Standard VDSL Technology

Overview of European (ETSI), North American (T1E1.4) and International (ITU-T) VDSL standard development

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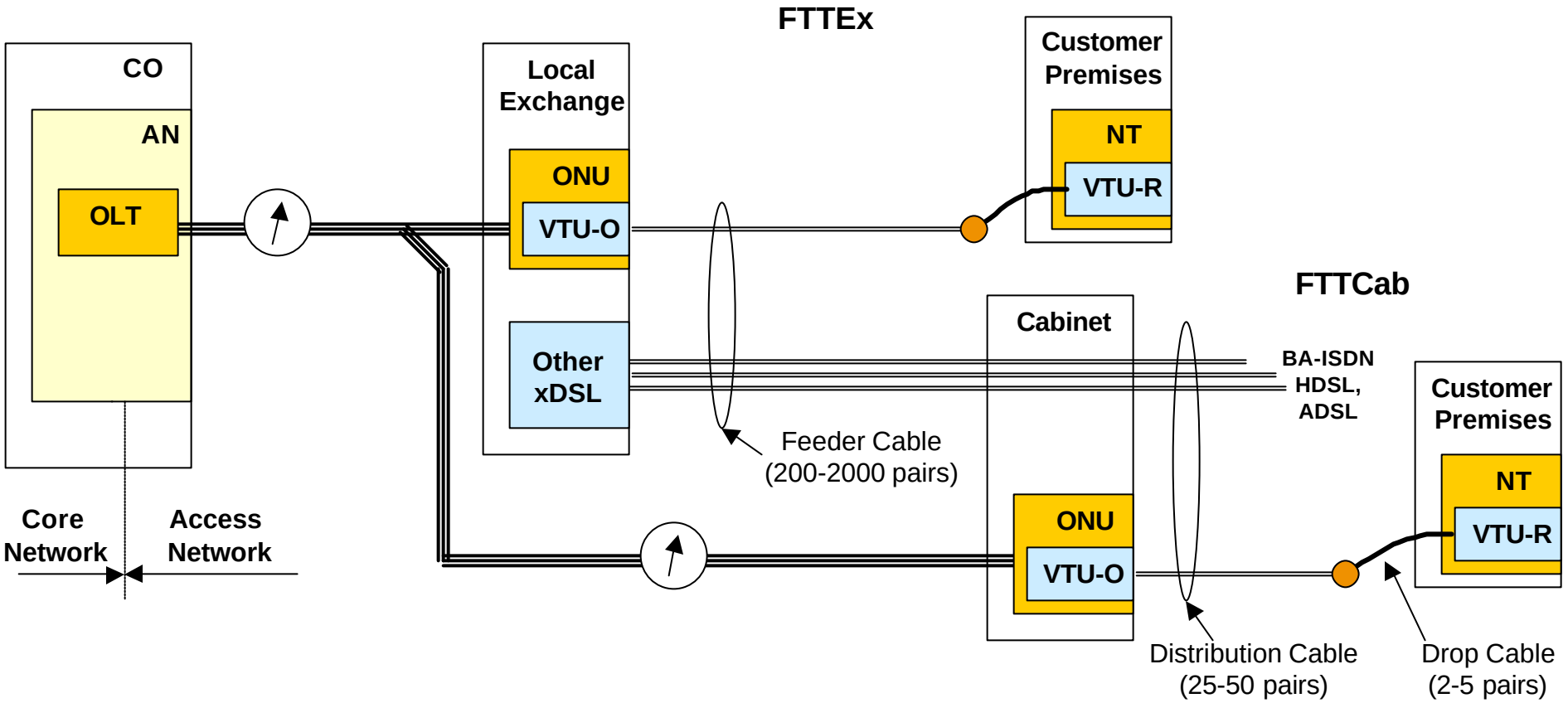
Current status of VDSL standards

- **Europe (ETSI TM6)**
  - First issue (1997-2000) of the VDSL standard (2 parts: Functional requirements, Transceiver specification) approved in December 2000
  - Single-carrier modulation (SCM) and Multi-carrier modulation (MCM) technologies are specified as possible implementations

- **North America (ANSI T1E1.4)**
  - First issue (1999-2001) of the trial-use VDSL standard (3 parts: Functional requirements, SCM Transceiver specification and MCM Transceiver specification) passed letter ballot in February 2001. Comment resolution is expected to be completed in August 2001

- **International (ITU-T)**
  - First issue (started in 1999) will include only Functional requirements (foundation document); expected to be ready for ballot in October 2001

Typical installation



- **Abbreviations:**

  AN - access network
  ONU - optical network unit
  VTU - VDSL transmission unit

Goals

- **Asymmetric transport:**
  - **Europe: 23/4, 14/3, 8.5/2, 6.5/2 Mb/s**
  - **North America: 22/3, 13/3 Mb/s**
- **Symmetric transport:**
  - **Europe: 28/28, 14/14, 8.5/8.5, 6.5/6.5 Mb/s**
  - **North America: 13/13, 9/9, 6/6 Mb/s**
- **Transport: Slow path or Slow & Fast paths**
- **Latency:**
  - **£ 1.0 ms for Fast path**
  - **£ 20 ms for Slow path, trade-off latency for burst protection up to 500 us**
- **POTS or BA-ISDN life-line over the same pair**

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Environment

- **Unbundled loops**
- **Spectrally compatible with:**
  - POTS
  - all xDSL using the band below 1.1MHz
  - T1/E1 (reduced performance)
  - HAM radio (standard European and NA bands)
  - AM radio
- **No centralized timing**
- **No centralized management system**

VDSL loop plant

- **Distribution cables:**
  - with or without sheath
  - aerial or buried
  - UTP
  - 50-2000 pairs, 25-50 pairs per binder
  - 26 AWG and thicker, 24 AWG is the most popular
  - bridged taps (in North America) - not terminated, 50-1500 ft

- **Drop cables**
  - no sheath
  - aerial or buried
  - 1- 50 pairs, single binder
  - mostly twisted, single flat pairs are possible
  - 0.5mm - 0.8mm

Impairments

- **Crosstalk noise (full binder):**
  Typically: 10 ISDN, 10 ADSL, 4 HDSL, 20 VDSL and
  2 T1/E1 (at CO, reduced VDSL performance)

- **Background noise:**
  White Gaussian noise of -140dBm/Hz

- **RFI (HAM radio and AM radio):**
  Standard amateur and broadcast radio bands

- **Impulse noise:**
  Includes high level noise bursts capable to erase the signal for up to hundreds microseconds

Transmission technique highlights

- **Duplexing:**
  FDD

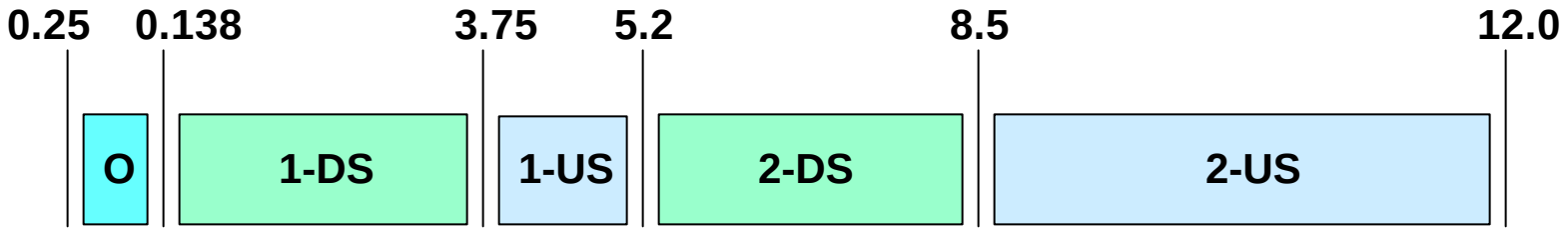
- **Modulation**
  Single-carrier modulation (SCM) - mostly QAM
  Multi-carrier modulation (SCM) - mostly DMT

- **Error correction**
  FEC, standard Reed-Solomon, up to 8 correctable octets

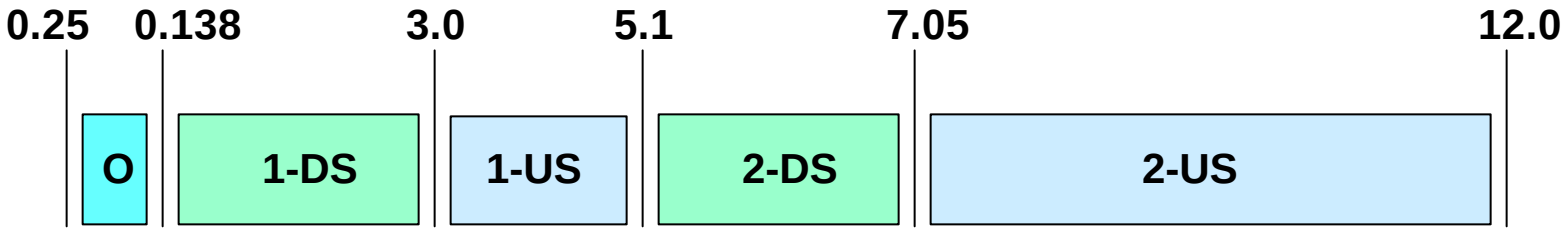
- **Impulse noise protection**
  Ramsey III interleaving, programmable latency, erasure correction up to 500 us

FDD Duplexing: spectral plans

- **Plan 998 (North America, Europe, Japan)**



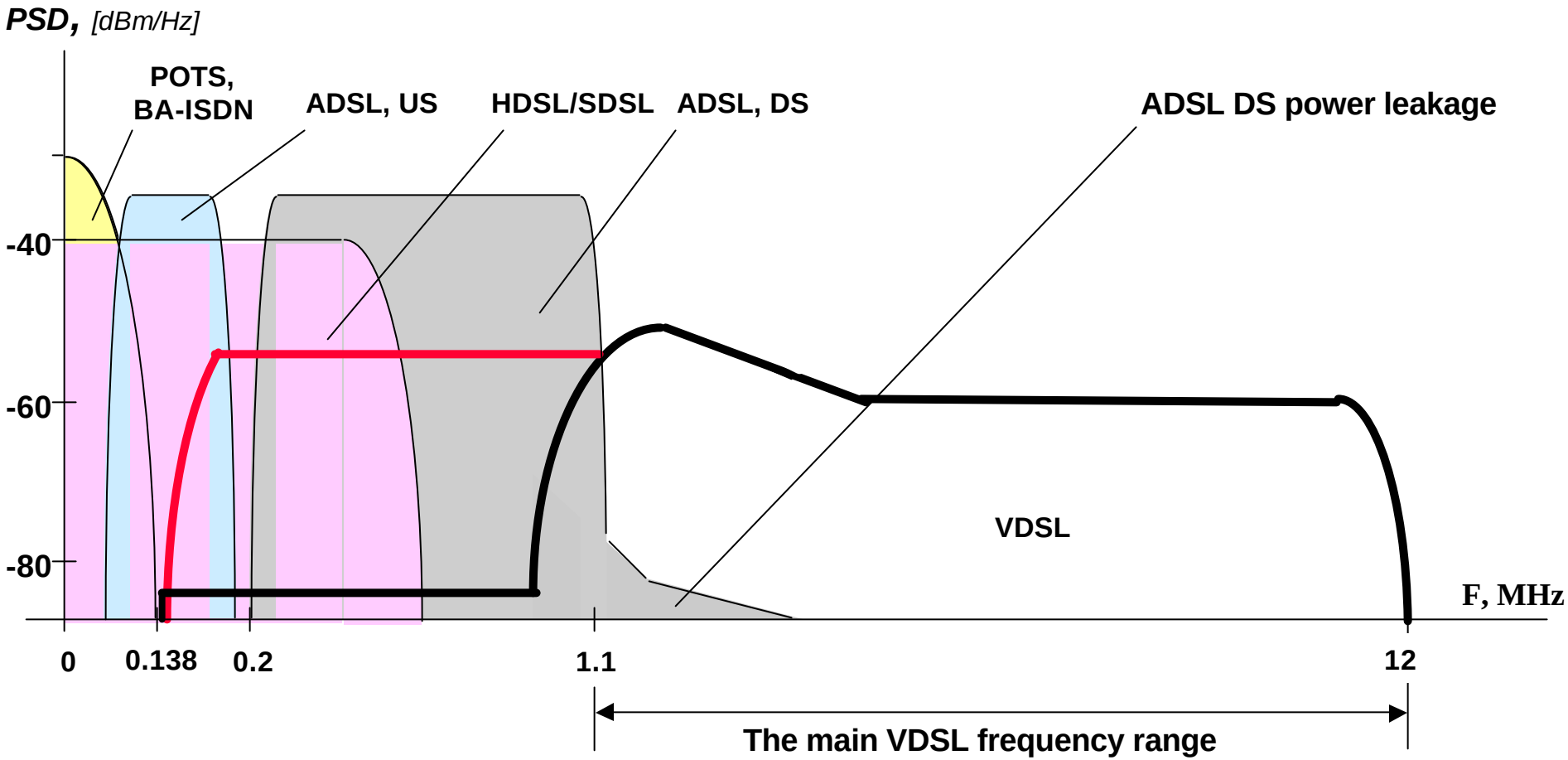
- **Plan 997 (Europe)**



- **Notes:**

  Band “O” is optional and could be used for either upstream or downstream transmission

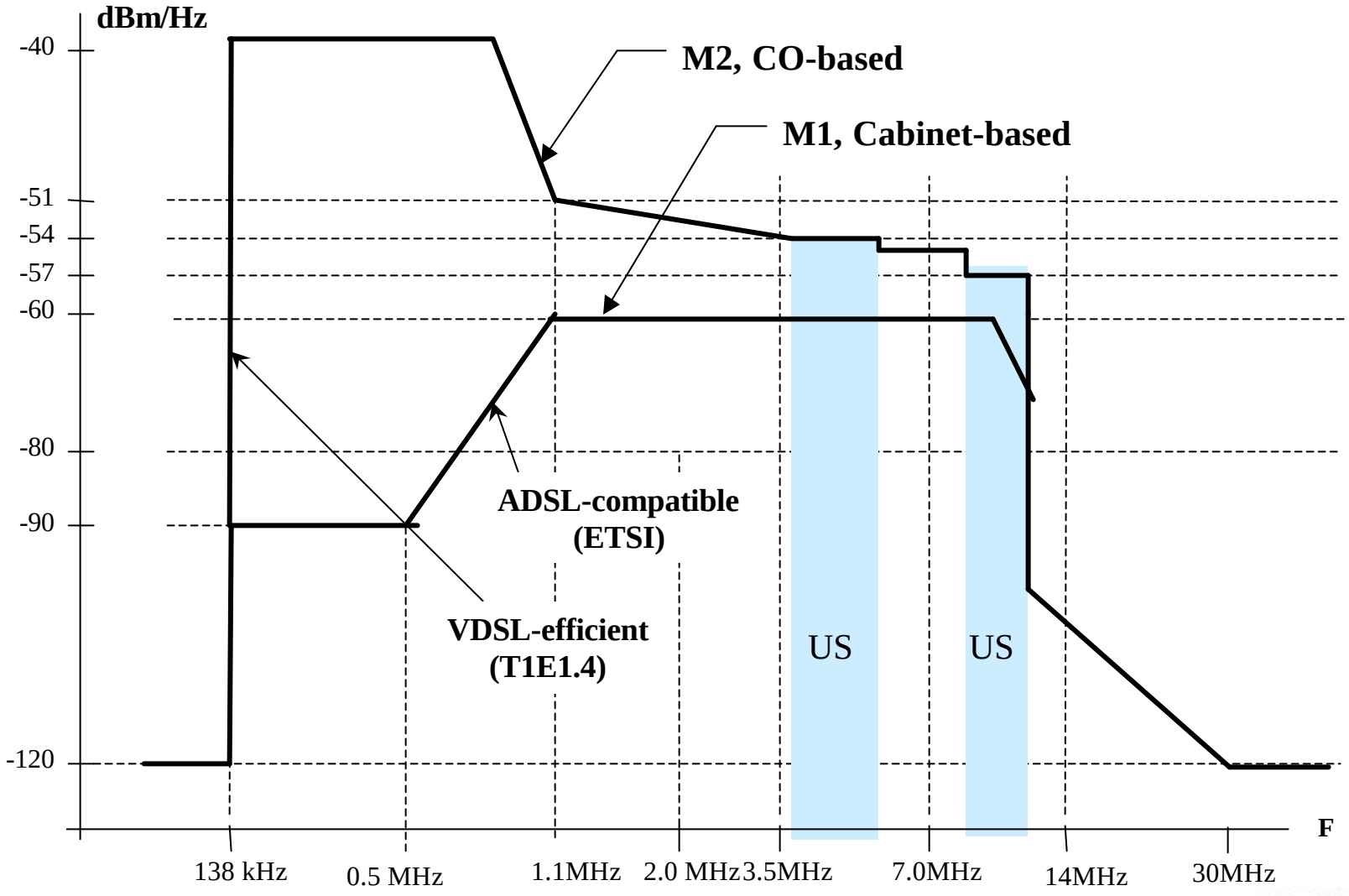
Spectral compatibility with xDSL



VDSL Efficient Mode (usually applied for FTTEx)

ADSL Compatible Mode (usually applied for FTTCab)

PSD mask: two examples



Spectral compatibility: “near-far”

The “near-far” problem in VDSL is due to FEXT generated by a loop is a function of the length. Short loops generate very strong FEXT and dramatically reduce performance of long loops if upstream power back-off (UPBO) is not applied.

- **The UPBO method-** requires setting of the transmit PSD (*Tx_PSD*) in the upstream direction using the estimation of the electrical length l_e of the loop as:

$$TxPSD = \min\{ PSD\_REF + kl_e\ddot{O}f \, , \, PSD_0 \}, \text{ dBm/Hz}$$

PSD_REF [dBm/Hz]: Reference PSD, independent of the loop type;
PSD_0 [dBm/Hz]: the absolute limiting PSD (upstream PSD mask).

Why FDD but not TDD?

FDD and TDD have almost the same performance characteristics. Sometimes TDD could be implemented with lower power consumption. However, operators selected FDD duplexing for VDSL due to following reasons:

- Easy to deal in unbundled environment:
  - spectral compatibility with other xDSL reached by appropriate band plan
  - different vendors are not limited by common timing
- No need for central synchronization
- Doesn't violate stationarity of the cable noise environment
- Can easily mix different services (symmetric/asymmetric, high rate/low rate)
- Well understood, mature, and cost effective technology

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Why Continuous but not Bursts?

VDSL transport technology was selected to be continuous (either SCM or MCM) for the following reasons:

- **Support of all types of service**
  VDSL supports both continuous and bursty services; it provides network timing reference (NTR) and timing recovery for ATM and STM applications

- **Stability**
  Stable and predictable performance independent of the instant network load

- **Stationarity**
  Crosstalk generated by continuous transmission is stationary. That improves performance of other systems in the binder

- **Latency requirements**
  In TDD burst transmission it is difficult to provide latency requirements for delay-sensitive services.

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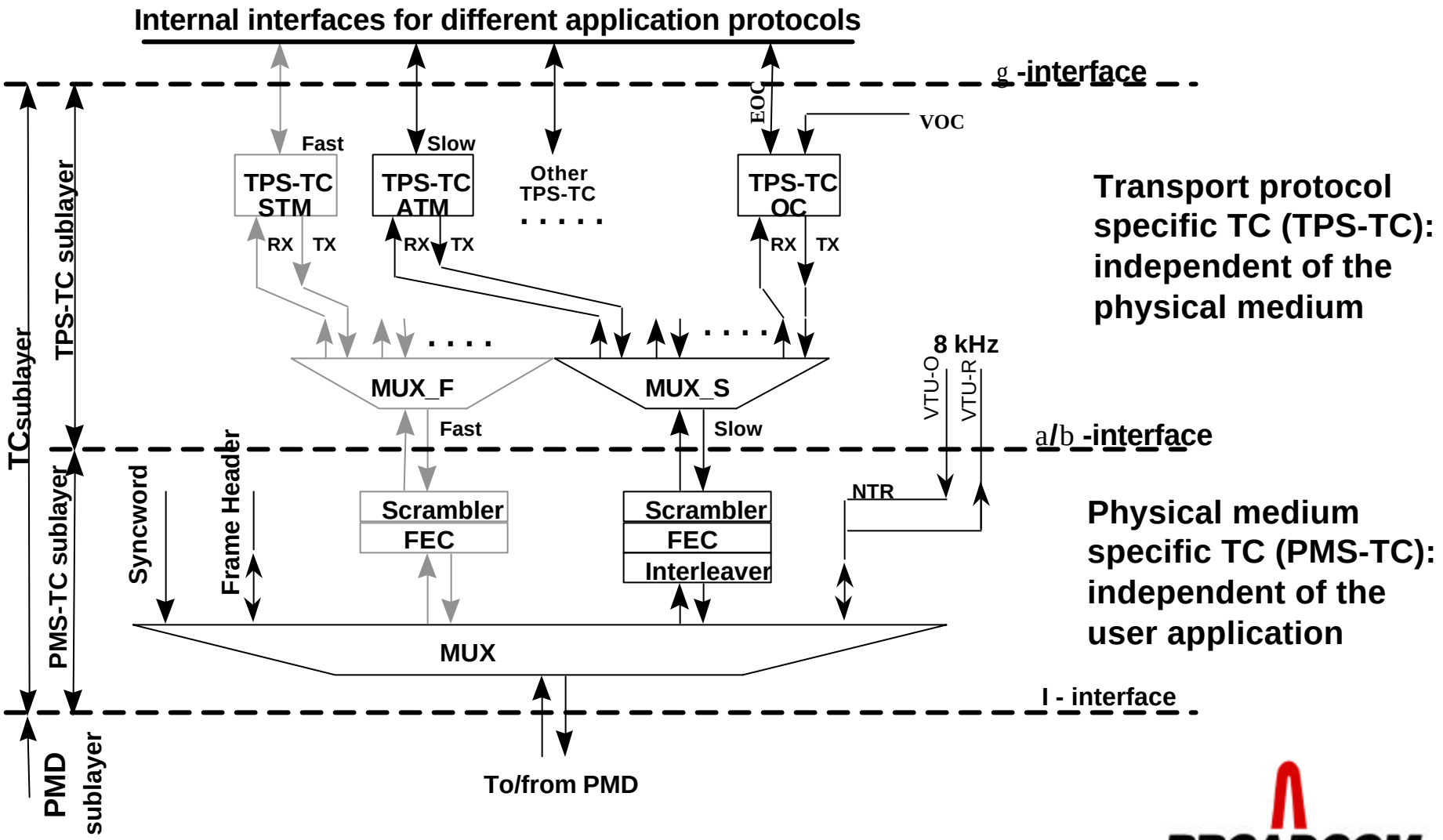
VDSL system architecture

- **Hierarchy: VDSL is specified as a PHY**
- **Sub-layers:**
  - Transmission convergence (TC)
  - Physical medium dependent (PMD)
- **Interfaces:**
  - User application interface - hypothetical, functional
  - Copper loop interface - physical
- **TC architecture:**
  - Single latency or Dual latency
  - Multi-service

VDSL TC sub-layer architecture



Flexibility and programmability

VDSL technology, both MSM and SCM, is flexible and could be adopted to a wide variety of deployment scenarios. Most of parameters are programmable

- **Physical medium (PMD):**
  - number of used frequency bands
  - spectrum allocation of the transmit signal
  - transmit PSD

- **Framing (PMS-TC)**
  - sharing transport capacity between the Fast and Slow channels
  - FEC capabilities
  - interleaving depth (latency to burst protection trade-off

- **Application (TPS-TC)**
  - multi-service configuration

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ITU: Packets over VDSL

The following ITU agreements specify transport of data packets:

- **Packets are transported transparently regardless of their contents and length, unless longer than the upper limit (preliminary equals 2000 octets).**
- **The encapsulation, frame delineation and error monitoring technique for packets is HDLC in octet stuffing mode: each packet is encapsulated into a separate HDLC frame.**
- **Depending on QoS requirements (layer 3) the packet could be transported over either Slow or Fast VDSL path (if available).**

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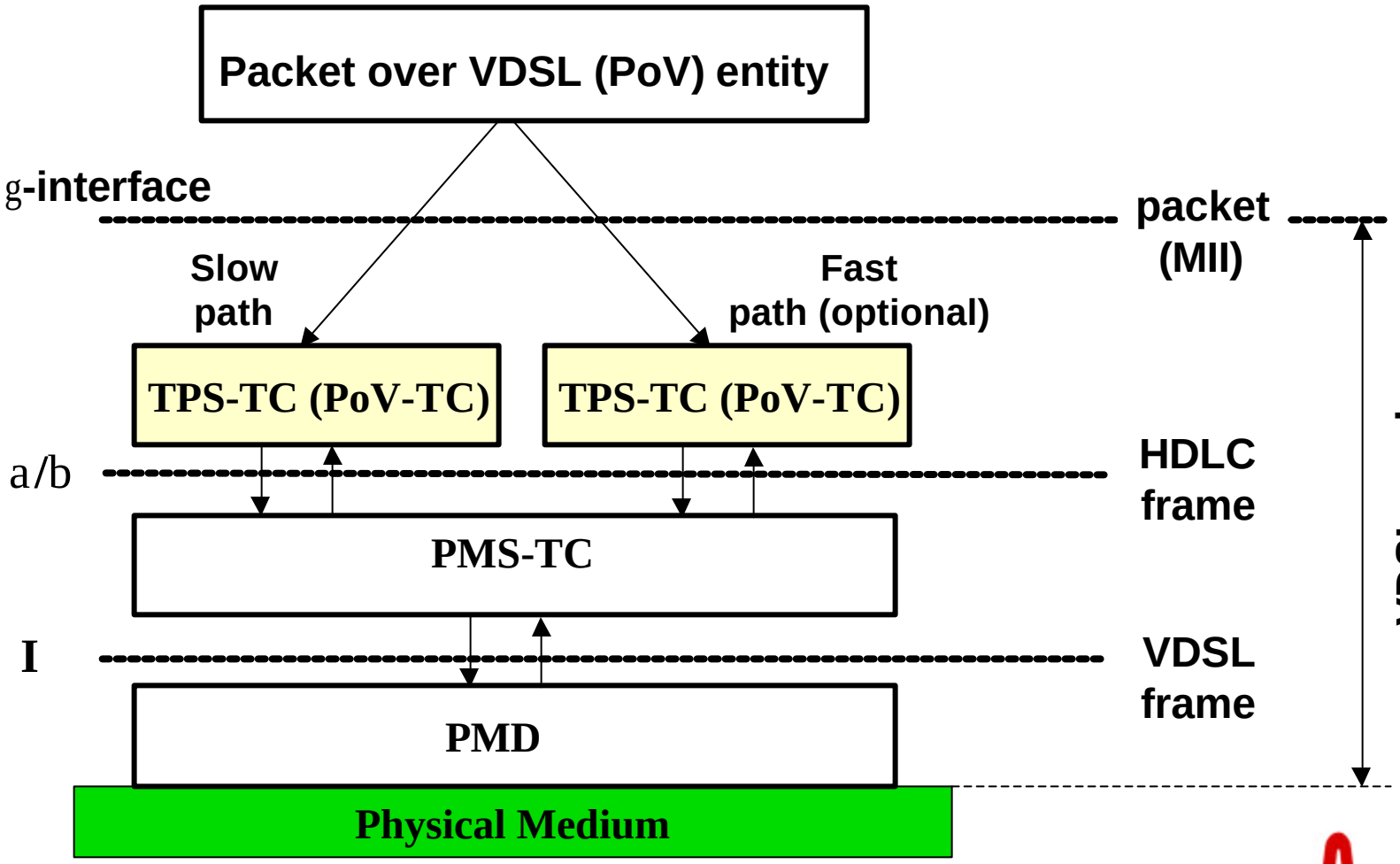
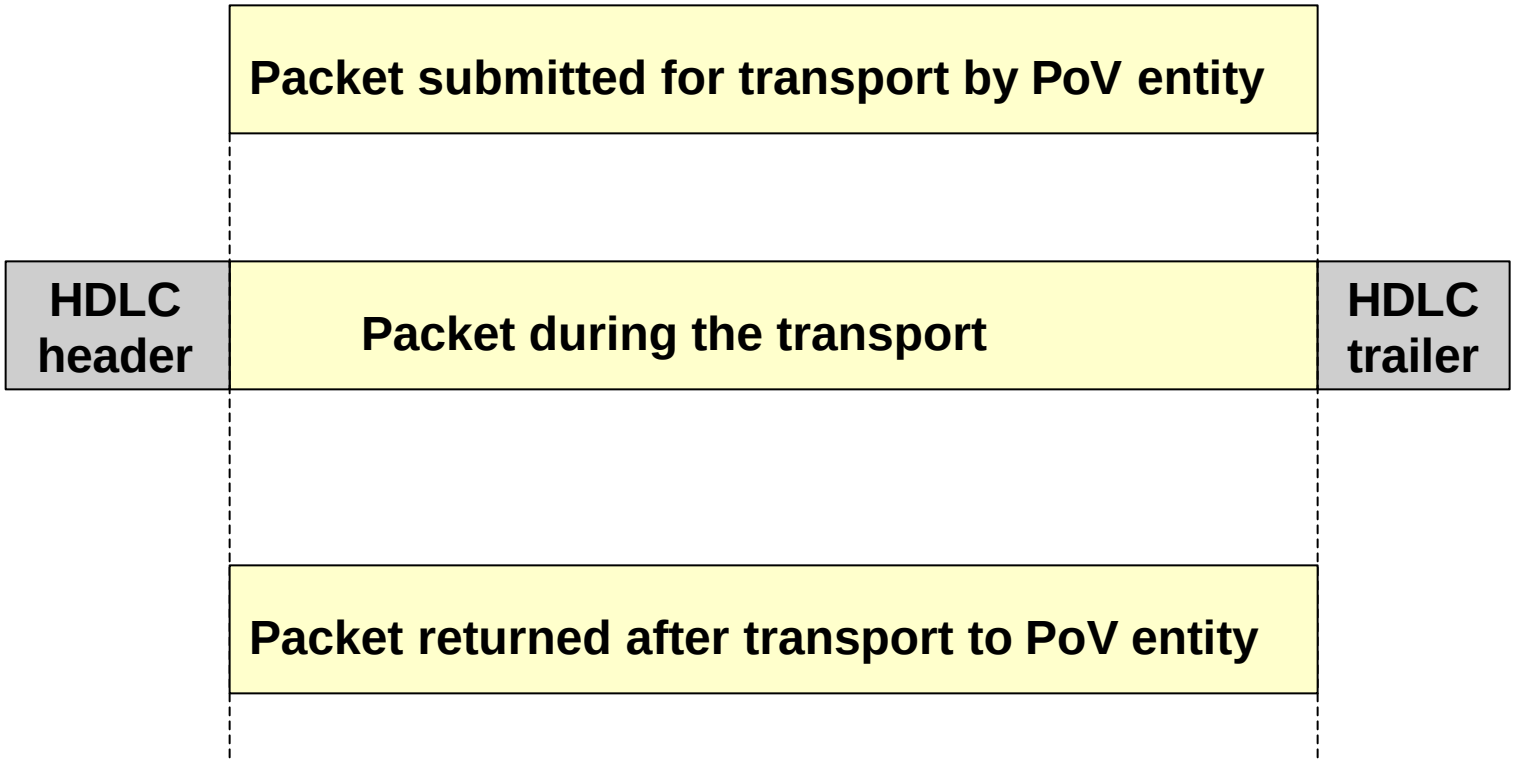
ITU: Packets over VDSL



Packets over VDSL: encapsulation



Performance evaluation

VDSL performance is usually specified by:

- **Test loop:**
  - 26 AWG, 24 AWG and mixed gauge
  - bridged taps (North America) - optional

- **Noise model:**
  - background noise of -140 dBm/Hz plus crosstalk from xDSL and 20 VDSL
  - background noise of -140 dBm/Hz plus RFI plus crosstalk from 20 VDSL

xDSL crosstalk models

- **Different xDSL crosstalk models are specified:**
  - **CO-based:** for a modem located at the CO or connected to the CO
  - **ONU-based:** for a modem located in the cabinet or connected to the cabinet

- **xDSL crosstalkers in North America:**
  - **ONU-based (Noise A):** **16 ISDN, 10 ADSL, 4 HDSL**
  - **CO-based (Noise F):** **16 ISDN, 10 ADSL, 4 HDSL, 2 T1**

- **xDSL crosstalkers in Europe:**
  - **ONU-based (Noise A,B):** **20 ISDN, 10 ADSL/ADSL-lite, 4 HDSL**
  - **ONU-based (Noise C):** **Noise A + 2 E1**
  - **CO-based (Noise D):** **90 ISDN, 180 ADSL, 40 HDSL**
  - **CO-based (Noise E):** **20 ISDN, 30 ADSL, 4 HDSL**
  - **CO-based (Noise F):** **Noise E + 2 E1**

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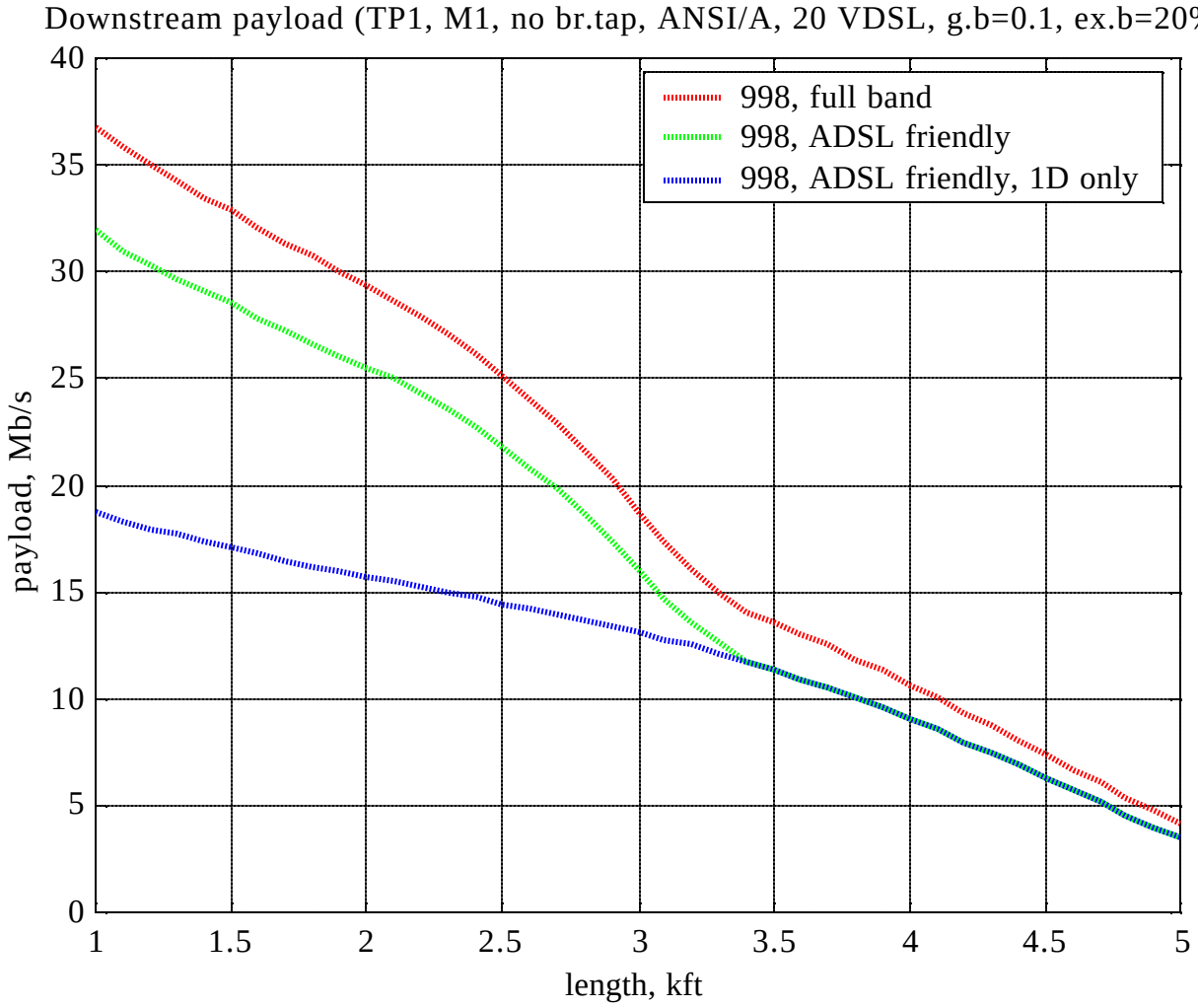
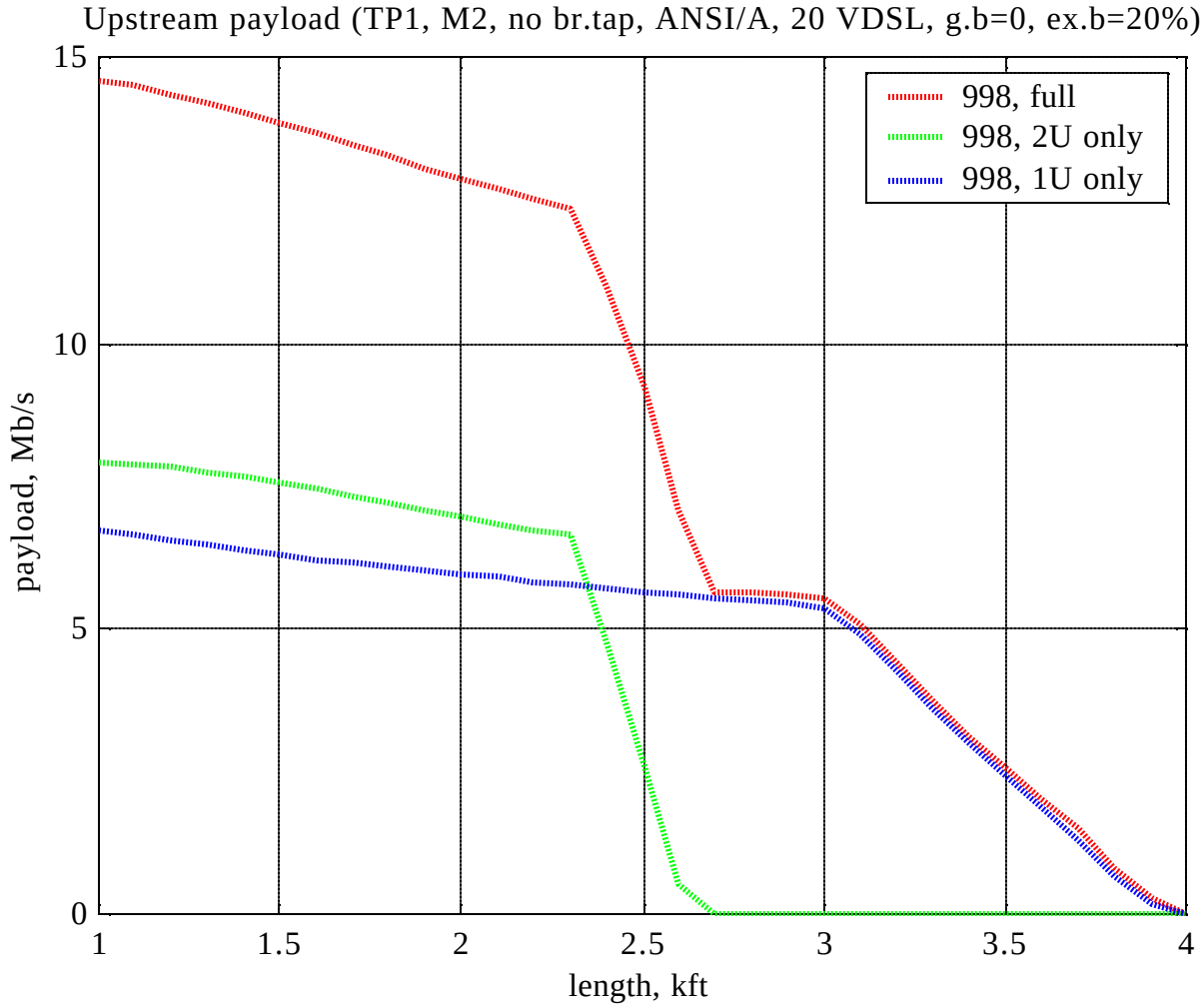
Example: downstream performance



Simulation data:

Plan	998
Loop	TP1 (26 AWG)
Br. Taps	no
PSD mask	M1 (-60 dBm/Hz)
Noise	-140 dBm/Hz ANSI model A 20 VDSL
Guard b.	0.15 MHz
Excess b.	20%

Example: upstream performance



Simulation data:

Plan	998
Loop	TP1 (26 AWG)
Br. Taps	no
PSD mask	M2 (-54 dBm/Hz)
Noise	-140 dBm/Hz ANSI model A 20 VDSL
Guard b.	0 MHz
Excess b.	20%

Notes:

1. Optional band (25-138) not used
2. Guard bands are reserved in DS

Conclusion

- **VDSL is a well developed technology at the last stages of standardization in Europe, North America and internationally**
- **VDSL is spectrally compatible with other xDSL and designed to operate in the presence of all kinds of impairments in copper pairs**
- **VDSL is a flexible technology and may be adopted for different environments and deployment scenarios**
- **The packet transport over VDSL is universal and could be used for any type of packets, particularly for Ethernet.**

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