ADSL for EFM

802.3ah Task Force

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Doug Artman, Texas Instruments

Supporters

- Michael Beck, Alcatel
- Miguel Peeters, Broadcom
- Jonas Gustafsson, Ericsson
- Krista Jacobsen, Texas Instruments
- Chris Hansen, Intel
- Marcos Tzannes, Aware
- Behrooz Rezvani, Ikanos
- Sabina Fanfoni, STMicro
- Michael Tsatsanis, Voyan
- Reza Alavi, ADI
- Daniel Bengtsson, Telia
- Massimo Sorbara, GlobespanVirata
- Andy Deczky, Catena Networks
- Les Brown, Centillium Communications
- Daun Langston, Metanoia Technologies
- John Cioffi, Stanford University
- Jacky Chow, ASTRI
- Mikael Isaksson, UpZide

Presentation Overview

- Long Reach Objectives and the 5 Criteria
- Summary of ADSL for EFM
- ADSL and the 5 Criteria
- Spectral Compatibility and Friendliness
- ADSL and VDSL-DMT, A True Single Port Solution
- Summary

EFM Long Reach Objectives and The 5 Criteria

Copper Long Reach Objectives

- Primary objective for long reach
  - PHY for single-pair non-loaded voice grade copper with distance >= 2700 m and speed >= 2 Mbps full duplex
- Other objectives
  - Copper PHY shall recognize spectrum management restrictions imposed by operation in public access networks
  - Copper PHY shall have optional ability to operate over multiple pairs for higher data rates

The 5 Criteria for EFM

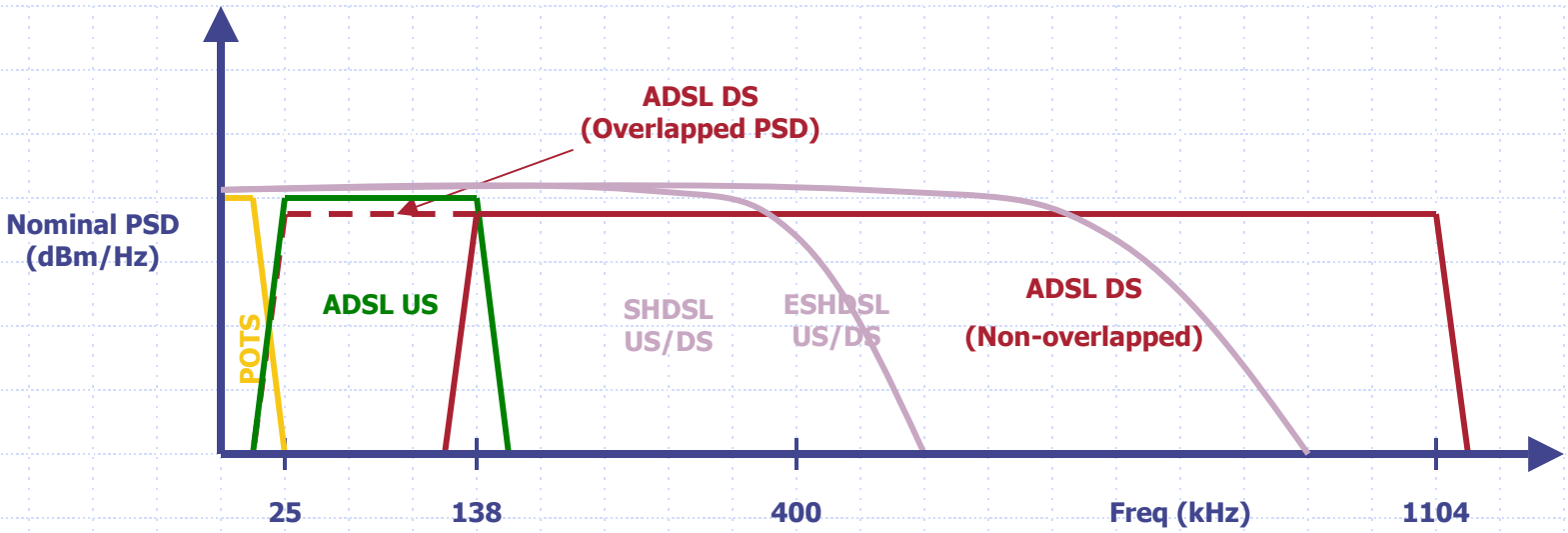
- Broad Market Potential
  - Broad set of applicability, multiple vendors/users, balanced costs
- Compatibility
  - Conformance with 802 architecture and related standards
- Distinct Identity
  - Unique solution solving single problem, easy to select relevant specification
- Technical Feasibility
  - Demonstrated feasibility, proven technology, reasonable testing, confidence in reliability
- Economic Feasibility
  - Known cost factors, reliable data, reasonable cost for performance, reasonable installation costs

Summary of ADSL for EFM

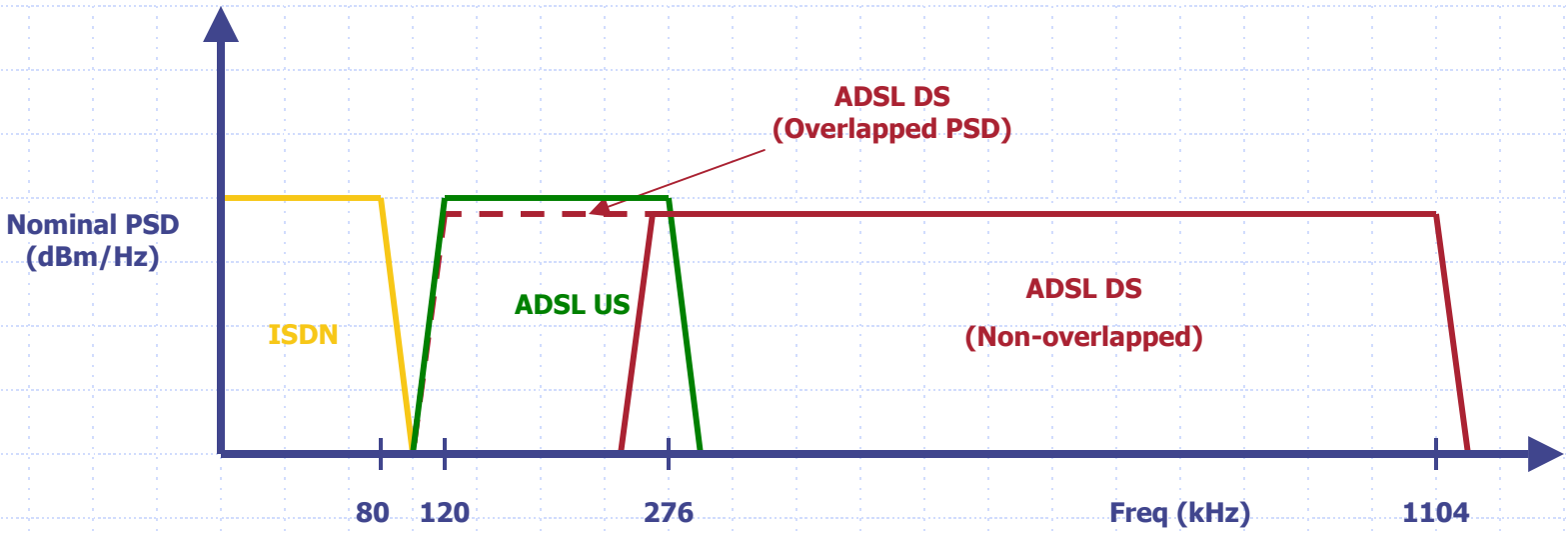
ADSL for EFM

- ADSL is by far the most prevalent form of DSL
  - G.992.1 Annex A (operation over POTS)
  - G.992.1 Annex B (operation over ISDN)
  - G.992.1 Annex C (operation over TCM-ISDN)
- Symmetric capability limited by narrow upstream band
  - Annex A utilizes 25-138 kHz band
  - Maximum symmetric rate of 1.5 Mbps
- G.992.3 (ADSL2) Annex J provides for a wider upstream
  - Support maximum upstream band of 3-276 kHz
    - POTS protection may be added into current Annex J masks
  - Wider band supports maximum symmetric rate of 3.5 Mbps

ADSL over POTS PSDs

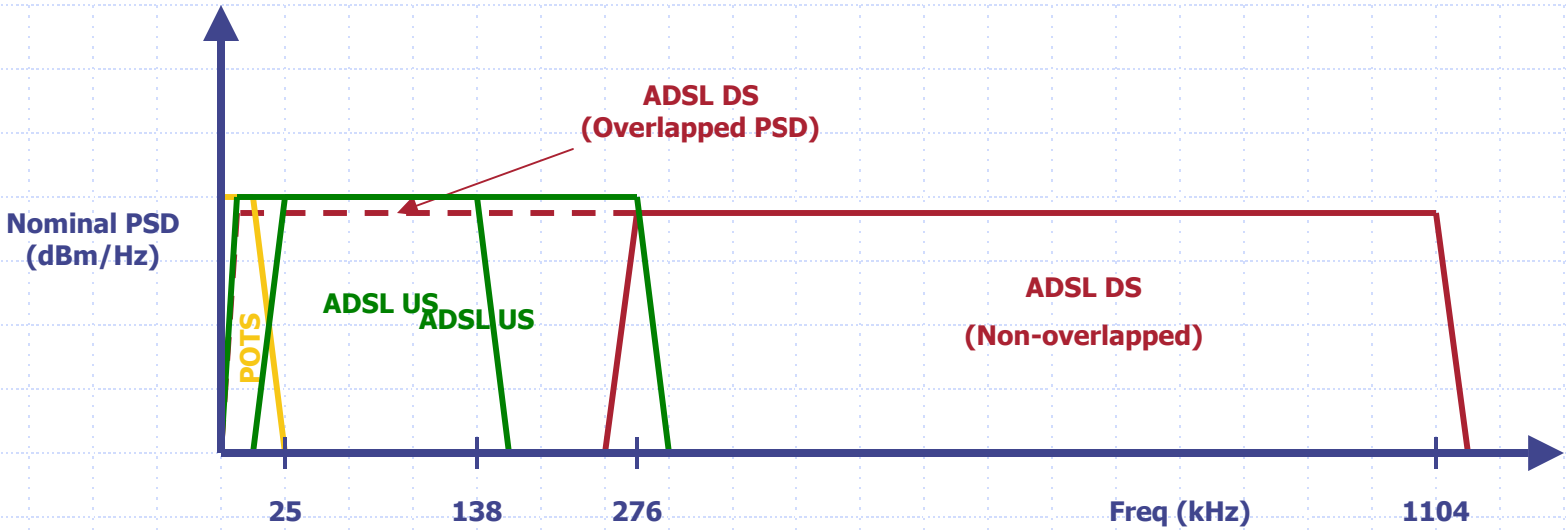


ADSL over ISDN PSDs



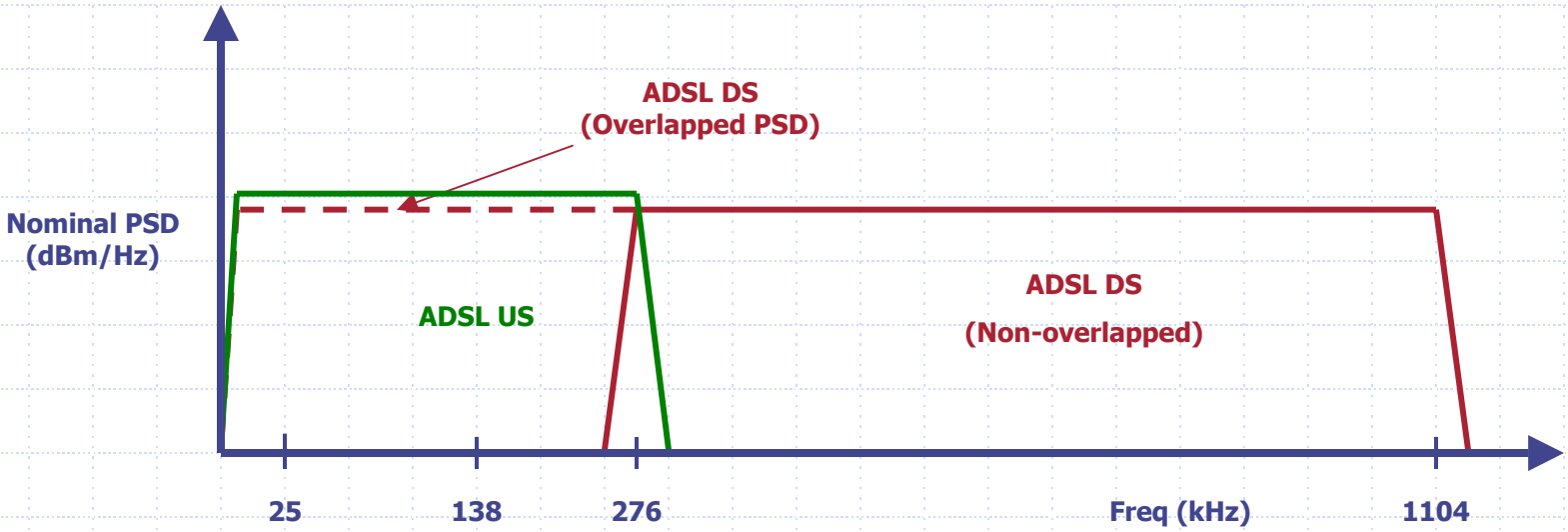
The Solution – ADSL2 (G.992.3)

- Symmetric rate w/ ADSL over POTS limited to 1.4 Mbps due to narrow upstream bandwidth
  - G.992.3 provides for a double bandwidth upstream channel
  - Same maximum frequency as ADSL over ISDN, but expands upstream bandwidth down to low frequencies



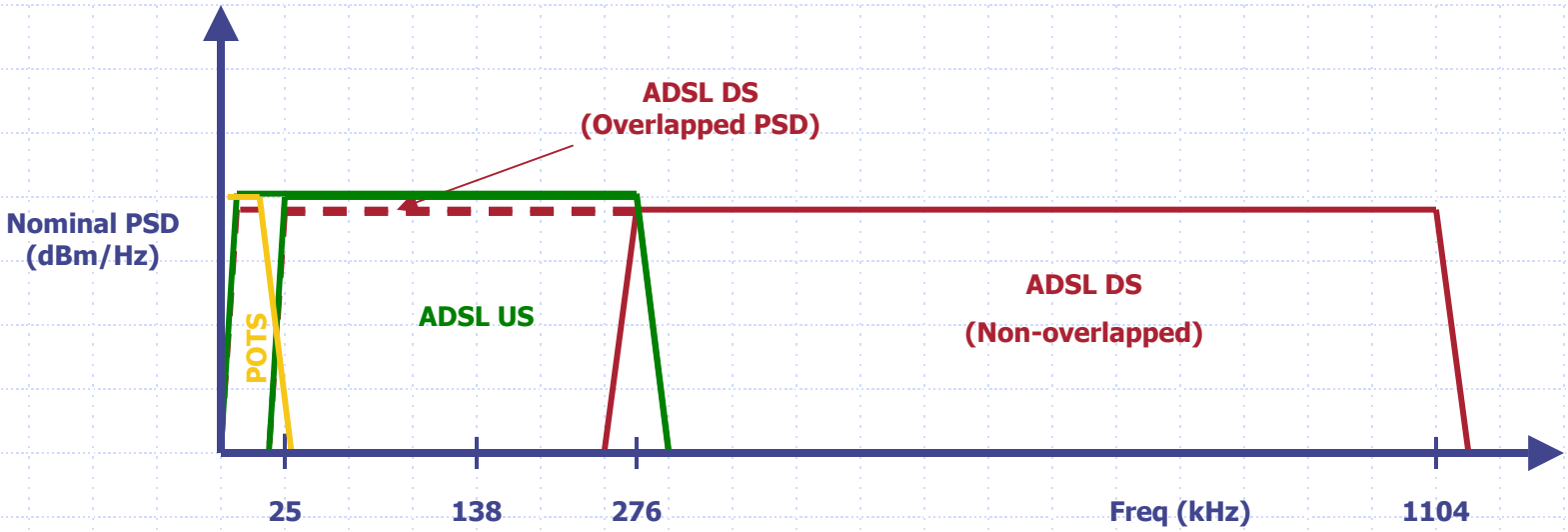
ADSL2 – A Variety of Applications

- The PSD masks for G.992.3 Annex J are only masks – submasks within these masks can be used for different applications



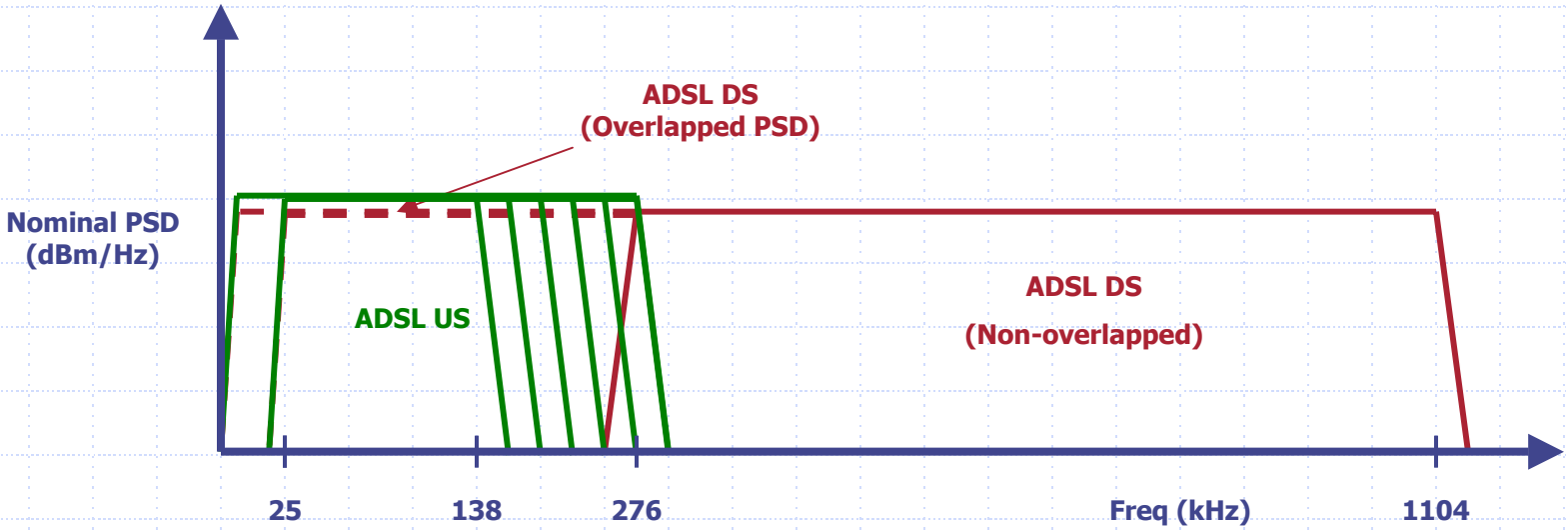
Operation over POTS

- Coexistence with POTS is easily achieved by moving the HPF cutoff of US/DS bands from 3 kHz to 25 kHz (same as ADSL Annex A)



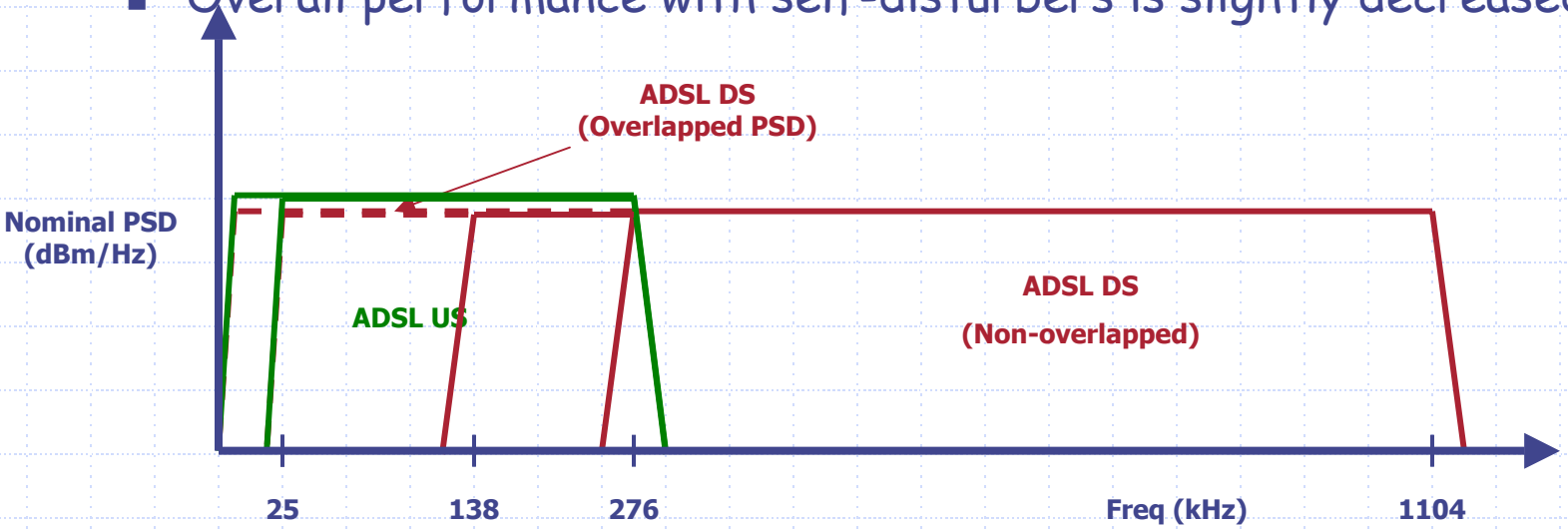
Variable upstream bandwidth

- Annex J provides family of 9 upstream PSD masks
  - Operators can choose maximum BW for regional requirements
    - Narrowest mask is same maximum frequency as ADSL over POTS
  - Downstream can be limited to provide FDD bandsplit with upstream masks



Partially Overlapped – Improved T1 Performance

- Performance in presence of T1s subpar for non-overlapped DS
  - T1 disturbers' sidelobes are not suppressed; impacts high frequency DS band
- Partially overlapping US & DS provides additional DS bandwidth
  - Overall performance with self-disturbers is slightly decreased



ADSL and the 5 Criteria

Broad Market Potential

The EFM Market

- Business or residential?
  - We haven't considered whether a distinction is necessary
- Short-reach or long-reach?
  - By specifying two objectives and going down the path of choosing different PHYs for the two objectives, we have implicitly split the total market into short-reach and long-reach customers
- Issues:
  - Would a different market distinction have been better (i.e., business and residential)?
  - Do we need two PHY devices to meet the two current objectives?

Broad Market Potential

- Market for EFM includes BOTH business and residential customers
  - In-Stat/MDR projects there will be over **32 million residential** EFM copper subscribers, world-wide, by 2006
    - As a reference point, there are now ~30 million total DSL subscribers – business and residential
    - Estimates 90% of residential EFM market will be non-U.S.
      - U.S. residential EFM market likely to be driven by CLECs
  - Size of residential DSL market is currently **>5x** size of business market (Source: Point Topic)
    - 83.7% of DSL are residential – vast majority are ADSL
    - One could argue most of the EFM market is residential…
- Total EFM market – business and residential - is huge

Broad Market Potential

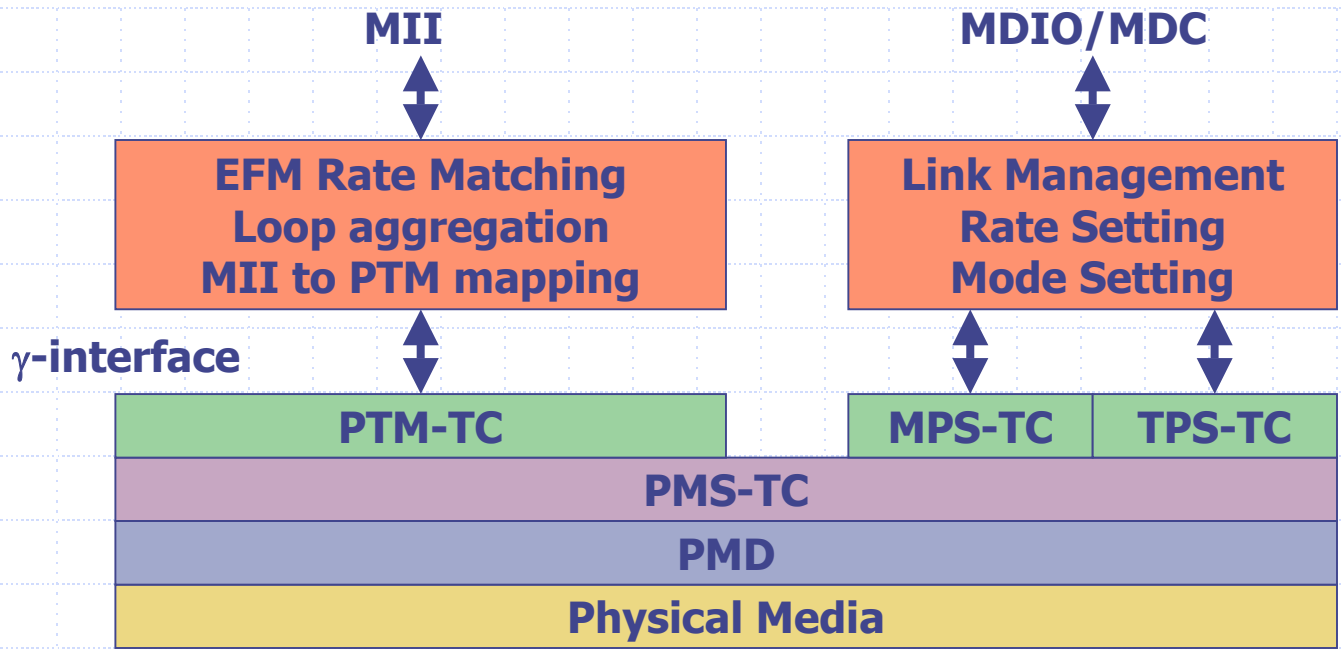
- ADSL Annex J definitely meets the needs of the residential market
  - Can operate over POTS
    - Customers don't need to dedicate a second phone line
    - Extra pairs are extremely limited in residential areas
  - Easily provisioned due to operation over POTS
    - No truck rolls by operators
  - Disturbs existing ADSL lines less than alternative solutions
    - We MUST assume there will be ADSL in the binder
  - Cheap due to ADSL chipset volumes
- ADSL Annex J can also serve business customers

ADSL and the 5 Criteria

Compatibility

Compatibility

- EFM over ADSL uses same reference model as EFM over other flavors of DSL
  - Utilizes packet-oriented TC layer operating over standards-based PMS-TC and PMD



ADSL and the 5 Criteria

Distinct Identity

Distinct Identity

- ADSL Annex J is a **single** solution that meets the long-reach objective of 2 Mbps at 2.7 km
  - As required, Annex J is one unique solution to the problem
- No other 802 standard addresses this rate/reach combination in the public network
- ADSL Annex J meets the criterion of distinct identity

ADSL and the 5 Criteria

Technical Feasibility

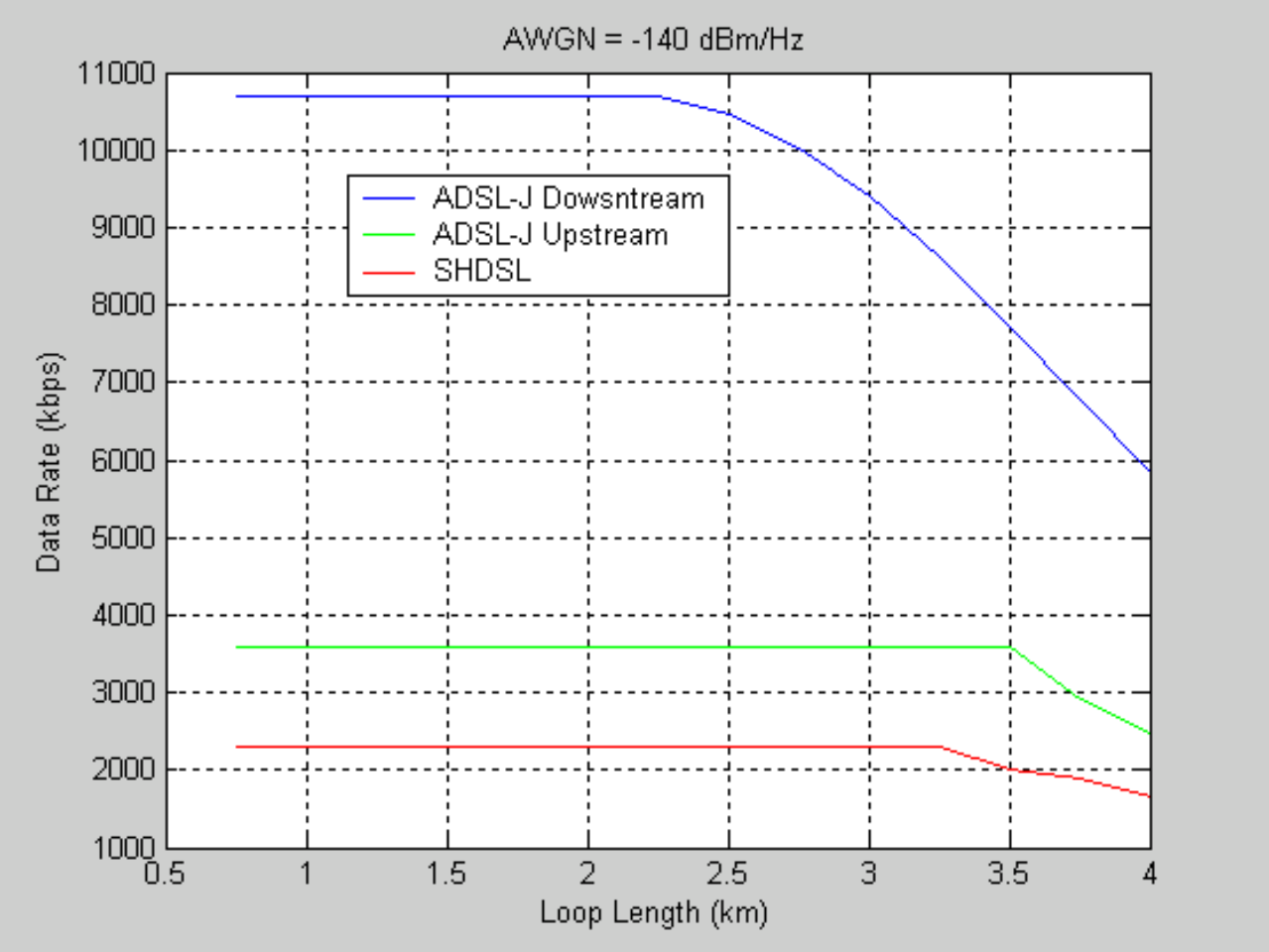
Crosstalk Scenarios

- Measure the impact of realistic crosstalk environments on performance of proposed solution
- All scenarios include –140 dBm/Hz line noise
- Simulated scenarios
  - No disturbers
  - 49 Self-disturbers
  - Residential mix (24 ADSL + 24 self-disturbers)
  - Business mix 1 (24 HDSL + 24 self-disturbers)
  - Business mix 2 (5 T1 + 12 self-disturbers)

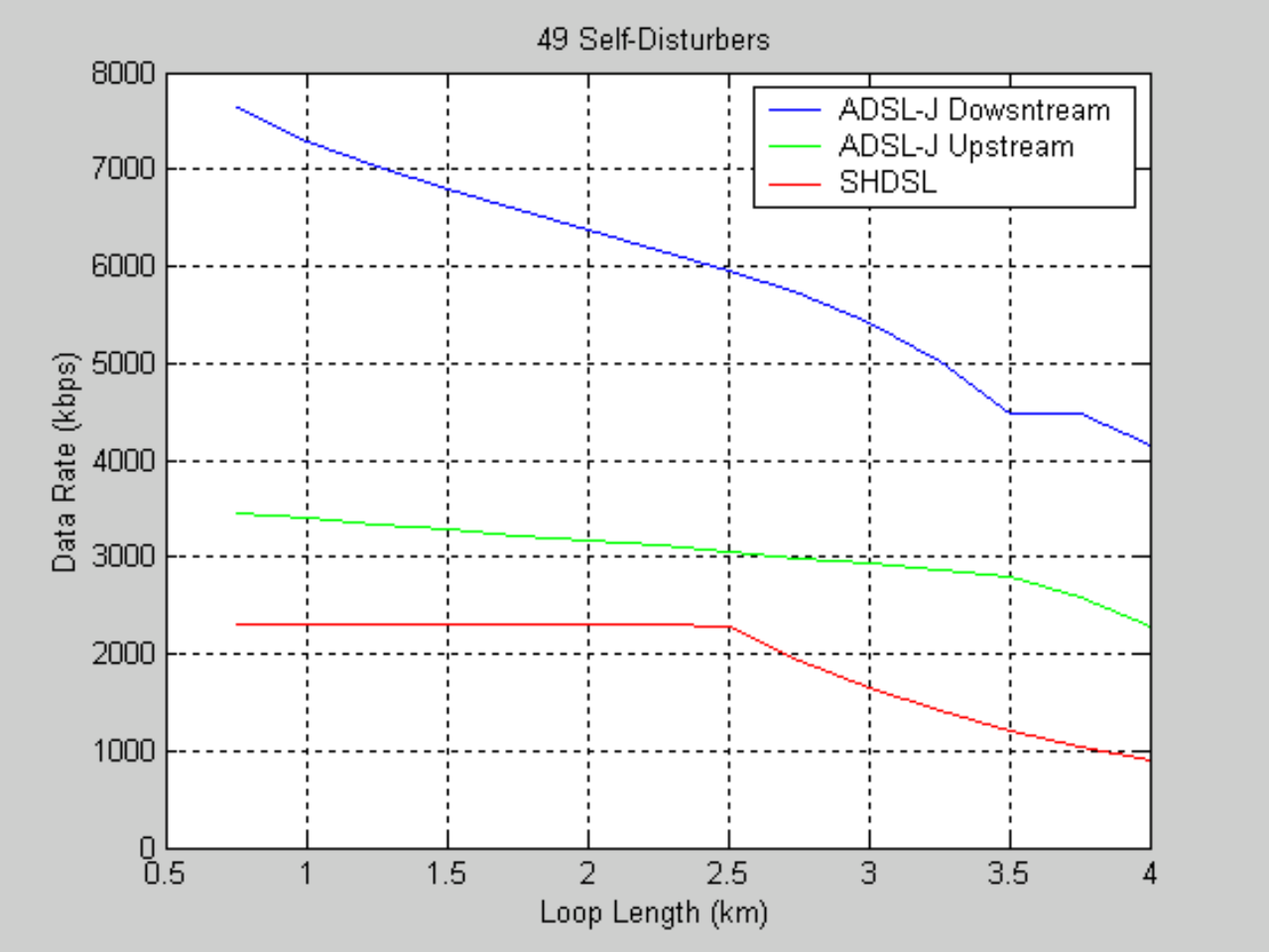
Simulation Parameters

- Coding gain = 5.1 dB (5.0 dB for SHDSL)
- Noise margin = 6.0 dB
- Bit allocations of 1 to 14 bits per tone (ADSL)
- Always include white noise at –140 dBm/Hz on the line
- Implementation Losses
  - ADSL Annex J
    - ADSL simulations assume realistic AFE noise floors
    - Additional implementation loss of 1.0 dB
  - SHDSL -> 1.6 dB
- Assumes 24 AWG loops
- Uses Annex J Upstream PSD masks
- FDD split between upstream and downstream bands
  - Reduces self-NEXT crosstalk
  - Results with T1s utilize partially overlapped masks

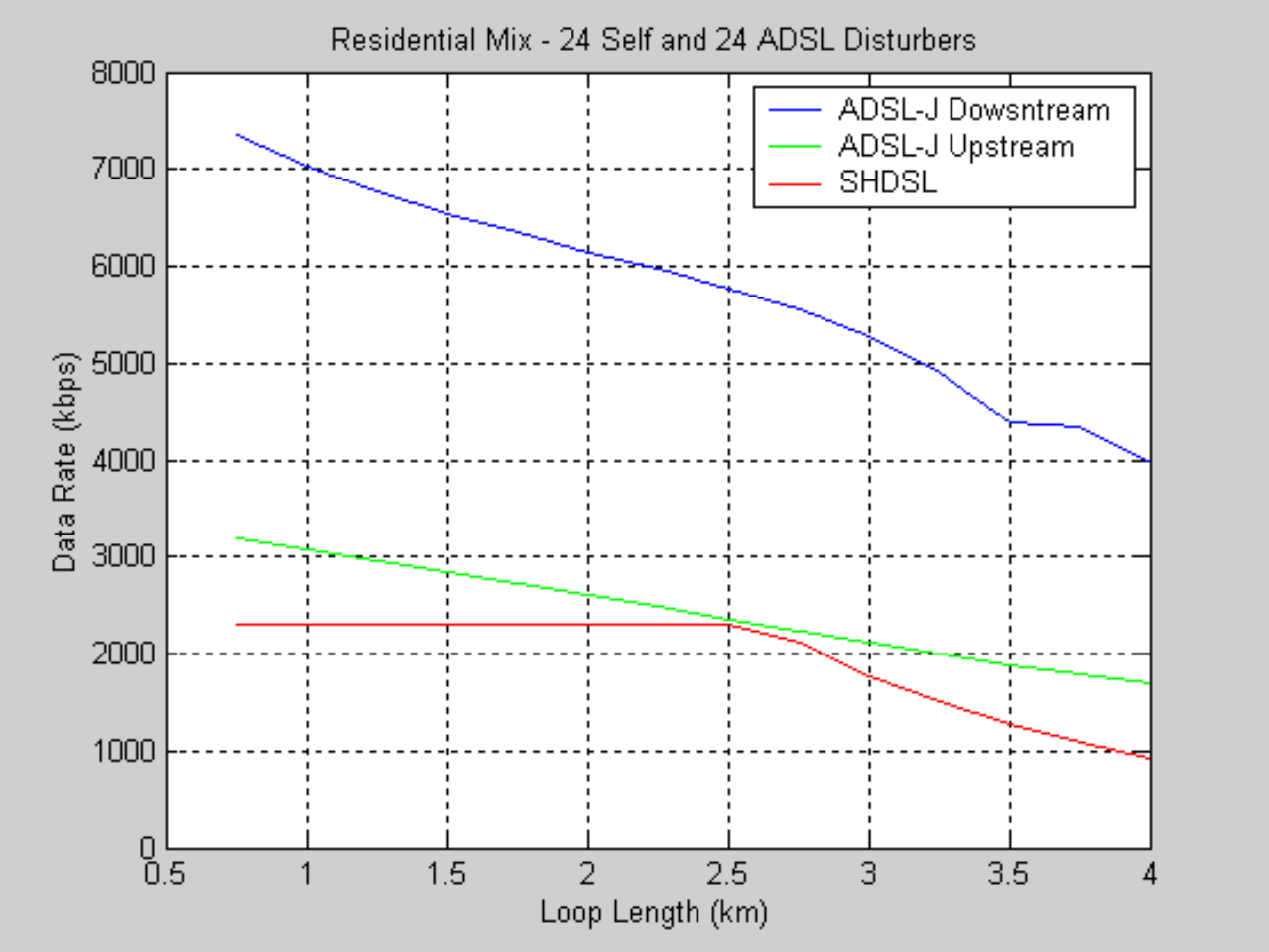
No Disturbers



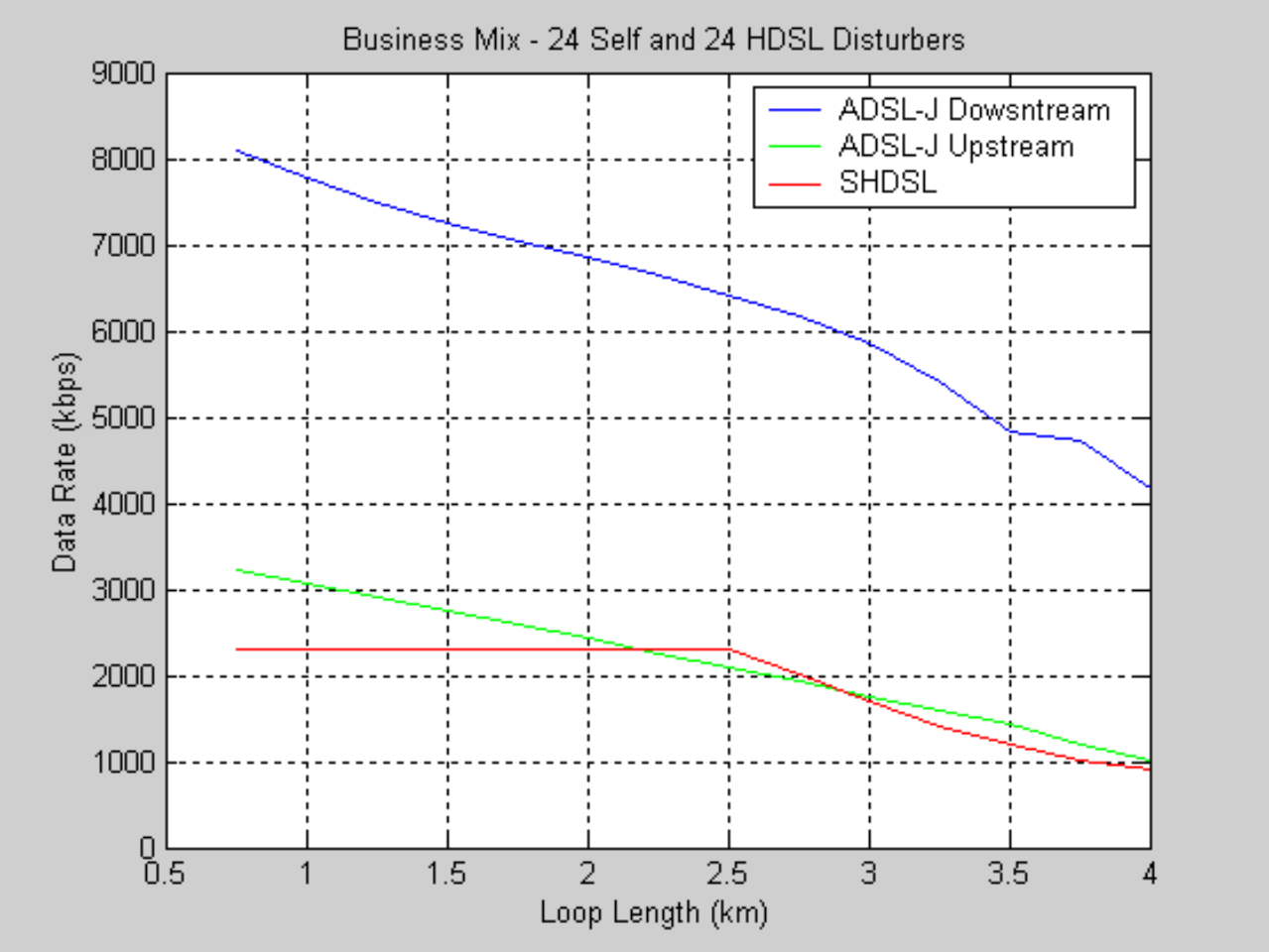
49 Self-Disturbers



Residential Mix - 24 Self- and 24 ADSL Disturbers

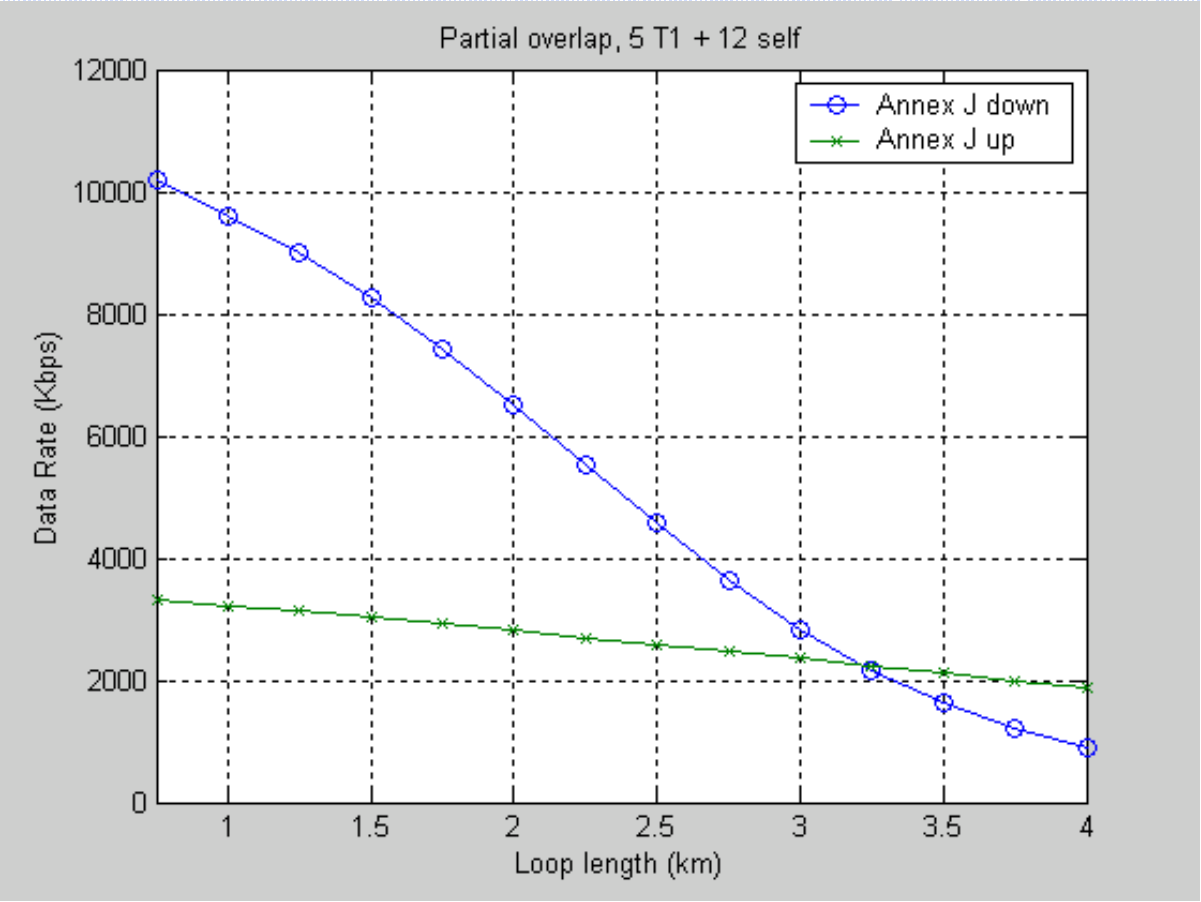


Business Mix 1 - 24 Self- and 24 HDSL Disturbers

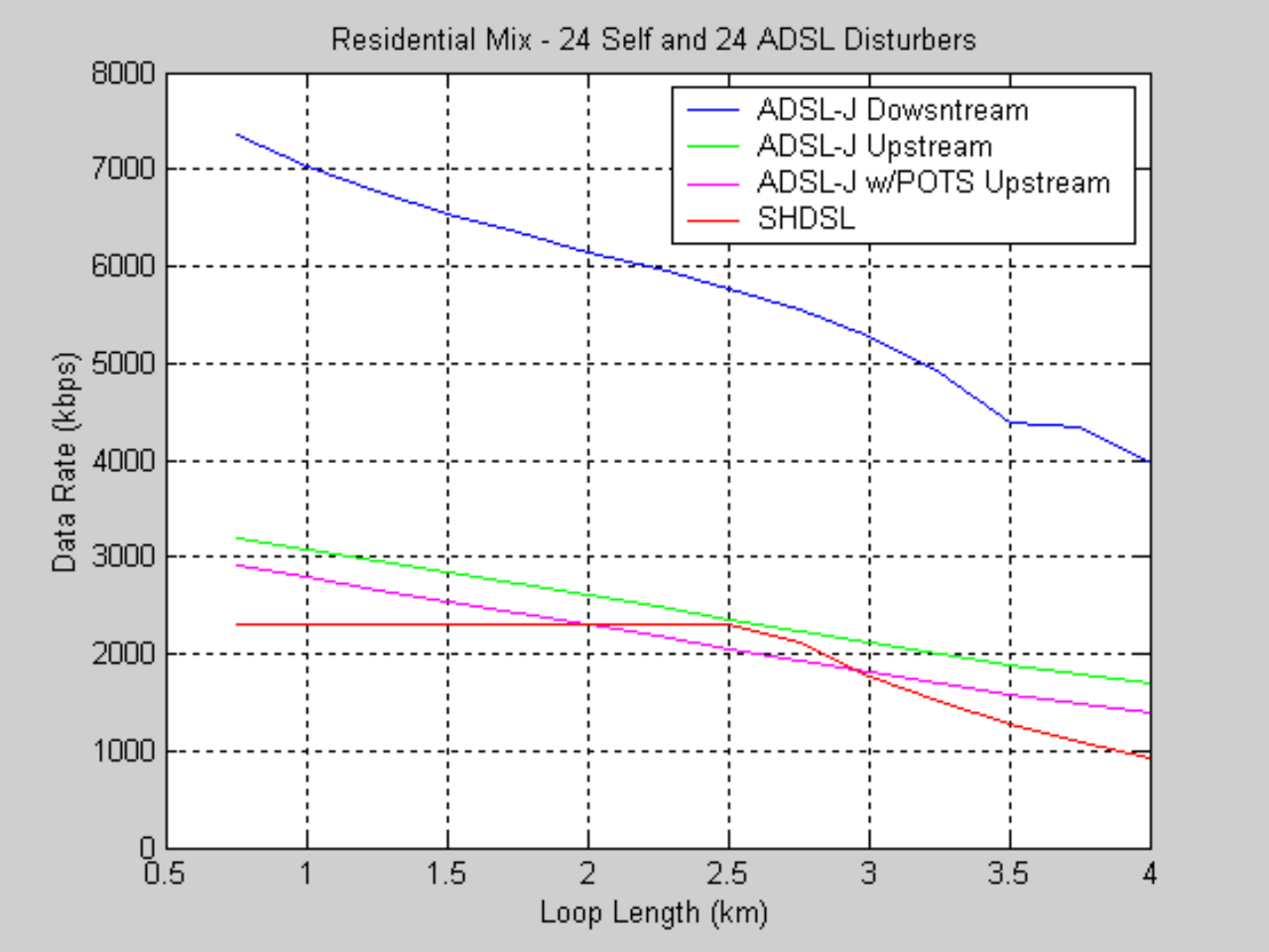


Business Mix 2 - 12 Self- and 5 T1 Disturbers (Partially Overlapped)

T1s are in an adjacent binder



Impact of POTS Protection on Performance



Additional Crosstalk Scenarios

(Realistic North American deployment)

Pairs/Binder ->	25	**8**	**12**	**16**	**20**	<--- Number of Interferers
Pairs/System ->	**4**	0.48	0.64	0.8	0.96	<--- Percent of Pairs used
25% DS-1						
HDSL		2	2	2	2	
HDSL2		0	1	2	3	
ADSL		5	7	10	12	
ISDN		1	2	2	3	
POTS Only		0	0	0	0	
50% DS-1						
HDSL		2	2	4	4	
HDSL2		2	4	4	6	
ADSL		3	5	6	8	
ISDN		1	1	2	2	
POTS Only		0	0	0	0	
75% DS-1						
HDSL		4	4	6	8	
HDSL2		2	5	6	7	
ADSL		2	2	3	4	
ISDN		0	1	1	1	
POTS Only		0	0	0	0	
75% DS-1 + T1 (T1 in SAME binder at CPE, in adjacent binder at CO)						
AMI T1		2	2	2	4	
HDSL		2	4	6	6	
HDSL2		2	3	4	5	
ADSL		2	2	3	4	
ISDN		0	1	1	1	
POTS Only		0	0	0	0	
T1 has one pair for Transmit at remote only, one pair for Transmit from 3 kft upstream, receive only at remote)						

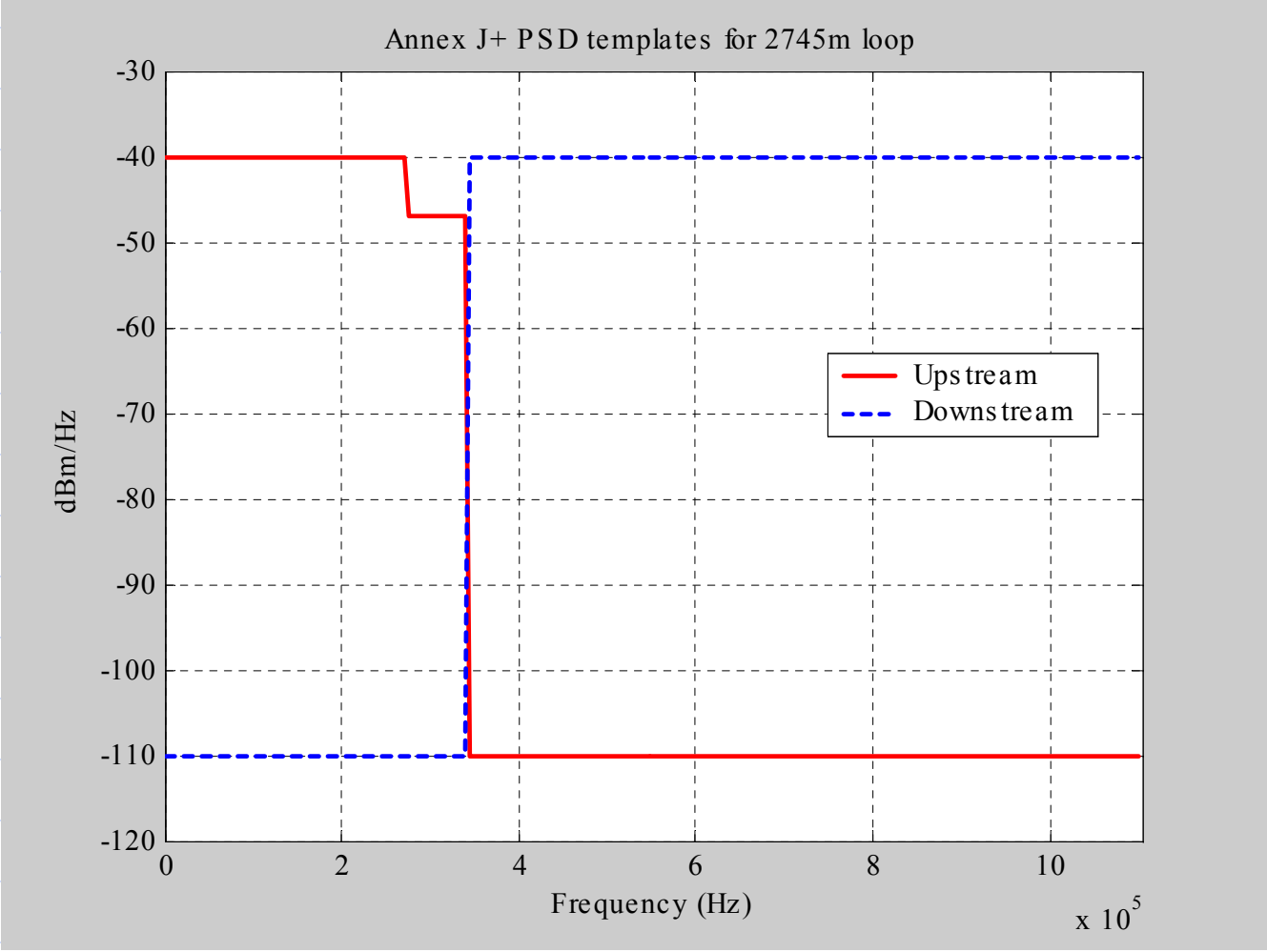
Simulation Settings

- Symmetric service
  - Upstream/Downstream rates shown separately
- **CSA range: 2745m (9000ft) of AWG26 cable**
- AWGN = -140 dBm/Hz
- SNR gap = 9.8 dB, Margin = 6 dB
- Coding gain: 5.1 dB
- All PSDs are spectrally compatible per T1.417 (Method A for G.shdsl, Method B for rest)
- All bitrates are maximized
  - DMT through bitloading, G.shdsl through joint optimization of symbol rate and constellation size
- Telcordia-measured crosstalk transfer functions
- 500 Monte Carlo runs are performed using random pair assignments for both in-domain and disturber lines; 1% worst case results are shown here

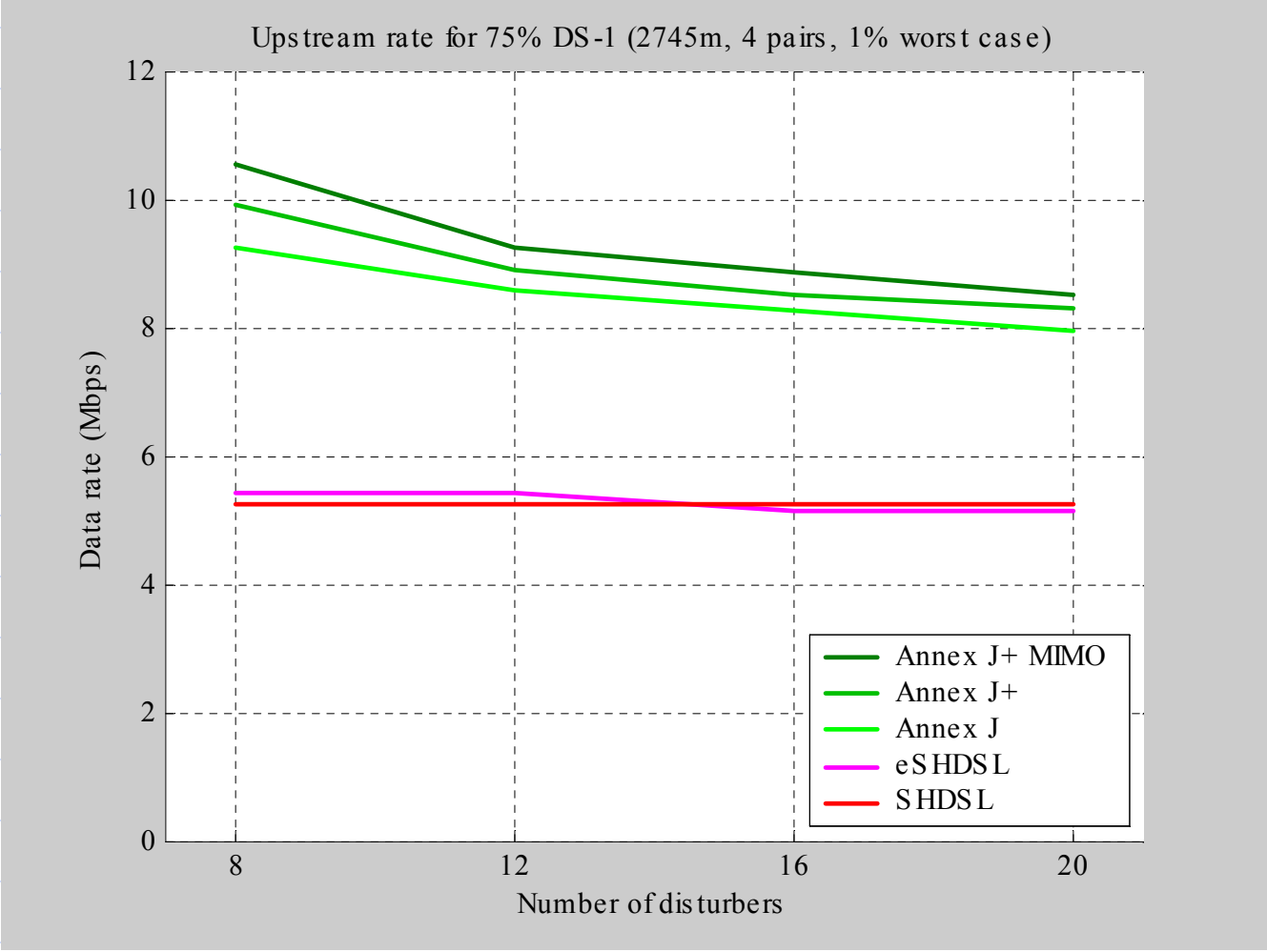
Services Compared

1. SHDSL: G.shdsl (G.991.2)
2. eSHDSL: enhanced G.shdsl
   - Increased PSD bandwidth up to Method B compatibility limits for each simulated loop length
   - Maximum constellation size up to 64-TCPAM (as dictated by SNR in each simulation run)
3. Annex J: G.dmt.bis (G.992.3) Annex J
4. Annex J+: Annex J with optimized PSD masks
   - Flexible FDM separation points for higher upstream rates
   - Voyan-proposed PSD masks that are Method B compatible for each simulated loop length
5. Annex J+ MIMO: Annex J+ with out-of-domain crosstalk mitigation through MIMO processing

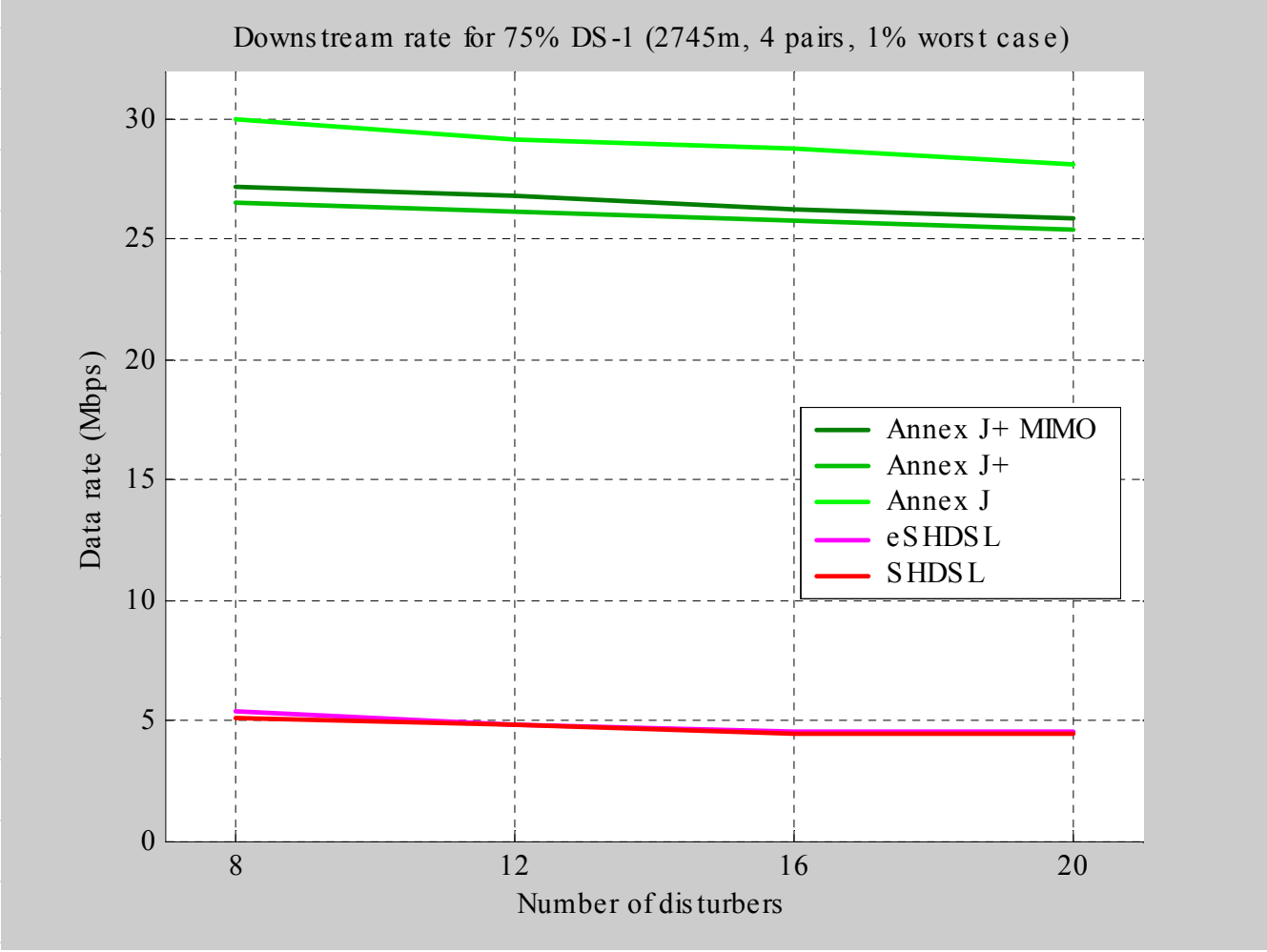
Annex J+ PSD Template



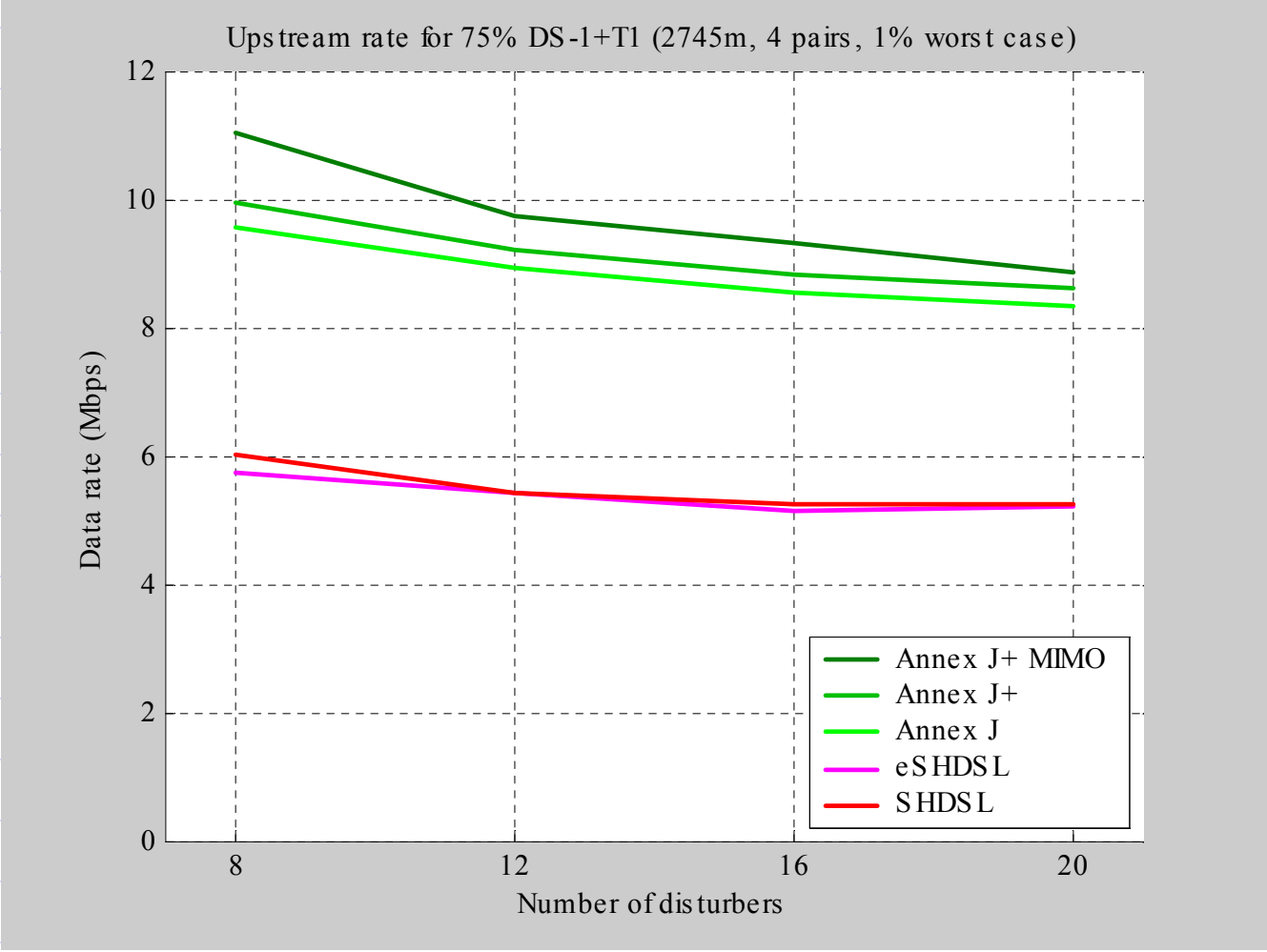
75% DS-1, Upstream



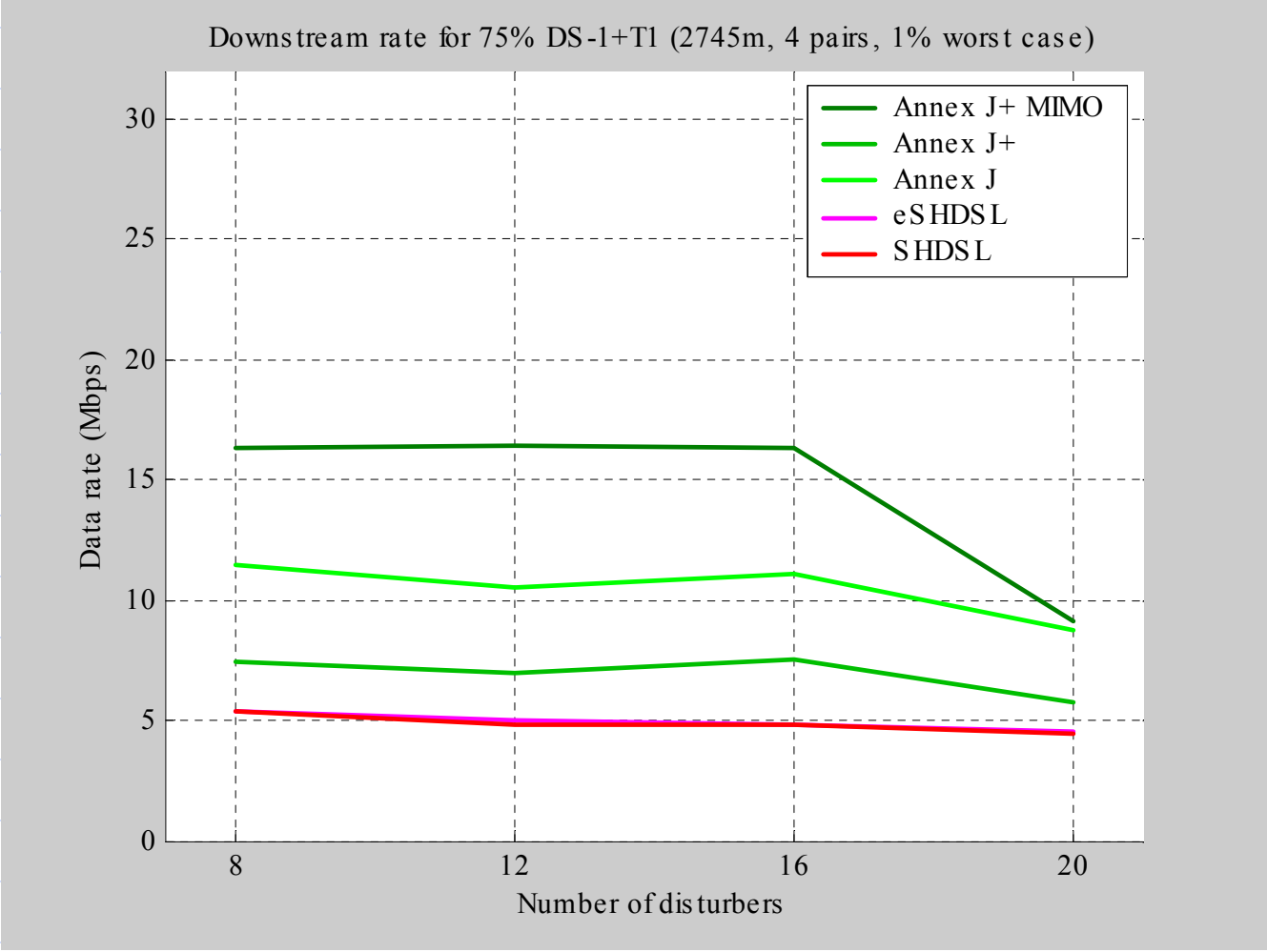
75% DS-1, Downstream



75% DS-1+T1, Upstream



75% DS-1+T1, Downstream



Conclusions

- G.shdsl (even enhanced) never gets close to 10Mbps on 4 pairs in the studied realistic scenarios
- Annex J gives better performance than G.shdsl in the studied scenarios and is much closer to 10Mbps on 4 pairs, even with T1 disturbers
- Annex J+ (Annex J with minor PSD changes that are spectrally compatible under T1.417 Method B) gives improved upstream performance at the expense of downstream performance
- MIMO provides robustness against T1 disturbers

ADSL – Proven Technology

- More than 23 million ports of ADSL (G.992.1) deployed in the world today (end of '02)
  - Asia-Pacific – 7.5 million
  - North America – 6.6 million
  - Europe – 5.6 million
  - Japan/China – 3.0 million
- Most ADSL vendors will release G.992.3 (ADSL2) solutions in 2003
- Solutions exists today with Annex J bandwidths on top of POTS
- Solutions exists today with ADSL and VDSL-DMT combined in a single piece of silicon

Spectral Compatibility

- ADSL2 Annex J verified to adhere to T1.417 Spectrum Management requirements
  - Verified against all T1.417 basis systems using Method B
- Widest mask (276 kHz) spectrally compatible out to 3700 m (24 AWG)
  - Narrower masks compatible out to longer loop lengths
- Crosstalk from ADSL Annex J solution has small impact on existing/planned services
  - ADSL (G.992.1/G.992.3 Annex A)
  - HDSL2/SHDSL
  - VDSL

ADSL and the 5 Criteria

Economic Feasibility

Economic Feasibility

- Due to economies of scale, ADSL chipsets are the cheapest of all DSL chipsets
  - Data is both known and reliable
- Given market projections, ADSL chipsets are likely to remain the cheapest of all DSL chipsets
- Performance is excellent for cost
  - ADSL provides more bits/$ than, say, voiceband modems
- ADSL installation costs are lowest of all DSL because customers can self-install

Spectral Compatibility and Friendliness

What is Spectral Compatibility?

- Adhering to a set of signal power limits and deployment guidelines
  - Ingress
    - Specifies realistic services and technologies in same binder
    - Target system must not suffer unacceptable performance degradation from other services
  - Egress
    - Set limits on the energy transferred from the target system
    - Must not cause unacceptable performance degradation to other services in the same binder
- Critical for ensuring compatibility among dissimilar services in the same binder

T1.417

- Spectrum Management standard published by T1E1
- Provides requirements and recommendations for "spectrally compatible" services
  - Power spectral density (PSD)
  - Total average power
  - Transverse balance
  - Longitudinal output voltage
  - Deployment guidelines
- Spectrum Management Classes
  - Proven egress characteristics
  - Protected from ingress of other services
- Provides analytical method for determining spectral compatibility of new services

Is T1.417 the Perfect Answer?

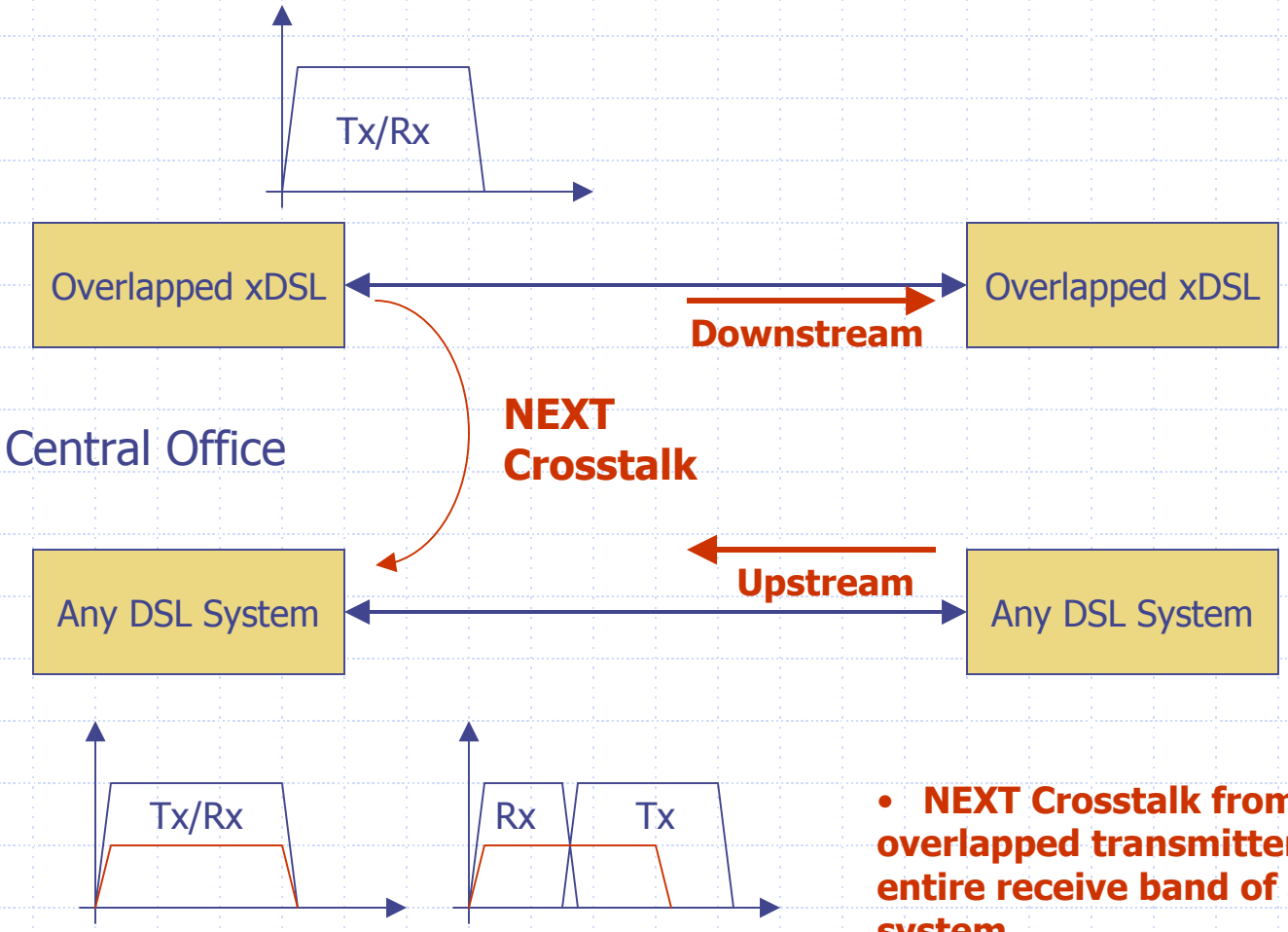
- T1.417 essentially sets a minimal bar for spectral compatibility
  - Standard is the result of a great number of compromises to allow dissimilar services (e.g. ADSL, HDSL, ISDN, HDSL2, SHDSL, VDSL) to be shown to be spectrally compatible with one another
- Adhering to T1.417 guidelines required for any service
- But… T1.417 does have its limitations and holes
  - Target services can be spectrally compatible and yet have vastly different impacts on existing services
  - Even T1s, known to be nasty interferers, can be shown to be spectrally compatible

What is Spectral Friendliness?

- A subjective measure of how different target services impact other existing services
  - Compares the impact of crosstalk from target systems on ADSL, SHDSL, etc.
- Impacts overall success of target service in a given market
  - Operators will be hesitant to deploy a target service in a given market if they know it will adversely effect existing services

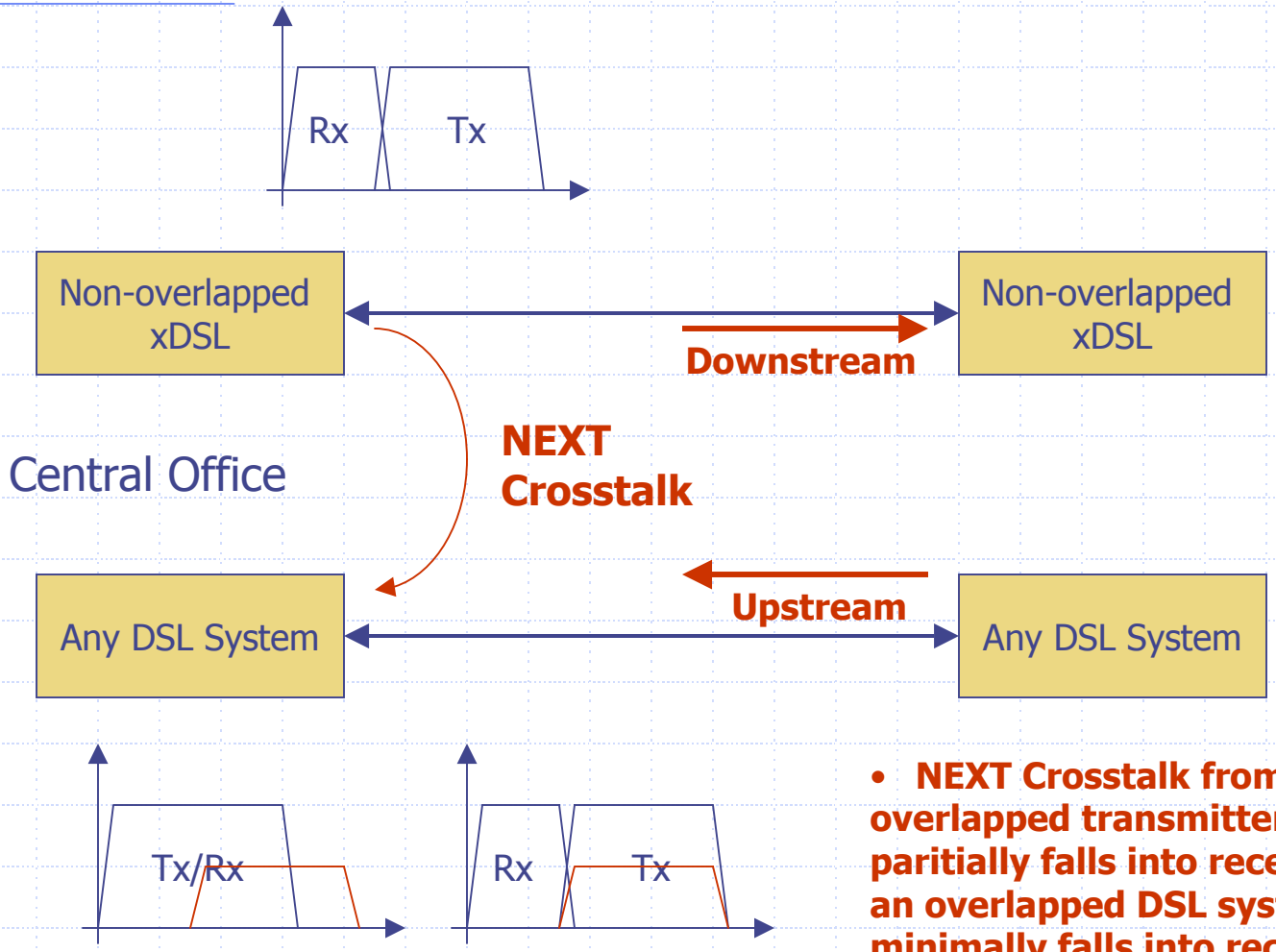
Impact of Self-NEXT

NEXT Crosstalk Issue – Overlapped Transmitters



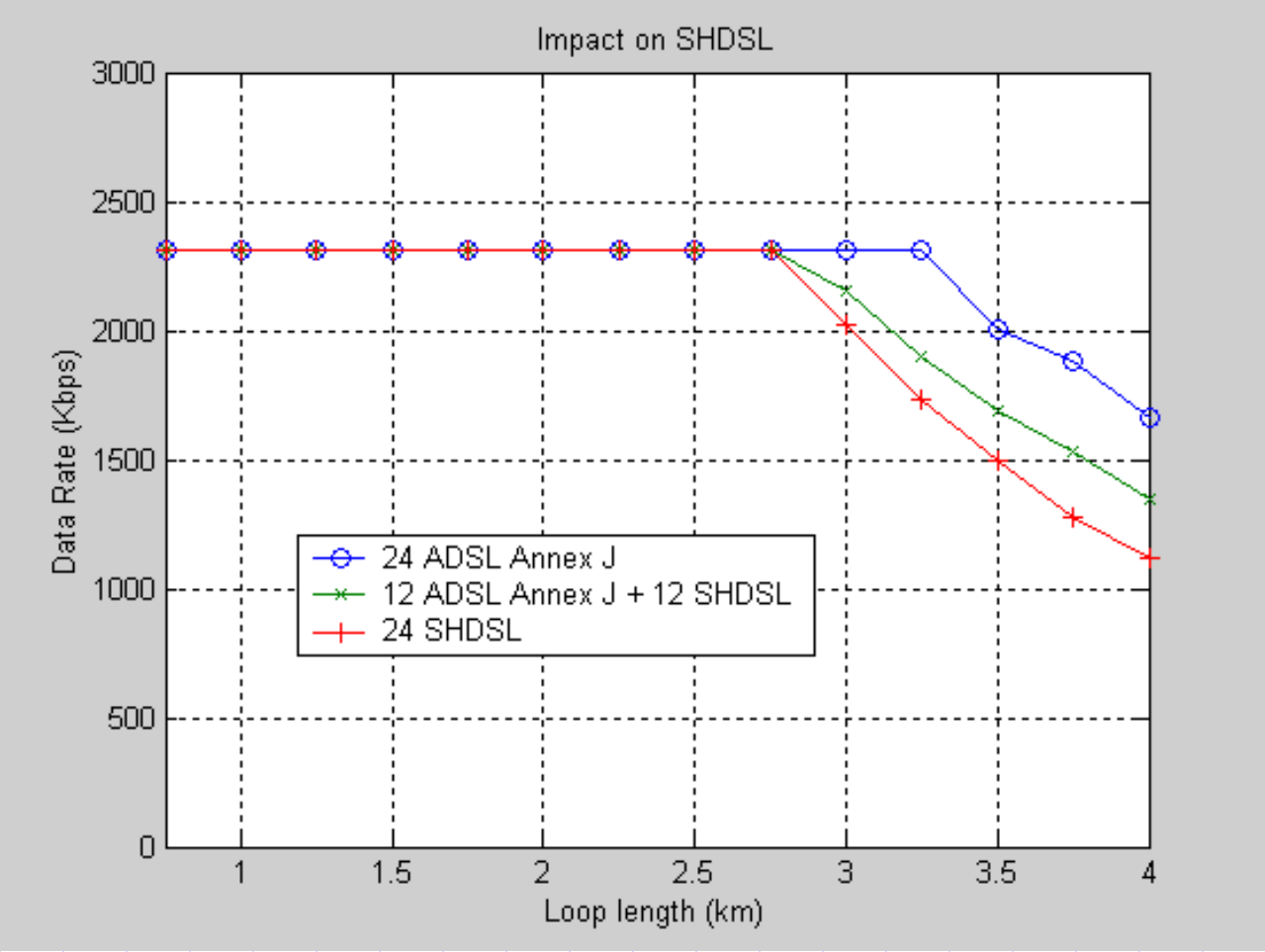
- **NEXT Crosstalk from overlapped transmitter falls into entire receive band of any DSL system**

NEXT Crosstalk Issue – Non-Overlapped Transmitters

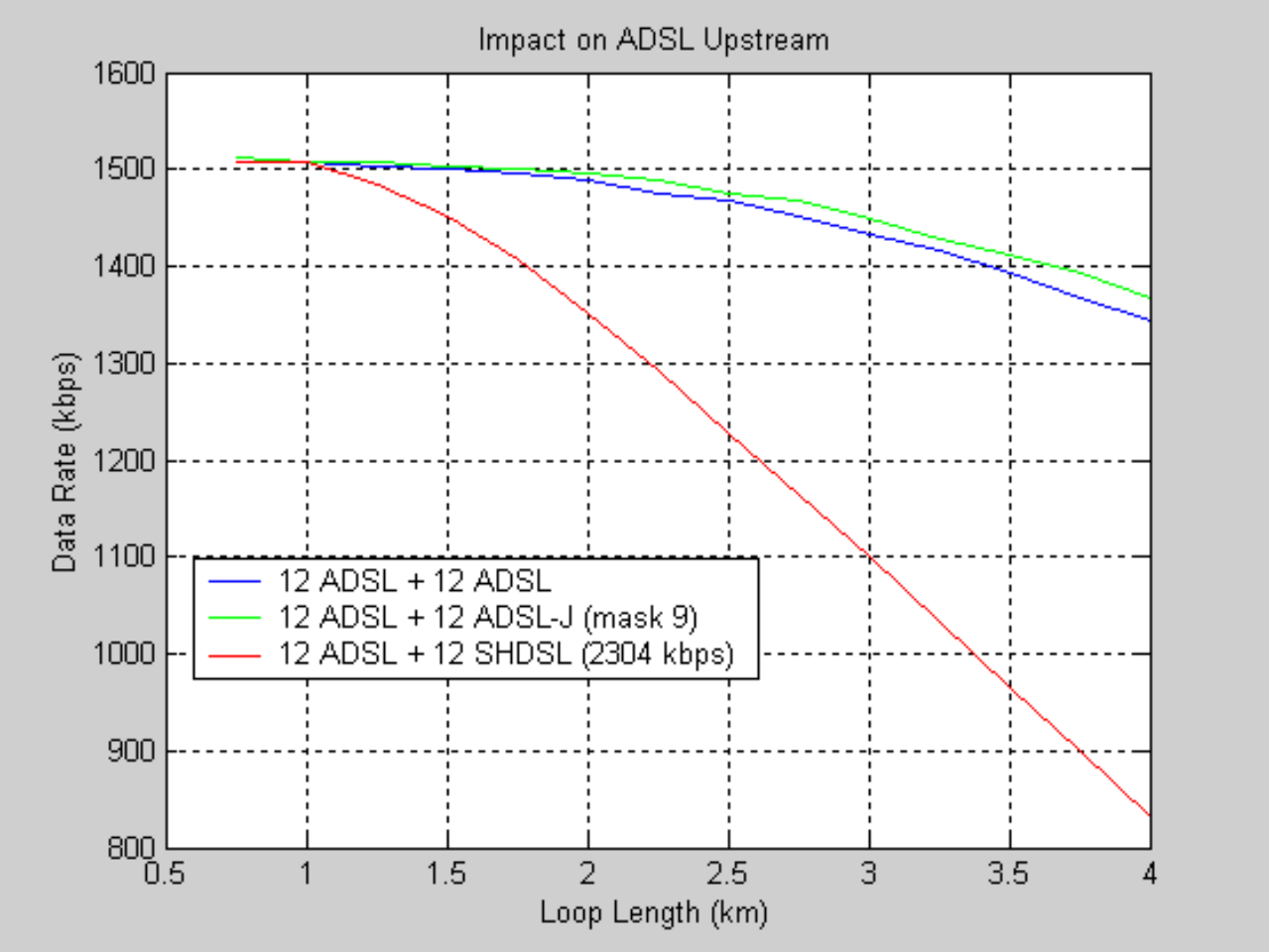


- **NEXT Crosstalk from non-overlapped transmitter only paritially falls into receive band of an overlapped DSL system and minimally falls into receive band of non-overlapped DSL system**

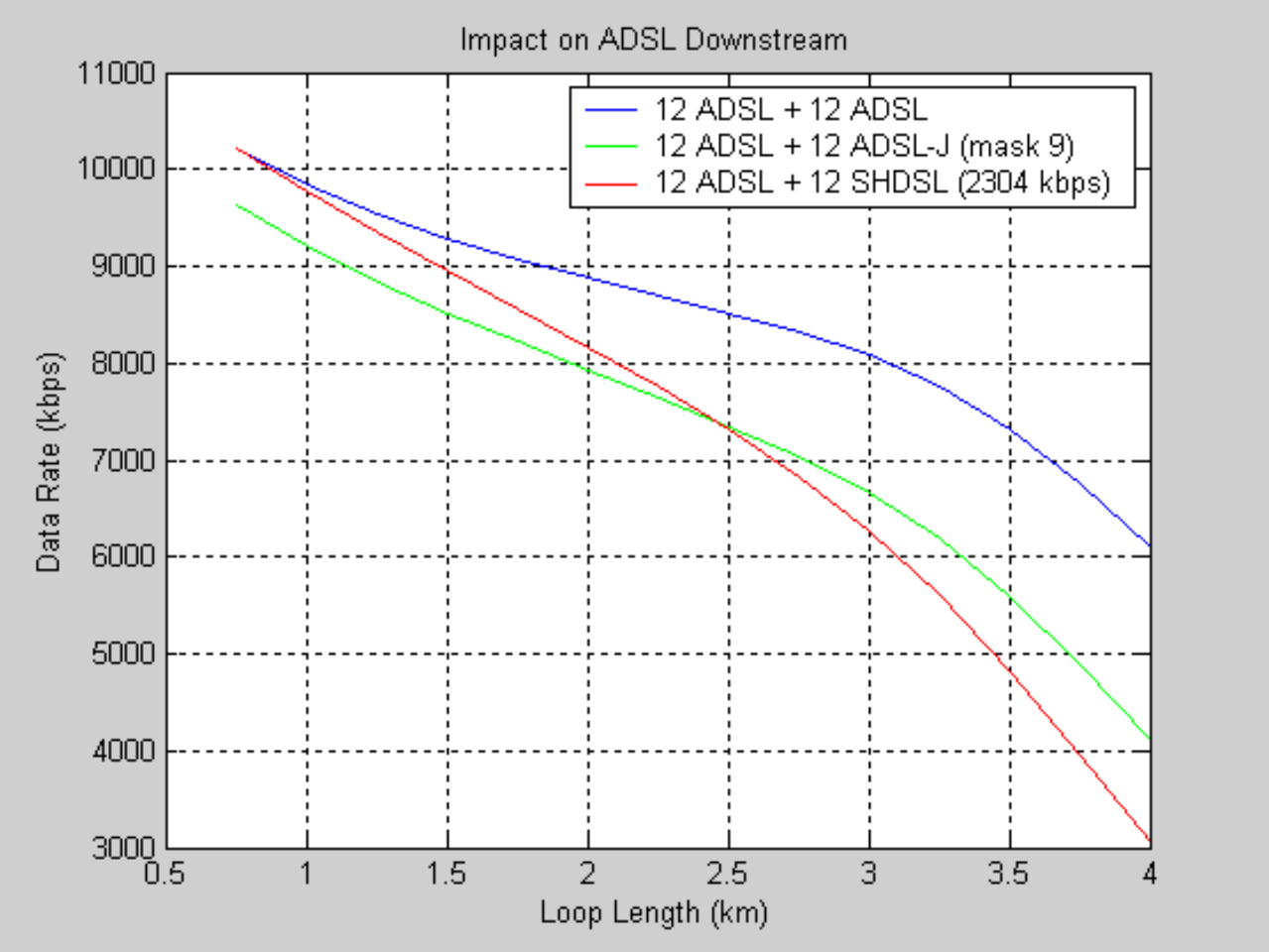
Impact on SHDSL (24 AWG)



Impact on ADSL POTS Upstream (24 AWG)



Impact on ADSL POTS Downstream (24 AWG)



Spectral Friendliness Conclusions

- ADSL Annex J has minimal impact on existing SHDSL services
  - In fact, Annex J has less impact than SHDSL itself!
- ADSL Annex J has little impact on existing ADSL upstream
  - Provides no additional crosstalk into ADSL upstream receive band
  - Annex J even friendlier than ADSL itself!
- Both potential services impact ADSL downstream
  - Both services transmit in ADSL downstream band
  - Annex J has more of an impact on shorter loops, but there is typically excess downstream bandwidth on those loops

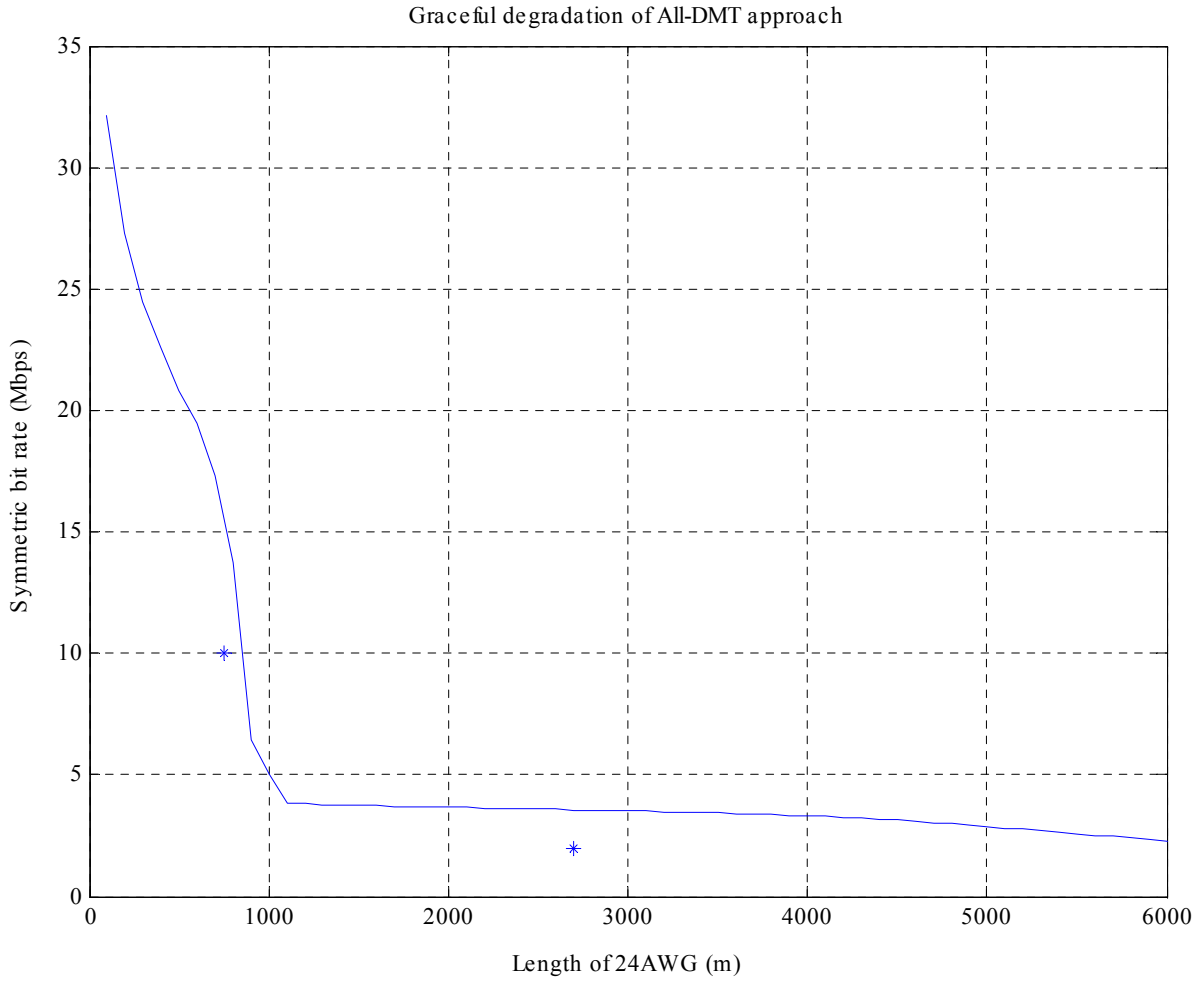
ADSL + VDSL-DMT

A single-port solution for EFM Copper

All-DMT Approach

- DMT VDSL was designed for compatibility with ADSL
  - The same chipset can support both Annex J and DMT VDSL
- A single DMT VDSL-based chipset with Annex J support can meet both the short-reach and long-reach objectives – **True Distinct Identity!**
- Advantages
  - Single device for all of EFM/Copper
  - Bit rates degrade gracefully with loop length
  - Plus all the economic advantages of ADSL (low cost, easy to provision, etc.)
- ADSL-based chipset capable of supporting multiple evolutive applications
  - ADSL Annex A, Annex B, Annex J, VDSL, ADSL+, etc.

Performance of All-DMT (12 self)



Summary

- ADSL is an excellent choice of existing, proven technology which meets EFM's 5 Criteria
  - Addresses broadest market potential by covering both business and residential
  - Compatible with existing higher layers of Ethernet
  - Single-device solution with VDSL covers entire EFM Copper space
  - Solutions exist today and leverage enormous investment in ADSL
  - Solution meets performance objectives and provides migration path to even higher performing solutions in the future
  - Leverages vast investments in ADSL silicon and systems and provides very low cost for performance
- Spectrally friendly to large amount of ADSL and HDSL currently deployed in the copper network
- Single-device solution
  - Allows vendors to build/support one solution
  - Allows operators to stock/deploy a single solution for EFM

Backup Slides

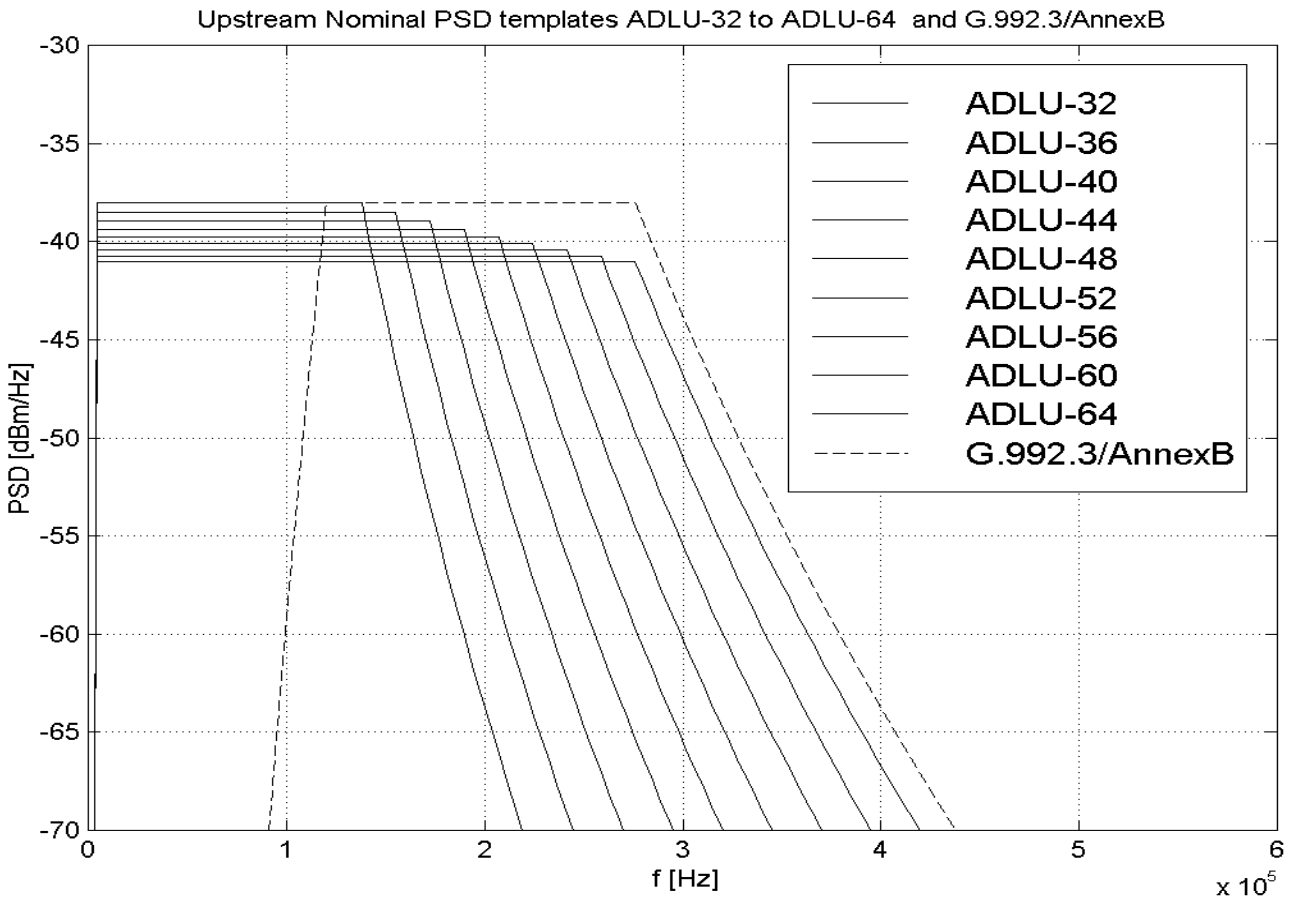
What are Deployment Guidelines?

- Deployments guidelines are restrictions on the length of loops for which specific services may be deployed
  - Utilized to protect the performance of existing services (basis systems in T1.417)
- Having the same deployment guideline does not mean you have the same spectral impact on other services

Selected Upstream PSD & Spectral Compatibility

- PSD selected to optimize performance and meet spectral compatibility (T1.417)
- Deployment Guidelines (24 AWG)
  - L < 3700 meters — Mask 9
  - 3700 <= L < 3900 meters — Mask 6
  - 3900 <= L < 4100 meters — Mask 4
  - 4100 <= L < 4300 meters — Mask 3
  - 4300 <= L < 4500 meters — Mask 2
  - L >= 4500 meters — Mask 1

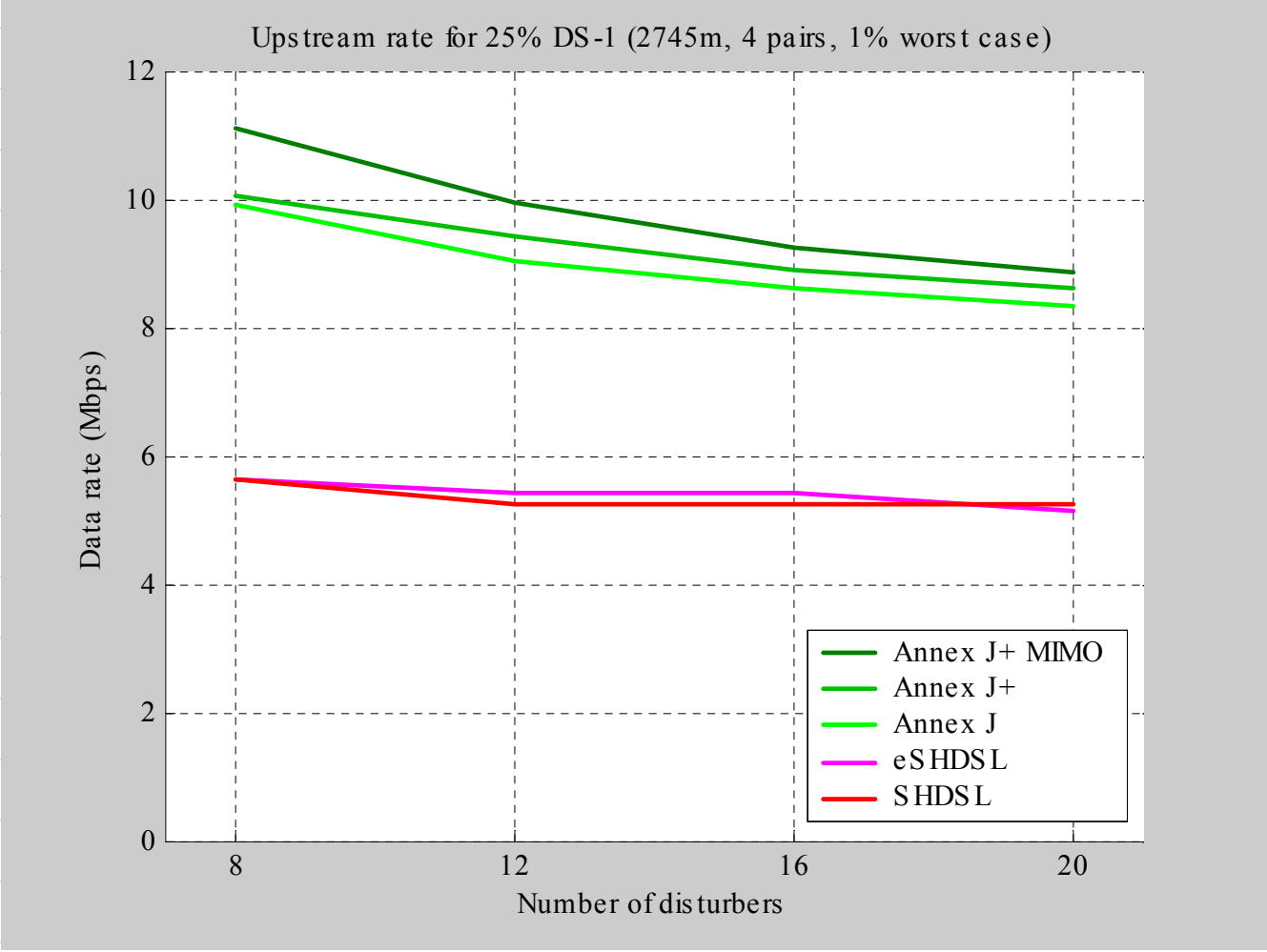
Annex J Upstream PSD Masks



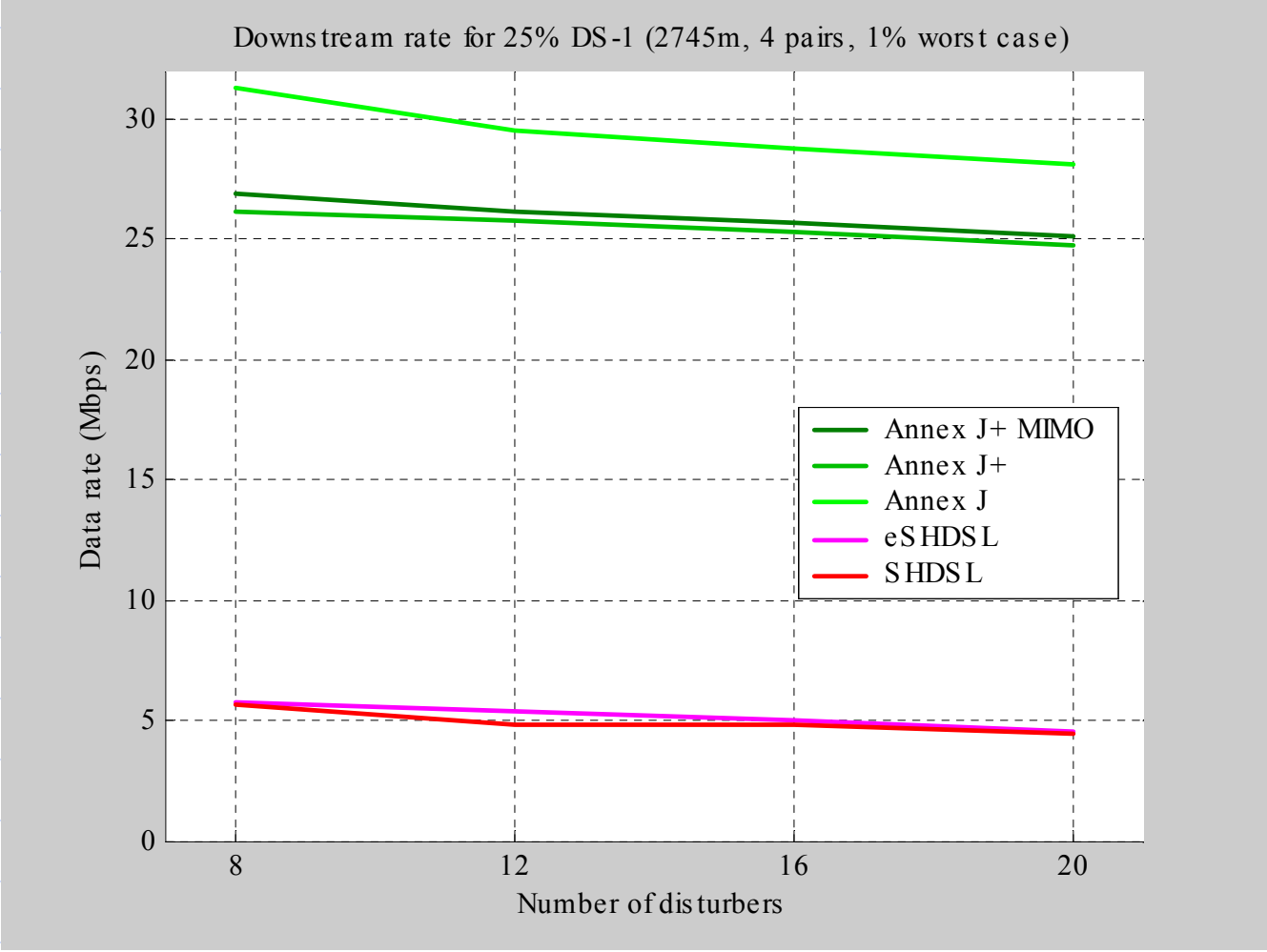
Annex J Upstream PSD Masks (cont'd)

Upstream Mask Number	Designator	Template Nominal PSD (dBm/Hz)	Maximum Aggregate Transmit Power (dBm)	Inband Peak PSD (dBm/Hz)	Frequency f1 (kHz)	Frequency f2 (kHz)
1	ADLU-32	-38.0	13.4	-34.5	138.00	307
2	ADLU-36	-38.5	13.4	-35.0	155.25	343
3	ADLU-40	-39.0	13.4	-35.5	172.50	379
4	ADLU-44	-39.4	13.4	-35.9	189.75	415
5	ADLU-48	-39.8	13.4	-36.3	207.00	450
6	ADLU-52	-40.1	13.4	-36.6	224.25	485
7	ADLU-56	-40.4	13.4	-36.9	241.50	520
8	ADLU-60	-40.7	13.4	-37.2	258.75	554
9	ADLU-64	-41.0	13.4	-37.5	276.00	589

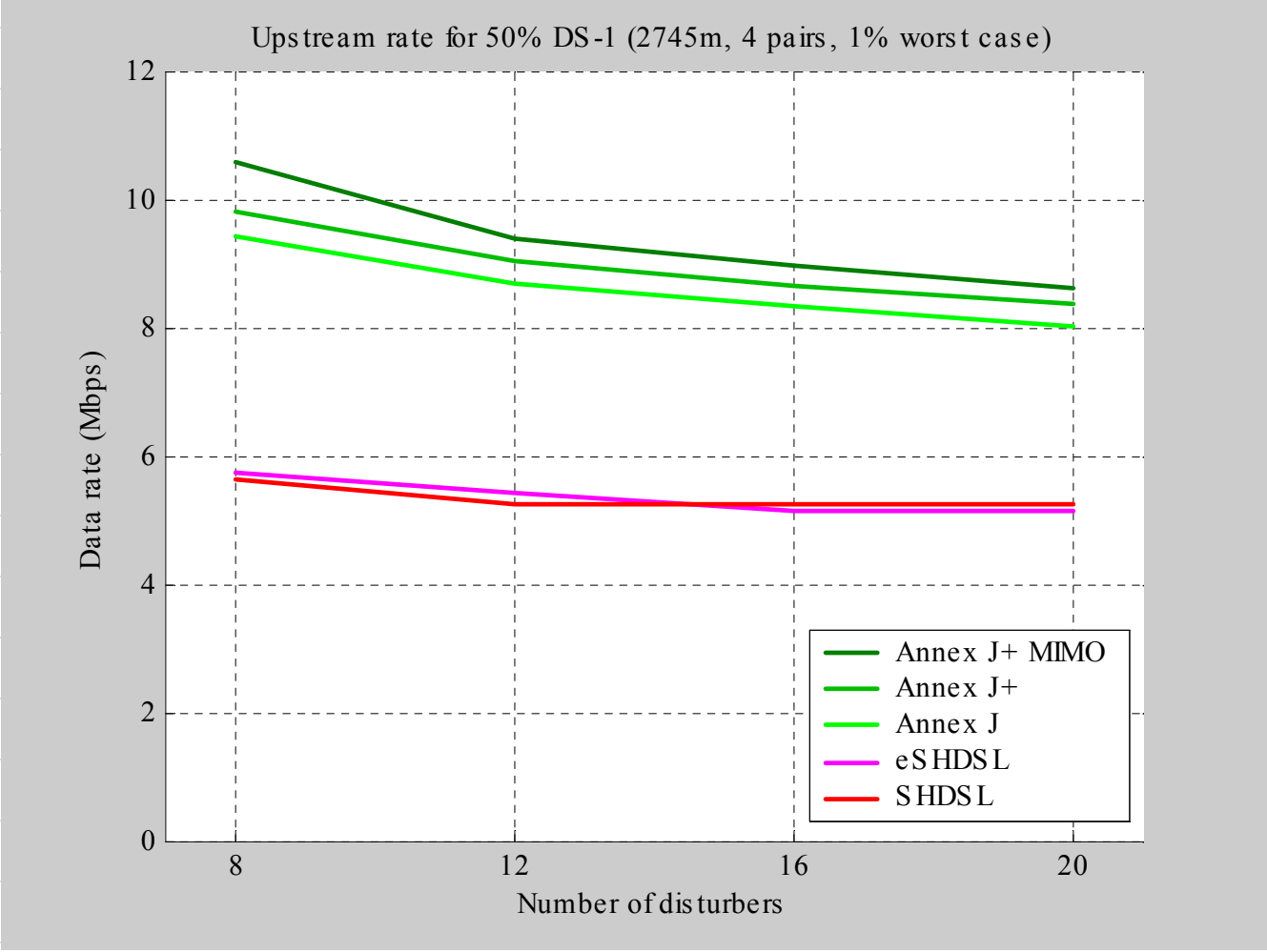
25% DS-1, Upstream



25% DS-1, Downstream



50% DS-1, Upstream



50% DS-1, Downstream