interference-awareness
- Dynamic performance and resource management
- *supports* of different *QoS requirements* need more efficient *dynamic* resource allocation
- *Better connectivity* needs *reconfigurable* topology that can adapt to the changes.
- Efficient utilities of resources,
- Relatively low cost and complexity.

APPROACHES:

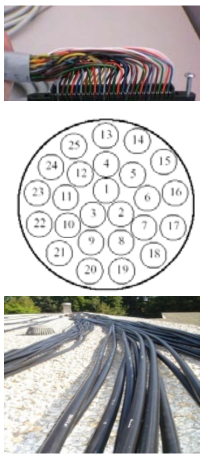
- adaptive multiple-dimensional transmission techniques in time-varying, frequency-selective fading channels:
  - space-time-frequency coding, precoding, modulation, decoding schemes that improves both coding and diversity gains
  - Reconfigurable, collaborative processing

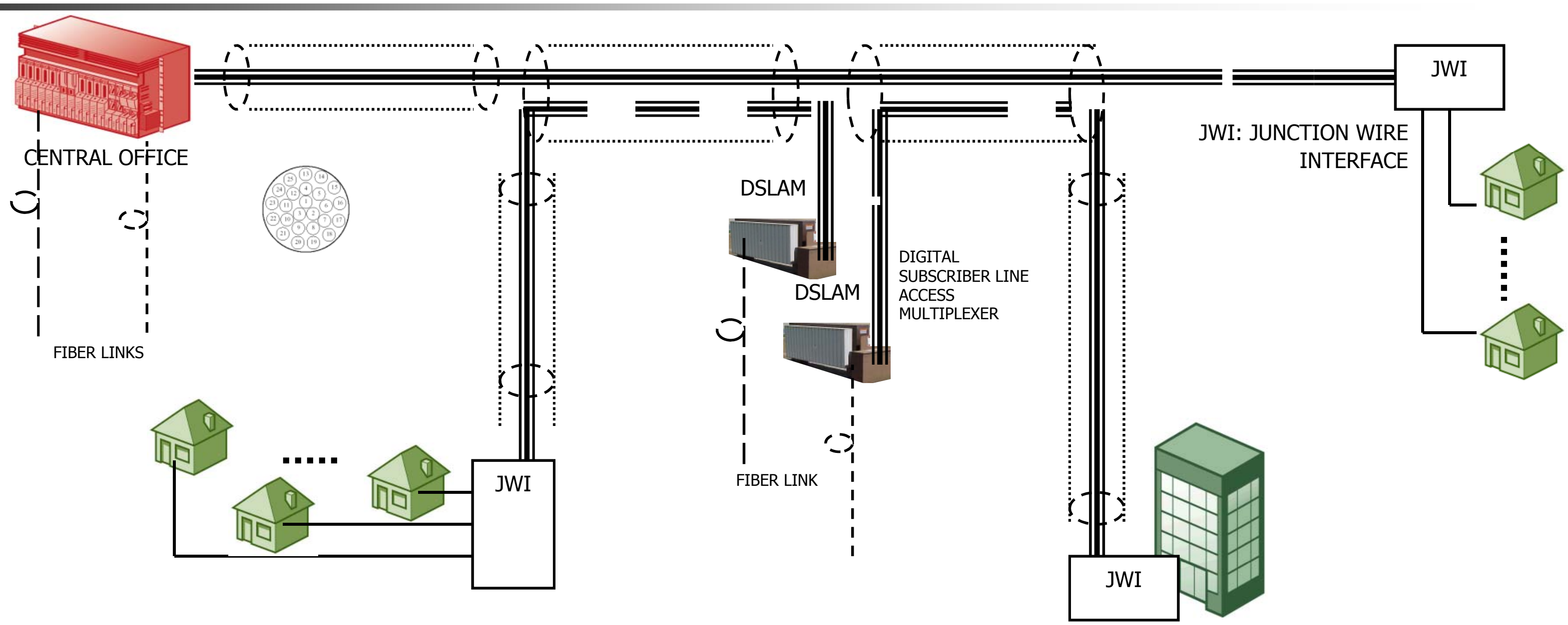
in conjunction with

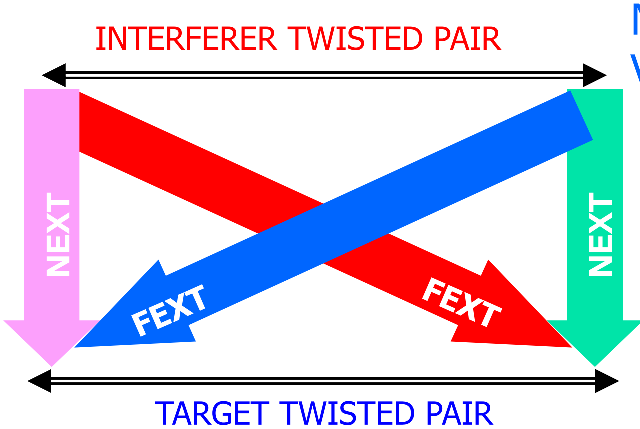
- dynamic resource allocation strategies across the “layers”
  - to improve resource utility in interference-limited environment
  - to promote collaboration between entities in efficiently sharing common communication resources

xDSL : An Overview

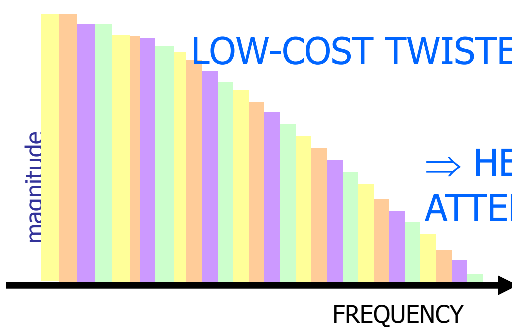
EXAMPLE OF xDSL NETWORK & ENVIRONMENT







MULTIPLE TWISTED-PAIRS OF DIFFERENT LENGTHS WITH VARIOUS SIGNALS IN THE SAME BINDERS $\Rightarrow$ CROSSTALKS

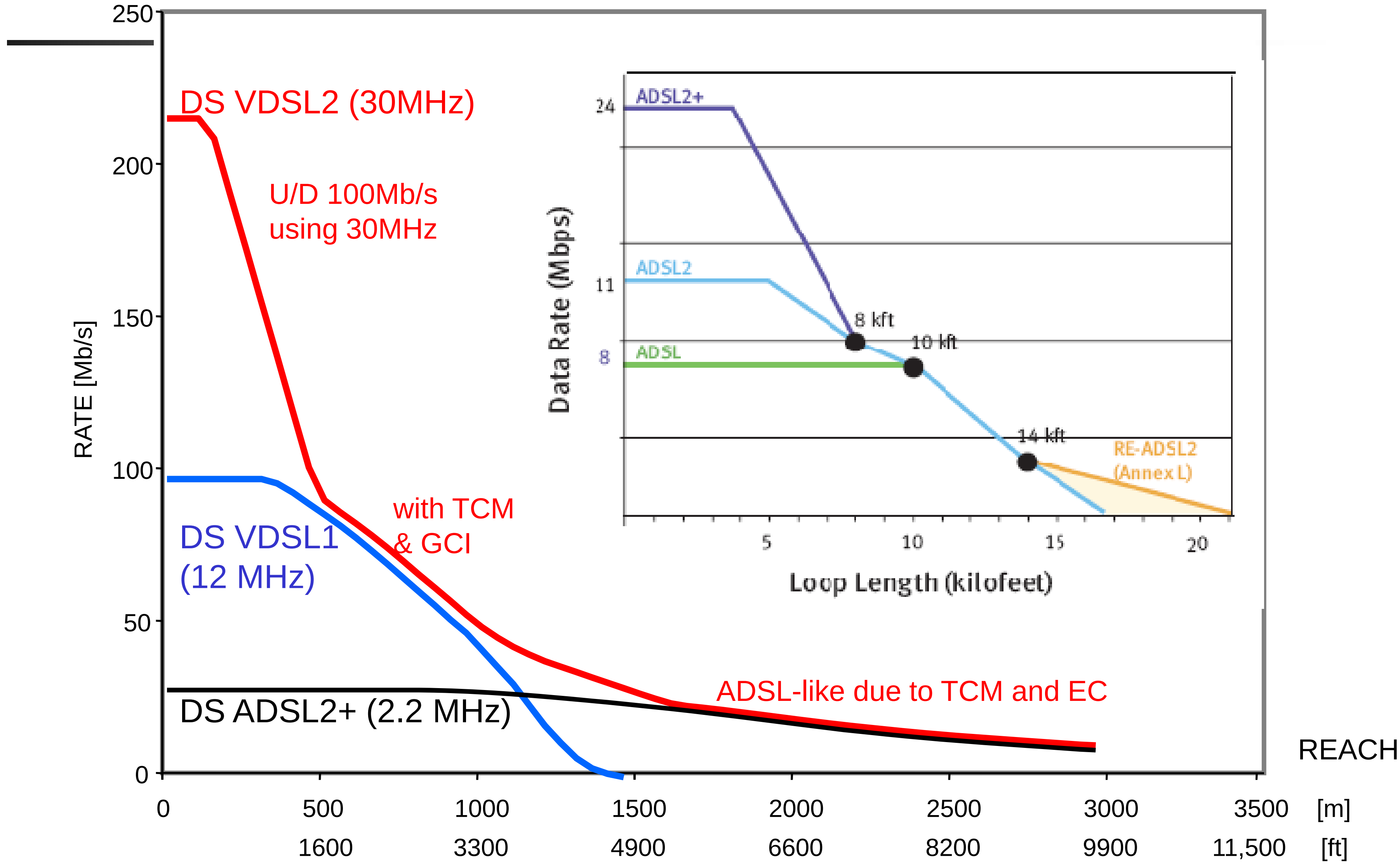


LOW-COST TWISTED-PAIRS ORIGINALLY USED FOR LOW-FREQUENCY VOICE

$\Rightarrow$ HEAVY FREQUENCY-SELECTIVE ATTENUATION, SEVERE DISTORTION:

$$\left|h_{ii}(f,l)\right| \approx \exp\left[-\alpha l f^{1/2}\right]$$

ADSL / VDSL Performance in AWGN channel -140dBm/Hz/ANSI-TP1



ADSL & VDSL: rates

Family	ITU	Maximum Speed capabilities
ADSL	G.992.1 G.dmt 1999	7 Mbps down 800 kbps up
ADSL2	G.992.3 G.dmt.bis 2002	8 Mb/s down 1 Mbps up
ADSL2plus	G.992.5 2003	24 Mbps down 1 Mbps up
ADSL2-RE Reach Extended	G.992.3 2003	8 Mbps down 1 Mbps up
SHDSL (updated 2003)	G.991.2 G.SHDSL 2003	5.6 Mbps up/down
VDSL	G.993.1 2004	55 Mbps down 15 Mbps up
VDSL2 -12 MHz long reach	G.993.2 2005	55 Mbps down 30 Mbps up
VDSL2 - 30 MHz Short reach	G.993.2 2005	100 Mbps up/down

Examples

USA, Canada, Europe, China

- Triple-Play with at least 3 HDTV channels + 5Mbps surfing + VoIP
- 30Mbps down, 3Mbps up

Japan, Korea, Taiwan

- Upgrade of existing 70Mbps services to 100Mbps sym

Wireless Access Communications: An Overview

Cellular Wireless System Evolution

- 1G (Early 1980s): Analog FDMA for voice communications, e.g., AMPS
- 2G (Early 1990s): Digital TDMA and narrowband CDMA for voice communications, e.g., started with GSM (mainly voice), IS-95 (cdmaOne), PDC,
  - 2.5G: Adding Packet Services: GPRS, EDGE
- 3G (Late 1990s): global standard introduced by International Mobile Telecommunications (IMT)-2000, e.g., Release 99 (Mar. 2000): UMTS/WCDMA, cdma2000, and TD-SCDMA
  - Global harmonization and roaming.
  - Wideband CDMA
- 3G Extensions (3GPP): IP Multi Media Subsystem (IMS), Inter-working with WLAN (I-WLAN)
  - High-Speed Packet Access (HSPA): HSDPA in Rel 5 (2002) and HSUPA in Rel 6 (2005) (D:down, U:up)
  - Rel-7 (2007): DL MIMO, IMS (IP Multimedia Subsystem), VoIP, gaming, push-to-talk.
- beyond 3G: evolutionary path beyond IMT-2000 (IMT-Advanced): targets 100Mbps (high mobility) and 1Gbps (low mobility, e.g., nomadic, local area):
  - 3GPP Long Term Evolution (LTE) & System Architecture Evolution (SAE): Adding Mobility towards I-WLAN and non-3GPP air interfaces
  - 3GPP2 Ultra Mobile Broadband (UMB)
- IEEE 802.16m (WiMAX) is also evolving towards 4G.

Motivation

- Spectrum:
  - Highly efficient radio technology
    - Increased spectrum efficiency for larger carriers and therefore increased capacity
    - Lower cost per bit and lower prices for the end user
  - Flexibility and scalability in deployment
    - Operating in various frequencies and bandwidths
    - Operators can start with smaller deployment and increase bandwidth as demand increase
    - Supports resource aggregation of radio band resources
- Architecture:
  - Architecture simplicity and reduced protocol complexity
  - reduced number of network elements
  - Simplified protocol stack & all IP network
    - Reduced latency
    - Easier network management
- Mobility: Seamless handover ensuring service continuity with legacy systems

Faster & More Responsive

- **30-10msec latency for**
  - Improved user experience
  - Fast VoIP call set-up
  - Instantaneous web pages
  - Streaming fast buffering
  - Online mobile gaming
- **40-100Mbps for**
  - True high-speed mobile data
  - Full-motion HD video anywhere
  - Stream any content
  - Mobile peer-2-peer & Web 2.0
  - Quadruple play
  - Faster email access
  - Instantaneous web pages

LTE history

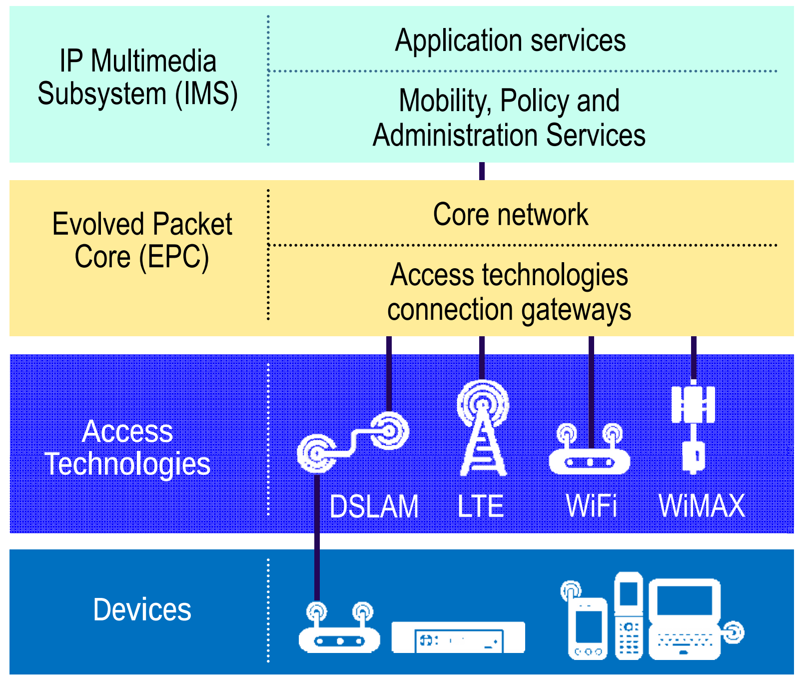
- November 2004: Kick-off in RAN LTE Toronto workshop
- November 2005: Decision on basic LTE radio access, DL: OFDM, UL: SC-FDMA
- June 2006: Close of LTE Study Item, Start of LTE Work Item
- Study Item: TR feasibility on system level (Dec 2004 – June 2006)
  - TR 25.912: Feasibility Study for Evolved UTRA and UTRAN
  - TR 25.913: Requirements for E-UTRAN
  - TR 25.813: EUTRA and EUTRAN radio interface protocol aspects
  - TR 25.814: Physical layer aspects for E-UTRA
- March 2007: Approval of LTE, Stage 2 specification
- June 2007: Detailed standard work: Standardized in the form of Rel-8.
- January 2008: Spec finalized and approved.
- Target deployment in 2010.
- LTE-Advanced study phase in progress.

3GPP LTE / SAE

- **Long Term Evolution (LTE)**: work of RAN WG started in 2004 to create a new evolved RAN (E-UTRAN), and technology as an emerging broadband wireless access solution
- **System Architecture Evolution (SAE)**: work of SA2 WG in parallel to LTE
  - to develop a framework for an evolution or migration of the 3GPP system to higher data rate, lower latency, packet-optimized system, support multiple RATs
  - Focus on creating an evolved packet core (EPC) including interfaces to selected external network entities

LTE/SAE Architecture Features

- New core network architecture to support the high-throughput/low latency LTE access system
- Simplified network architecture
- All IP (packet-switched) network
- Support mobility between multiple heterogeneous access system
    - 2G/3G, LTE, non 3GPP access systems, e.g., WLAN, WiMAX
    - Inter-3GPP handover (e.g., between GPRS and E-UTRAN):
    - Inter 3GPP/non-3GPP mobility



3G LTE features

- Very high data rates
  - Peak data rates: >100 Mbps (downlink)/50Mbps (uplink) in 20MHz
  - Improved cell-edge user throughput
- Very low latency: U-Plane transit time (<10ms); C-Plane dormant-to-active transition(<50ms)
- Spectrum flexibility
  - Deployable in a wide-range of spectrum allocations of different sizes
  - Both paired and unpaired spectrum
  - Scalable bandwidths: 1.25-20 MHz
- Coverage: 5km (full performance), 5-30km (slight degradation), up to 100km, Up to 200 active users in a cell (5 MHz)
  - improved inner cell average data throughputs (MIMO needed)
  - improved "cell edge rates" and spectral efficiency (e.g. 2-4 x Rel6)
- Mobility: Optimized for 0-15 km/h, high performance for 15 -120 km/h, supported up to 350 km/h (500 km/h).
- less complexity in RAN (architecture, signaling procedures/protocols)
- economic usage of backhaul capacity; simplified and unified transport (IP)
- interworking with legacy 3G and cost effective migration
- support of available and future advanced services VoIP
- Enhanced multimedia broadcast multicast service (E-MBMS)
- Enhanced support for end-to-end QoS

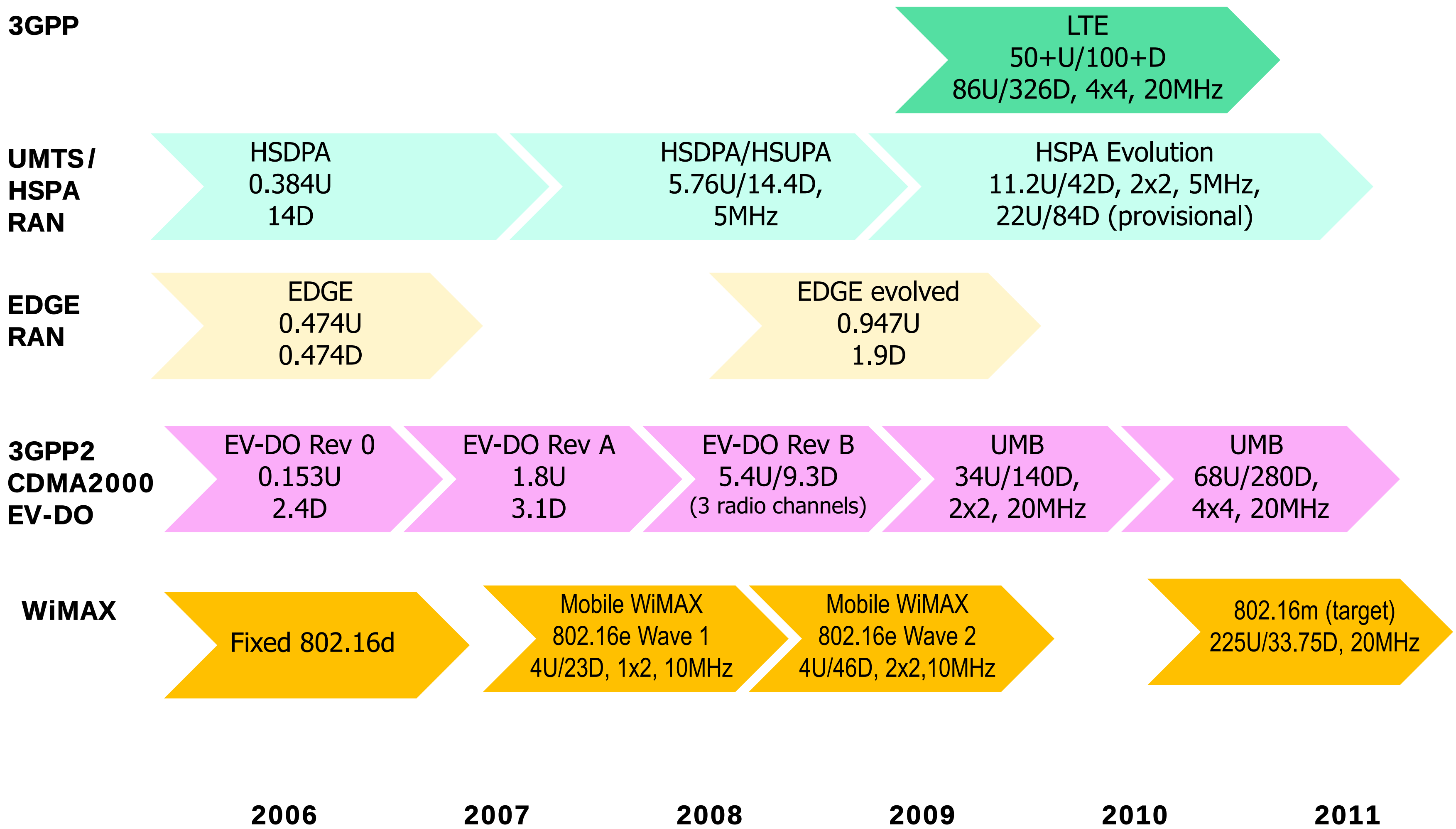
IEEE 802.16 Evolution

- 802.16 (December 2001): LOS fixed PMP operation in 10-66GHz, single carrier (SC) PHY
- 802.16a (2003): Non-LOS "last mile" fixed broadband access for 2-11GHz, OFDM/OFDMA
- 802.16c, system profile for the 10-66 GHz 802.16.
- 802.16d (2004): superseded 802.16 a/b/c, aligned with ETSI HIPERMAN
- 802.16e (2005): QoS, scalable OFDMA, vehicular mobility and asym link, (“Mobile WiMAX”)
- 802.16f-2005 — Management Information Base
- 802.16g-2007 — Management Plane Procedures and Services
- 802.16k-2007 — Bridging of 802.16 (an amendment to 802.1D)
- 802.16h — Improved Coexistence Mechanisms for License-Exempt Operation
- 802.16i — Mobile Management Information Base
- 802.16j — Multihop Relay Specification
- 802.16Rev2 — Consolidate 802.16-2004, 802.16e, 802.16f, 802.16g and possibly 802.16i.
- 802.16m (for approval by March 2010): Higher data rate (100Mb/s mobile , 1Gb/s fixed), cellular, macro and micro cell coverage, flexible BW (20 MHz or higher), reduced latency, and efficient security mechanism.

3GPP2 Evolution

- CDMA2000 1X (1999):CDMA
- CDMA2000 1xEV-DO (2000): CDMA/TDM, All-IP, Broadband Downloads
- EV-DO Rev. A (2004): OFDM introduced for multicast, Advanced QoS - VoIP, Broadband Uploads,
- EV-DO Rev. B (2006): Multi-carrier Rev A (up to 5MHz *), Improved Peak, Avg & Cell Edge Data Rates, lower delays, consistent high data rates
- EV-DO Rev. C/ IEEE 802.20 (2007): Ultra Mobile Broadband (UMB), FLASH-OFDM, OFDMA solution, New/Vacant Spectrum for wider bandwidth (5-20 MHz), FDD and TDD modes, MIMO and SDMA (enhanced capacity) , higher Data Rates, Support for flat network architecture, multimode devices provide seamless migration

Wireless Access Evolution



WCDMA, HSPA, LTE

	WCDMA	HSPA	eHSPA	LTE
DL(Mb/s)	2	14	42 (84 provisional)	100+
DL with MIMO				172.8 (2x2) 326.4 (4x4)
UL(Mb/s)	0.384	5.7	11.52 (22 provisional)	50+ 57.6 (1x2)
BW(MHz)	5	5	5	1.25-20
DL Modulation	QPSK	4/16QAM	4/16/64QAM	4/16/64QAM
MIMO option			up to 2x2	up to 4x4
UL modulation	π /2 BPSK	π /2 BPSK, QPSK	π/2BPSK,4/16QAM	4/16/64QAM MIMO
Access	CDMA	CDMA	CDMA	OFDMA DL SC-FDMA UL
3GPP release	99/4	5/6	7/8	8

HSPA evolution: HSPA+ or eHSPA

802.16e, 3GPP LTE, 3GPP2 UMB

	802.16e (Mobile WiMAX):	3GPP LTE	3GPP2 UMB:
Duplexing:	TDD	FDD and TDD	FDD and TDD
Bandwidth (MHz):	5, 7, 8.75, 10	1.4, 3, 5, 10, 15, 20	1.25, 2.5, 5, 10, 20
UL access:	OFDMA	SC-OFDMA	OFDMA and CDMA,
DL access:	OFDMA	OFDMA	OFDMA
FFT in 5MHz/ Δf (kHz) :	512/10.94	512/15	512/9.6
Modulation:	4/16/64QAM	4/16/64QAM	4/8PSK, 16/64QAM
Channel coding:	CC, turbo, LDPC (opt)	CC, turbo	CC, turbo, LDPC
MIMO features:	SM, STC, BF	SM, STFC, sTxD, CDD	SM, ST Tx diversity, SDMA, BF

sTxD: Switched Tx diversity
CDD: cyclic delay diversity
CC: convolutional coding
subcarrier hopping and mapping are used.

Broadband Satellite Access Communications: A Brief Overview

Satcom for multimedia services

Multiple-beam configuration: an example

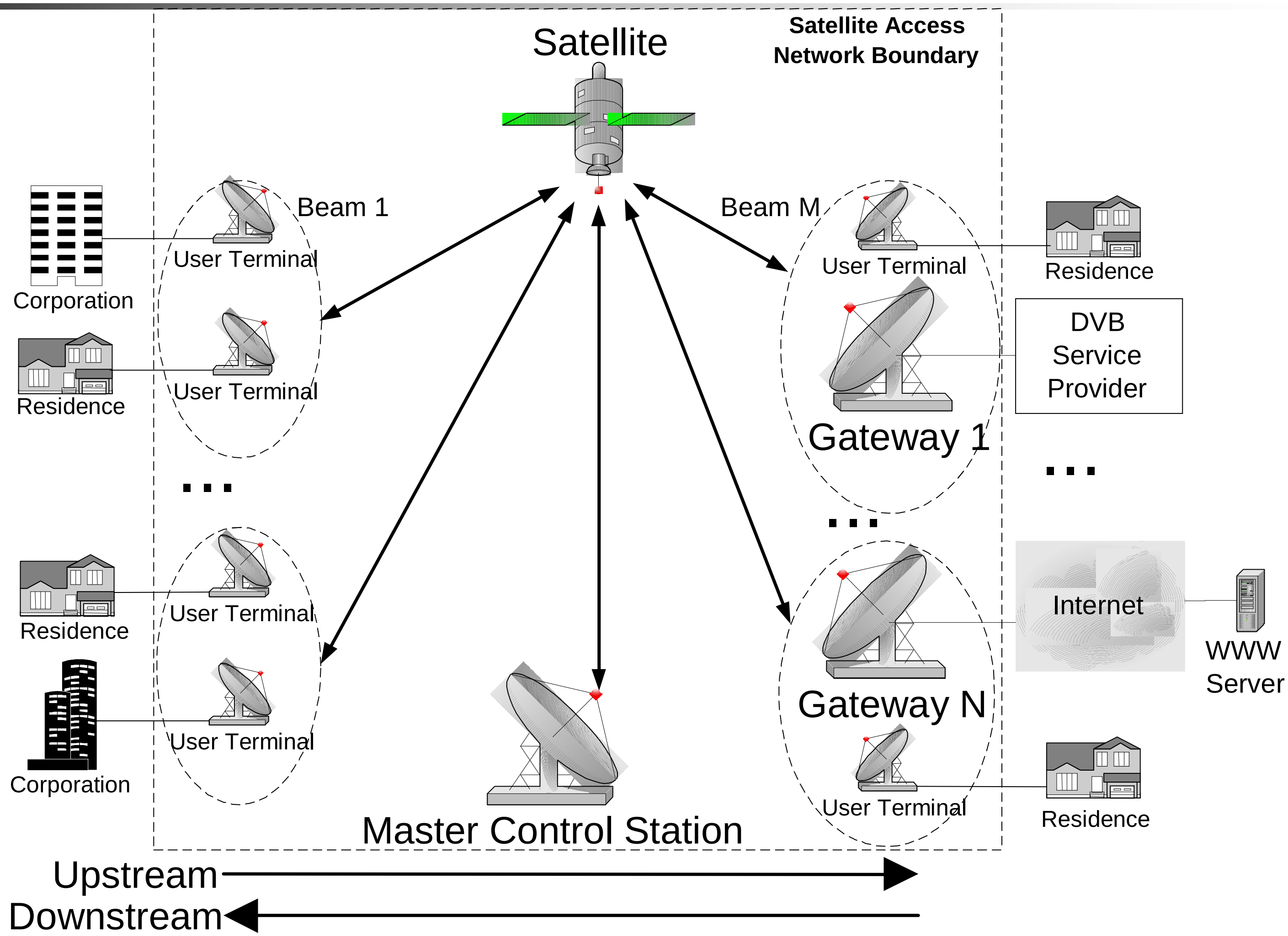
MF-TDMA

DVB-S, DVB-S2 & DVB-RCS

ACM

performance

SATELLITE COMMUNICATIONS NETWORK



Example of a multi-beam system: IPSTAR-1

Beam Configuration:

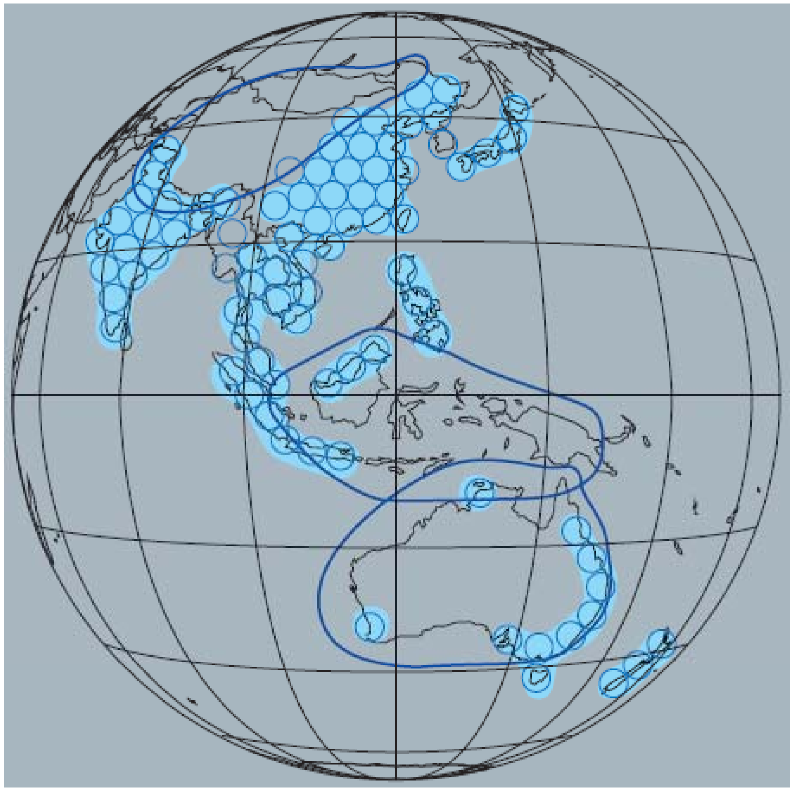
• 84 Ku-Spot Beams

• 3 Ku-Shaped Beams

• 7 Ku-Wide Regional Broadcast Beams

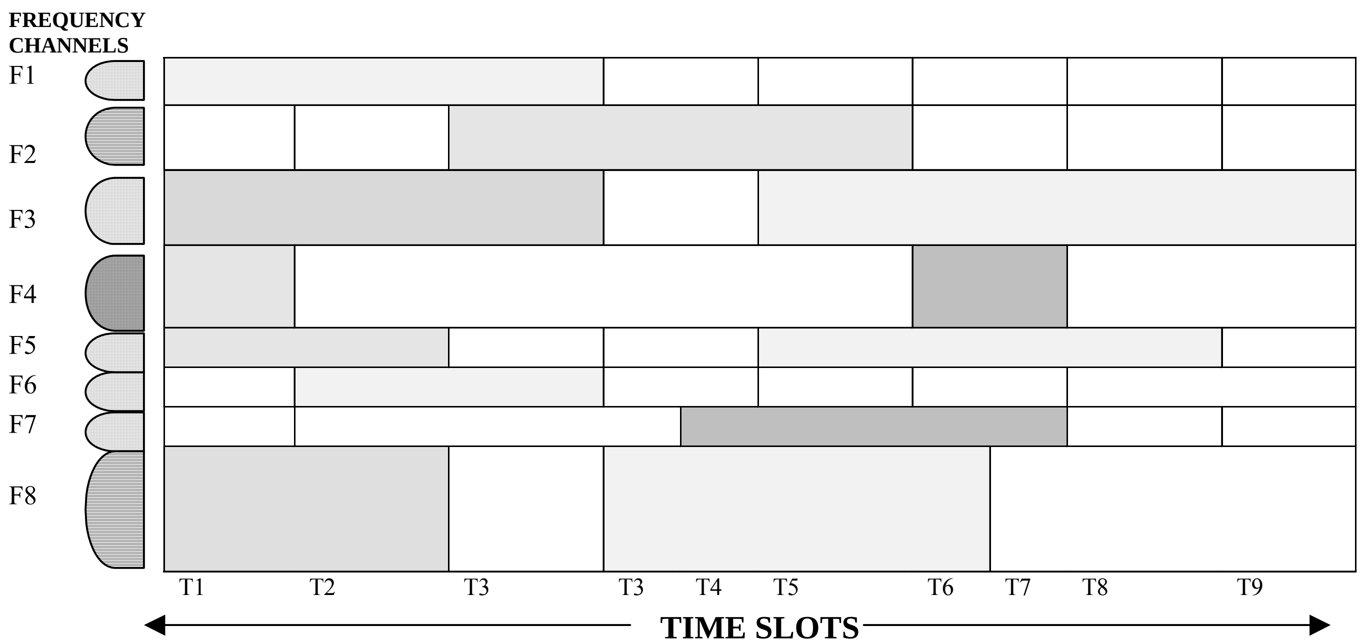
Capacity: Total 2-way 40+ Gbps calculated at clear sky conditions with dynamic BW management, using 1.20m antenna for spot, and 1.8m antenna for shaped beams.

1.1Gbps using 1.20m antenna for broadcast beams based on edge of service area with rain fade condition of 99.5% link availability



Multi-frequency (MF)-TDMA

- TDMA provides flexibility, more capacity (than FDMA) at the costs of large Tx power & Tx/Rx gain (i.e., large antenna) requirements, which makes small earth-terminal applications unfeasible!
- For user (with small terminals), uplink uses combined FDMA/TDMA called Multi-frequency (MF)-TDMA
  - A *channel* is defined by a time-frequency *slot*.

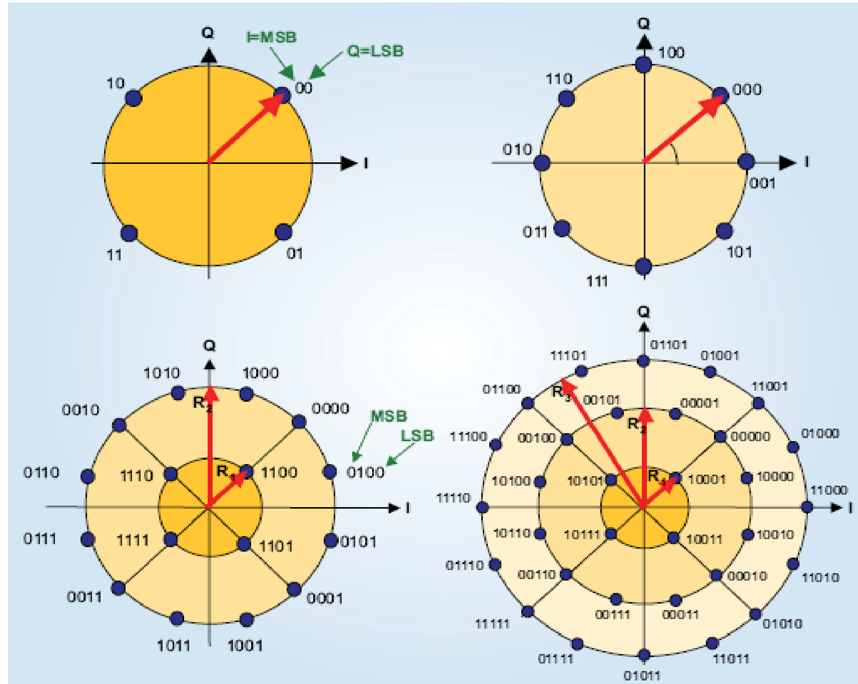


***Flexible* MF-TDMA Structure with *variable-size* frequency channels and time slots**

Modulation schemes used in DVB-S2

QPSK, 8PSK for broadcast applications through non-linear satellite transponders driven near to saturation.

16APSK and 32APSK are more geared towards professional applications requiring semi-linear transponders. The latter schemes trade-off power efficiency for much greater throughput.



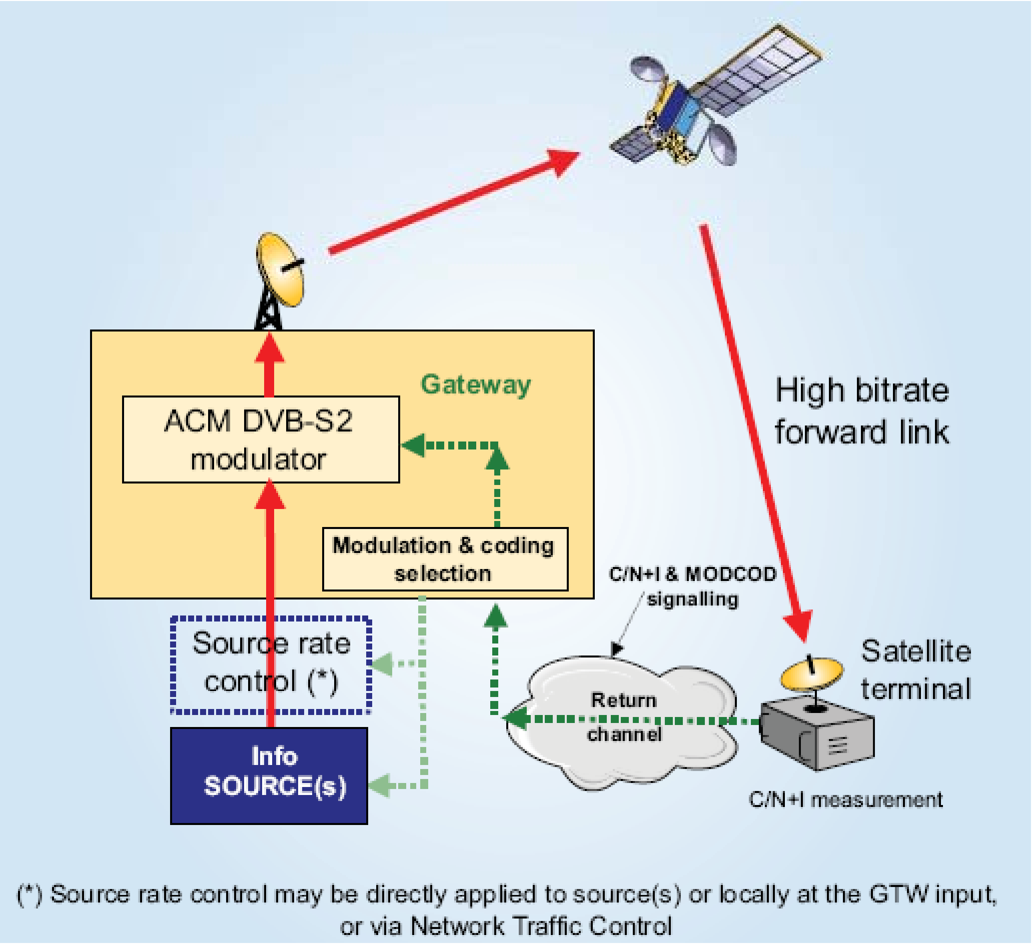
Modulation order M	Satellite channel losses (dB)	Satellite HPA OBO (dB)	Synchronization demodulator losses with worst-case phase noise mask (dB)	Total losses wrt to theoretical codec performance (dB)
4	0.25	0.4	0.2	0.85
8	0.3	0.4	0.3	1.0
16	0.45	1.15	0.5	2.1
32	0.9	2.0	0.7	3.6

DVB-S2 capacity for broadcast applications

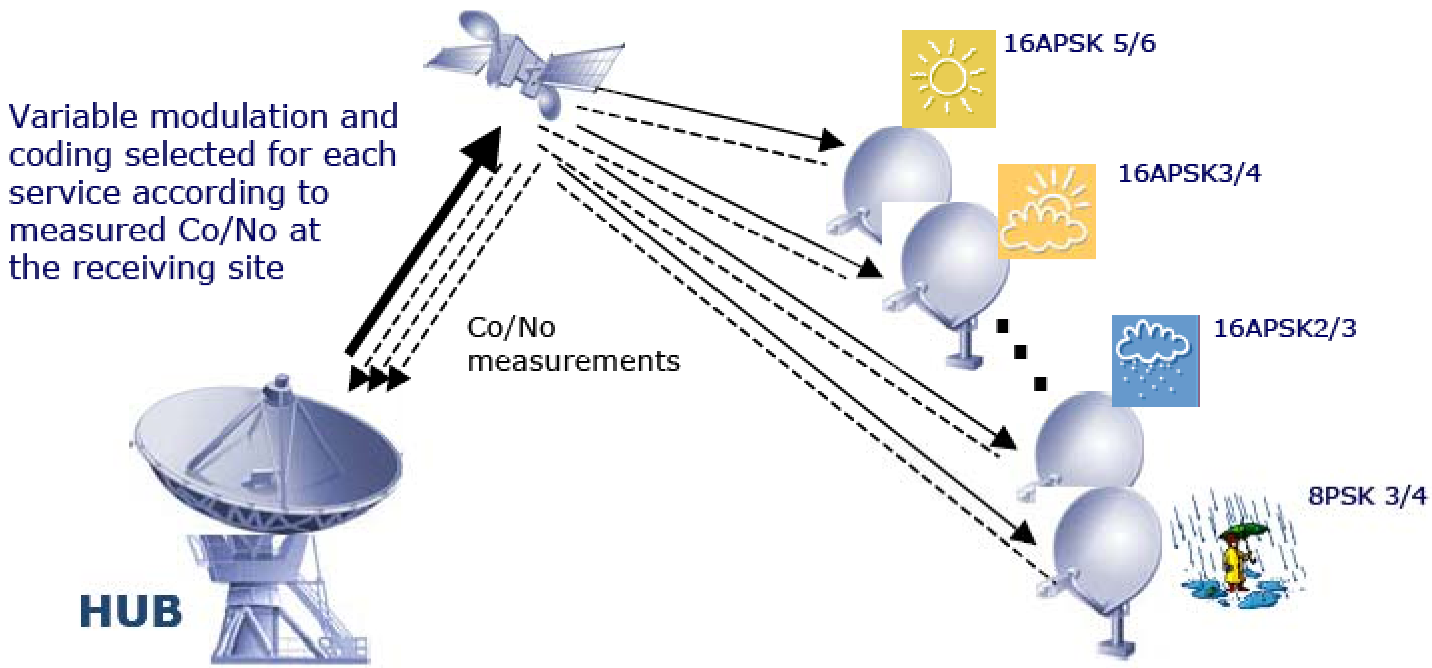
- QPSK, 8PSK for broadcast applications through non-linear satellite transponders driven near to saturation.
- Bandwidth and Roll-off: For tighter bandwith shaping, DVB-S2 adds roll-off factors of α=0.25 and 0.20 to the DVB-S traditional α=0.35

Satellite EIRP (dBW)	51		53.7	
System	**DVB-S**	**DVB-S2**	**DVB-S**	**DVB-S2**
Modulation & Coding	QPSK 2/3	QPSK 3/4	QPSK 7/8	8PSK 2/3
Symbol Rate (Mbaud)	27.5 (α = 0.35)	30.9 (α = 0.2)	27.5 (α = 0.35)	29.7 (α = 0.25)
C/N (in 27.5MHz) (dB)	5.1	5.1	7.8	7.8
Useful Bitrate (Mbit/s)	**33.8**	**46 (gain = 36%)**	**44.4**	**58.8 (gain = 32%)**
Number of SDTV Programmes	7 MPEG-2 15 AVC	10 MPEG-2 21 AVC	10 MPEG-2 20 AVC	13 MPEG-2 26 AVC
Number of HDTV Programmes	1-2 MPEG-2 3-4 AVC	2 MPEG-2 5 AVC	2 MPEG-2 5 AVC	3 MPEG-2 6 AVC

DVB-S2 ACM link



ACM examples

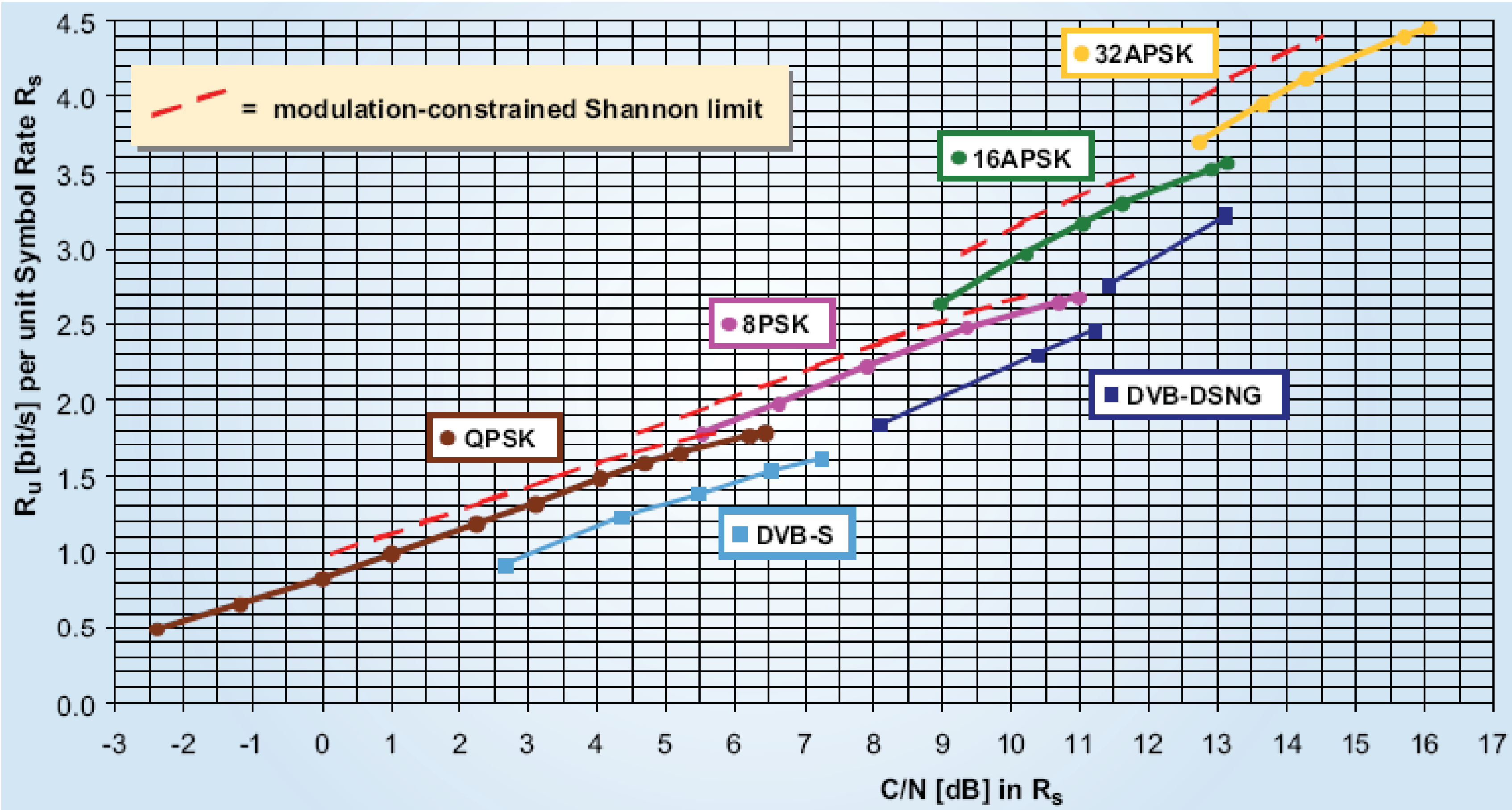


DVB-S & DVB-S2: Tx performance

- DVB-S:
  - QPSK modulation with channel coding and error correction.
  - Further of 8PSK and 16QAM additions for DVB-DSNG

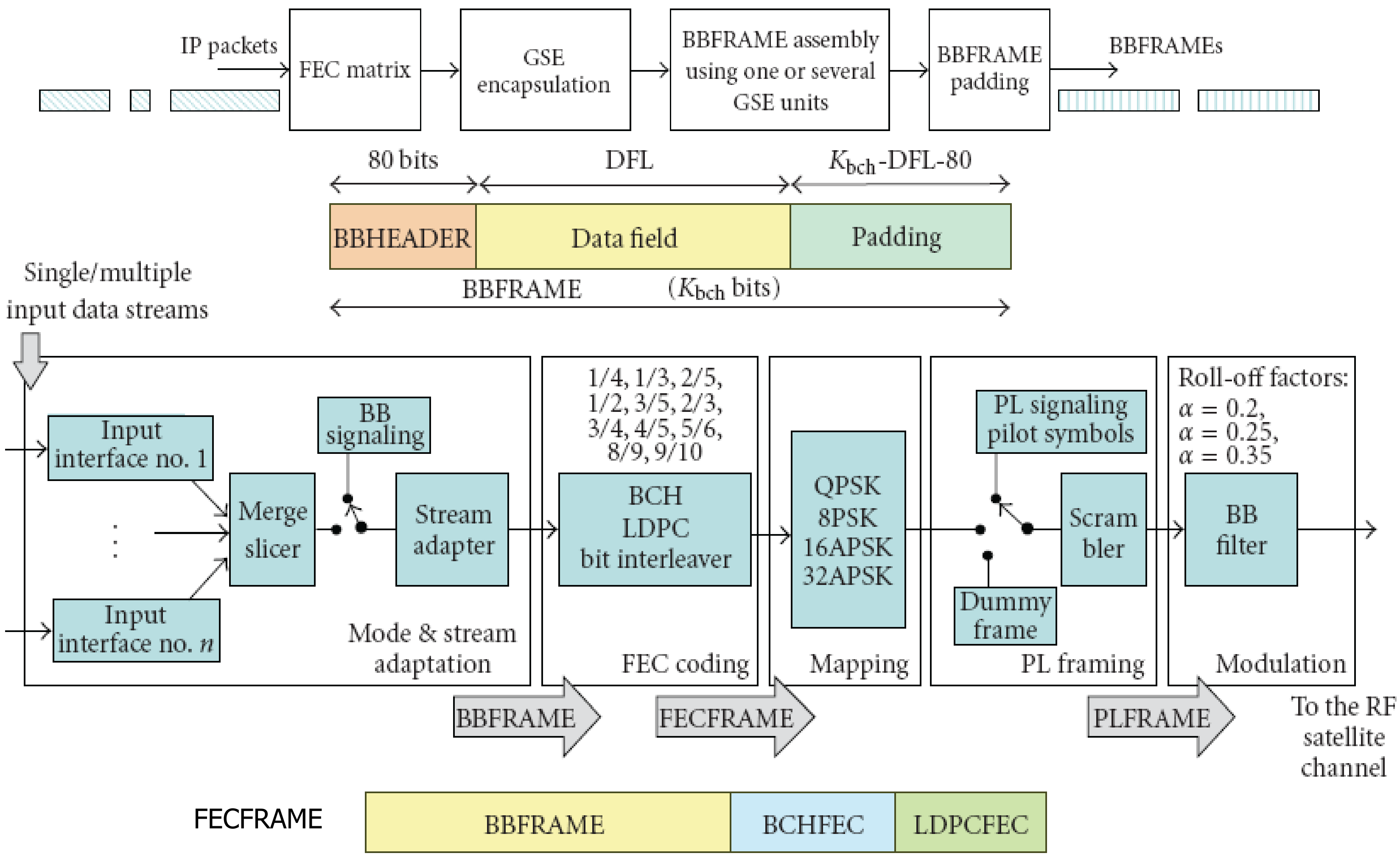
- DVB-S2 is designed to benefit from technology advances for more applications:
  - delivery of advanced video and audio services, e.g. Microsoft Windows Media 9, MPEG-4, HDTV.
  - an increased range of applications by combining the functionality of DVB-S (for direct-to-home applications), and DVB-DSNG (for professional applications)
- DVB-S2:
  - QPSK and 8PSK intended for broadcast applications in non-linear (close to saturation) satellite transponders
  - 16APSK and 32APSK: higher bandwidth efficiency @ higher C/N.
  - Forward Error Correction: concatenation of BCH (outer) and LDPC (inner).
  - frame-by-frame Adaptive Coding and Modulation (ACM)
- 30% greater efficiency than DVB-S on average by using adaptive coding /modulation (CCM, VCM, ACM) to maximize the usage of value satellite transponder resources:
  - Bandwidth and Roll-off: 0.35 (DVB-S), 0.25, 0.20
  - Forward Error Correction : concatenation of BCH with LDPC (inner coding): performance, 0.7dB from the Shannon limit. Code rates can be changed dynamically, on a frame by frame basis.
- spectral efficiencies: 0.5 b/s/Hz - 4.5b/s/Hz providing high flexibility
- Operating C/N range: from -2dB (with QPSK) to +16dB (with 32APSK).
- optional “pilots” to help carrier recovery at low C/N.

spectrum efficiency vs Required C/N (AWGN channel , ideal demodulation)



From: A. Morello and V. Mignone, DVB-S2— ready for lift off", *EBU Technical Review* – October 2004

DVB-S2 architecture



DVB-RCS

- air interface specification for 2-way satellite broadband VSAT (ETSI as EN 301 790)
- highly dynamic, demand-assigned transmission capacity to residential and commercial, institutional users: up to 20 Mbit/s (outbound), and 5 Mbit/s (inbound) for each terminal
- DVB-RCS specification provides support for mobile and nomadic terminals as well as enhanced support for direct terminal-to-terminal (mesh) connectivity, including
  - live handovers between satellite spot-beams,
  - spread-spectrum features to meet regulatory constraints for mobile terminals,
  - continuous-carrier transmission for terminals with high traffic aggregation
  - link-layer FEC based on Raptor or Reed-Solomon codes, used as a countermeasure against shadowing and blocking of the satellite link.
- Turbo coding can be used for small user terminals in replacing convolutional and Reed Solomon coding
- Adaptive coding can support rain mitigation techniques in addition to different QoS requirements (initially for return path, but eventually also for forward path)

THANK YOU & QUESTIONS ?