EFM- Data rate analysis

Ikanos: Behrooz Rezvani

Alcatel: Thierry Pollet, Michael Beck

Globespan: Massimo Sorbara

Contact: behrooz@ikanos.com

Copper Channel Capacity and Applications

- Copper channel capacity = Economics
  - Maximum rate
    - Metro Fiber extension- I.e E-PON, FTTC, etc. for the last 1-2 kft is very expensive
    - Desired full capacity (upstream+downstream)
      - ***100 Mbps*** – Fast Ethernet applications
  - Maximum reach
    - 6+ kft reach covers Majority of businesses within USA and most of loops in Europe/Japan/Int.
    - Desired full capacity (upstream+downstream)
      - ***10+ Mbps*** – Ethernet application
  - Max Frequency of 12 MHz is desirable

Channel Capacity Issues

- Reference Channel noise
- Spectral Compatibility issues
- Cross-talk (FEXT and NEXT)
- Ham Channel
- RFI ingress
- Bridge-Taps
- Advanced error control codes

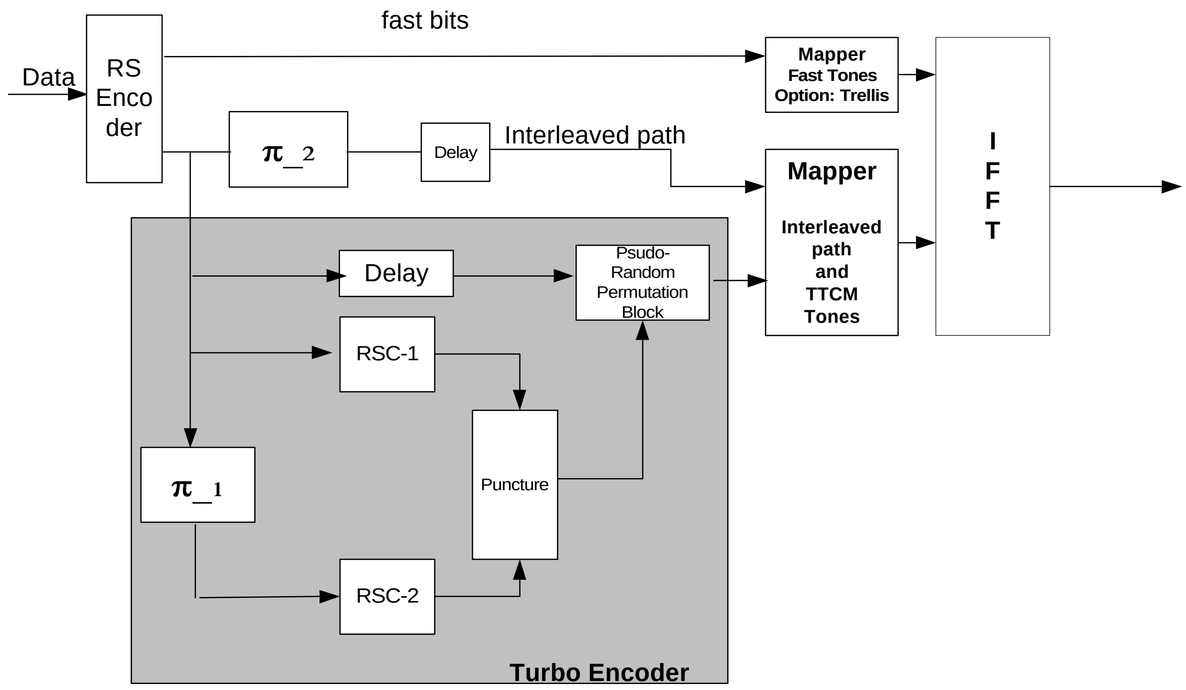
Spectral Compatibility

- Compatibility below 1.1 MHz: T1.417
  - POTS and Voicegrade services, EBS, DDS
  - ISDN
  - HDSL, HDSL2, SHDSL
  - ADSL
  - 2B1Q SDSL
- Compatibility beyond 1.1 MHz
  - Different frequency plans have been approved by standards bodies: 998, 997.

Reed Solomon coding and other advanced coding architectures

- RS codes have about 3 dB coding gain
- Concatenated RS+Trellis codes results to about 5.5 dB coding gain.
  - This method had been used extensively in ADSL modems. The encoder is very simple and it is a 4D Wei code.
- Turbo code potentially has a high coding gain (7 dB). Advanced coding schemes (Turbo, LDPC) have been discussed very actively at ITU-T
  - Turbo code has been used in wireless/OFDM applications

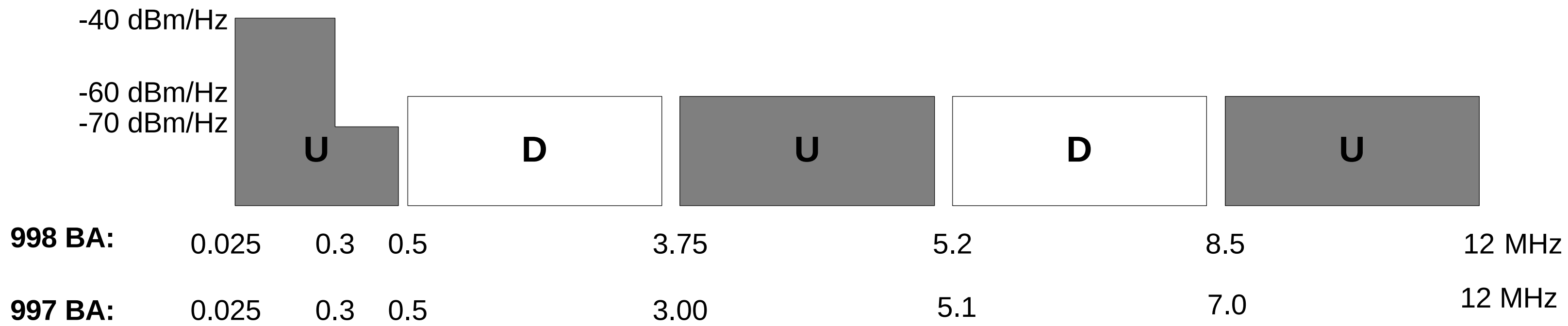
A potential programmable Turbo Trellis Architecture



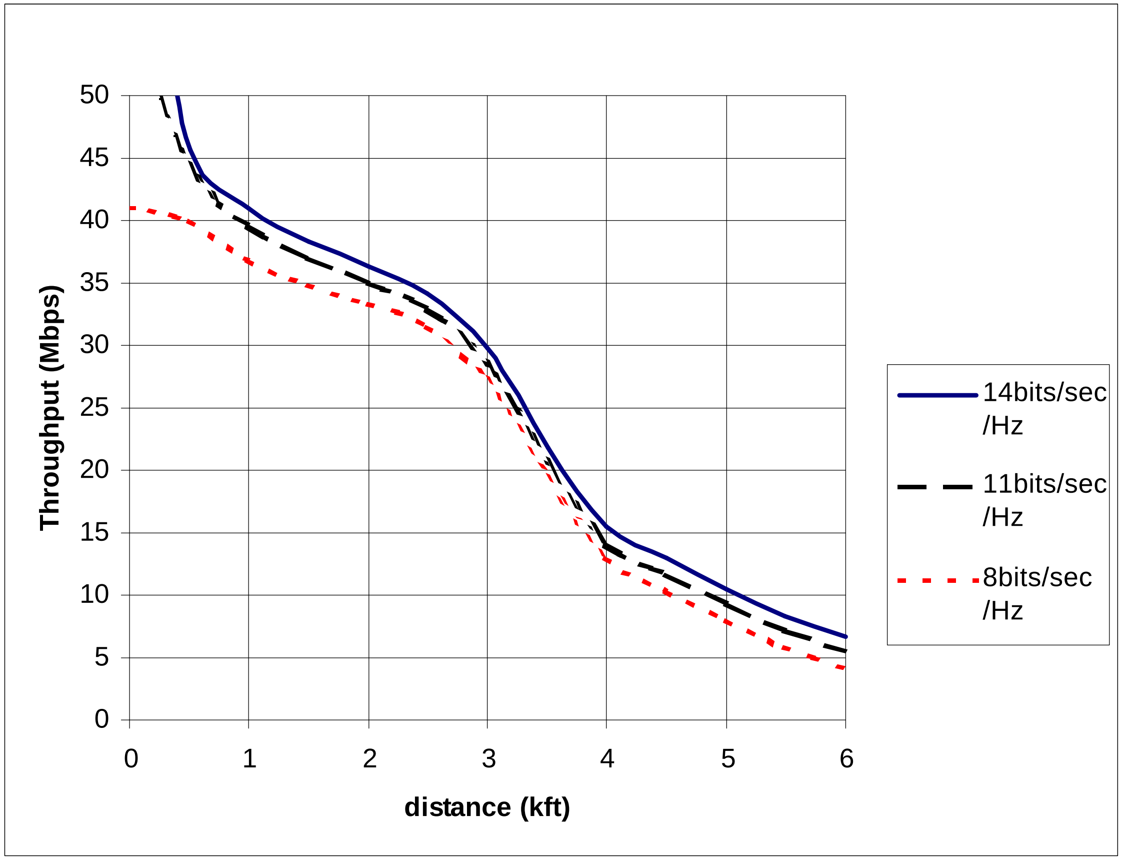
Proposed EFM System

- Utilizing most of the existing VDSL standards
  - Well understood
  - Faster Time to Market
- Programmable Frequency Plan, Spectrally compliant with:
  - In public network, all existing systems including VDSL 998/997
  - In MxU applications, with services below 1.1 MHz

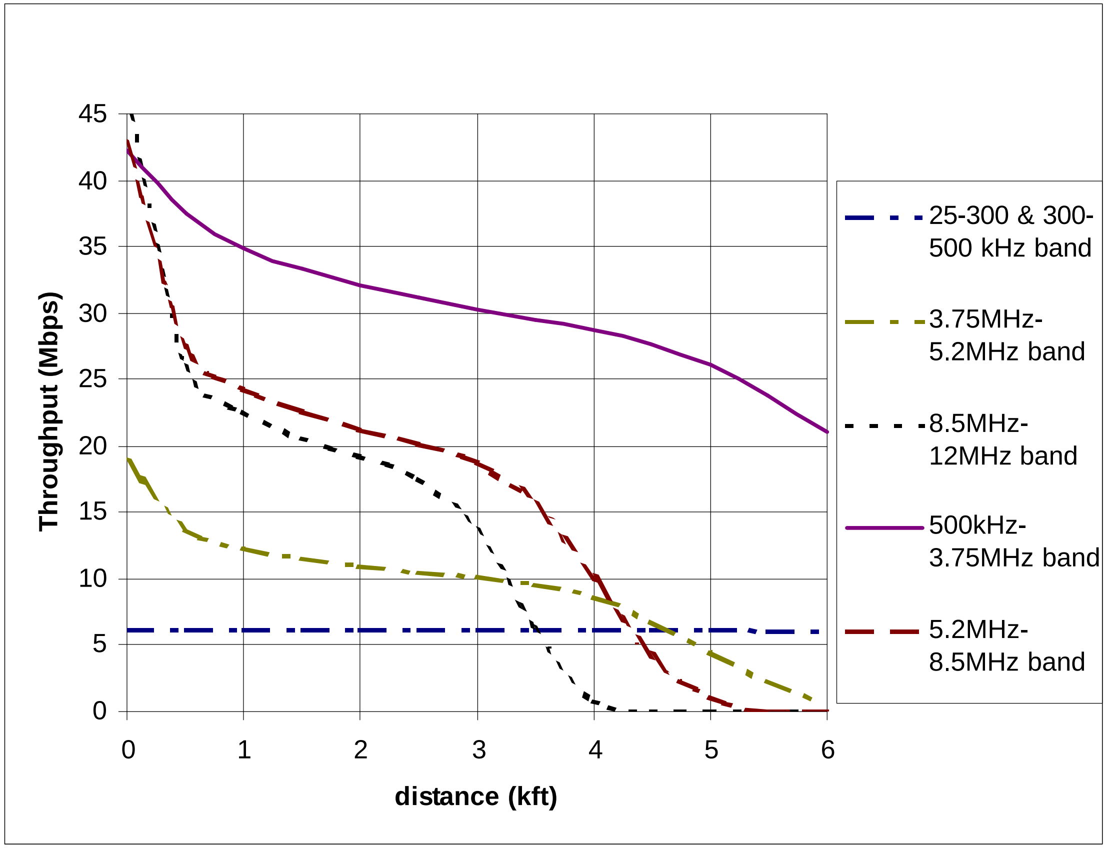
Potential Spectrally Friendly Programmable PSD



Symmetric rate vs. distance with 14, 11,and 8 bits/sec/Hz maximum, 7dB coding gain

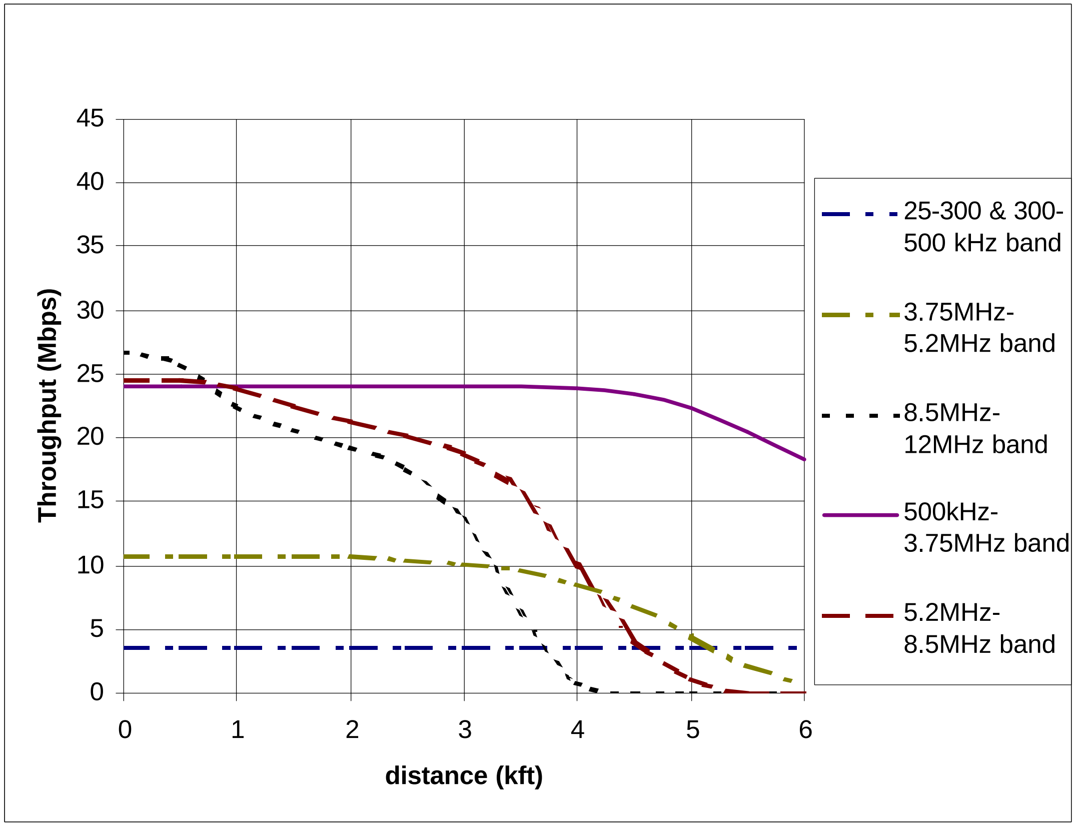


Rate vs distance for separate bands Maximum of 14 bits/sec/Hz



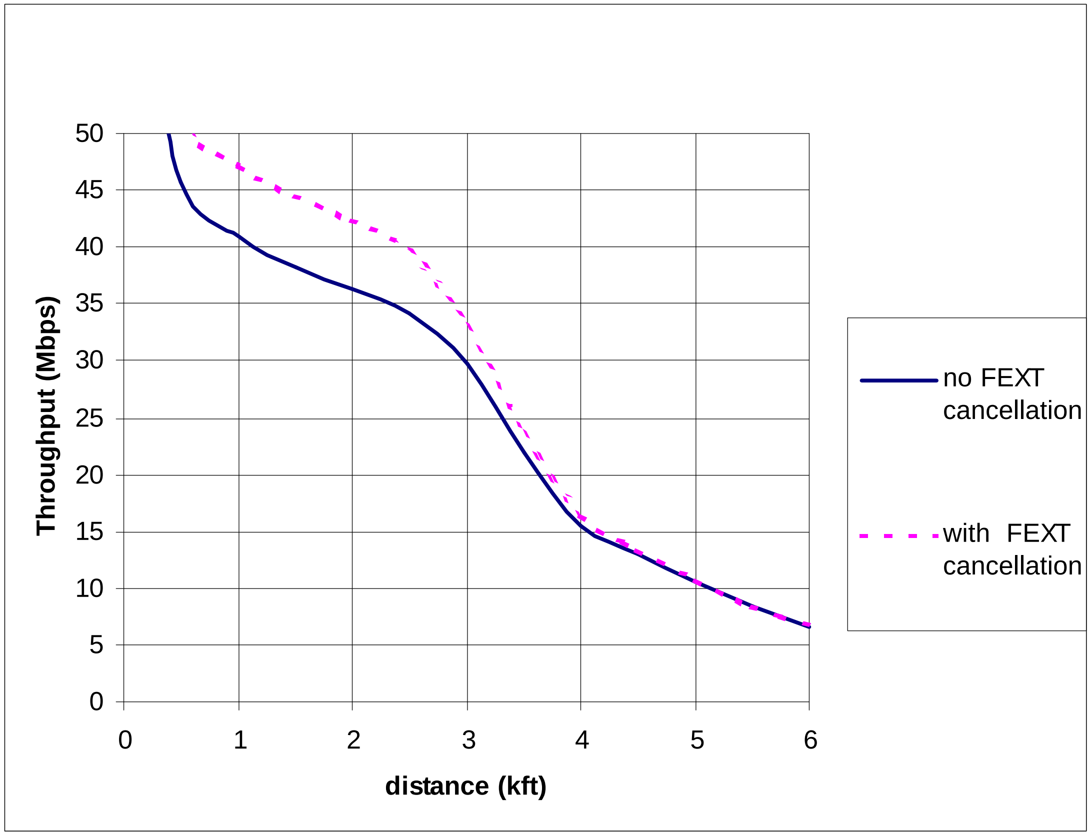
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 7 dB coding gain
- Maximum of 14 bits/sec/Hz

Rate vs distance for separate bands Maximum of 8 bits/sec/Hz



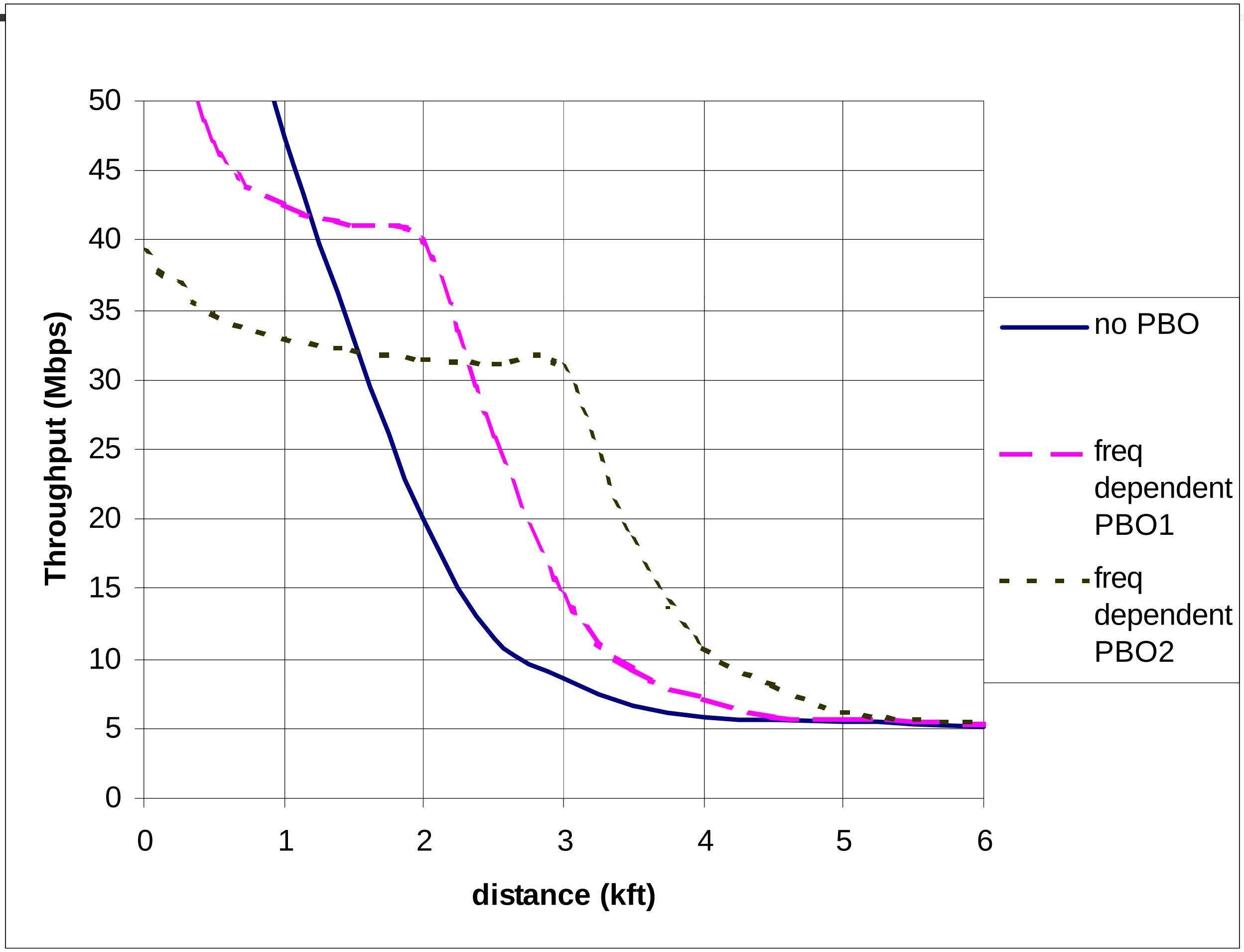
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 7 dB coding gain
- Maximum of 8 bits/sec/Hz

Symmetric rate vs distance for cancellation 4dB of FEXT cancellation



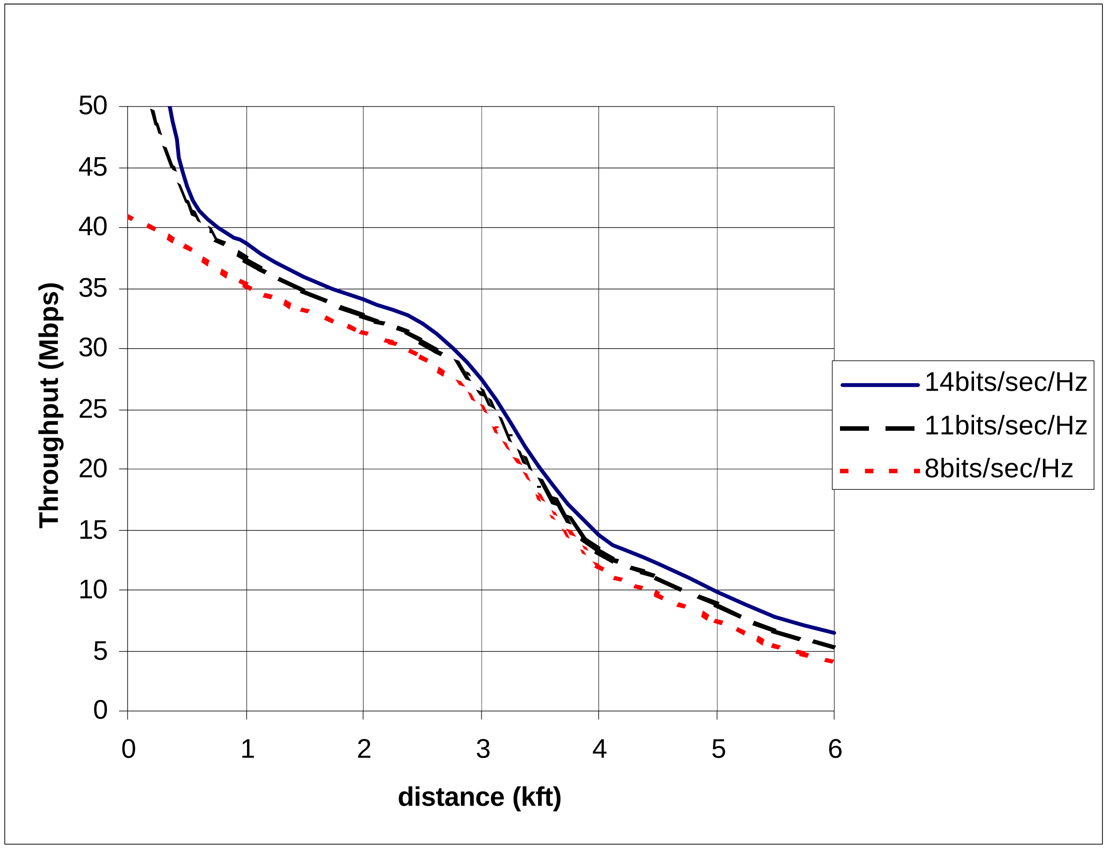
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 7 dB coding gain
- Maximum of 14 bits/sec/Hz

Upstream rate for 2 different methods of UPBO



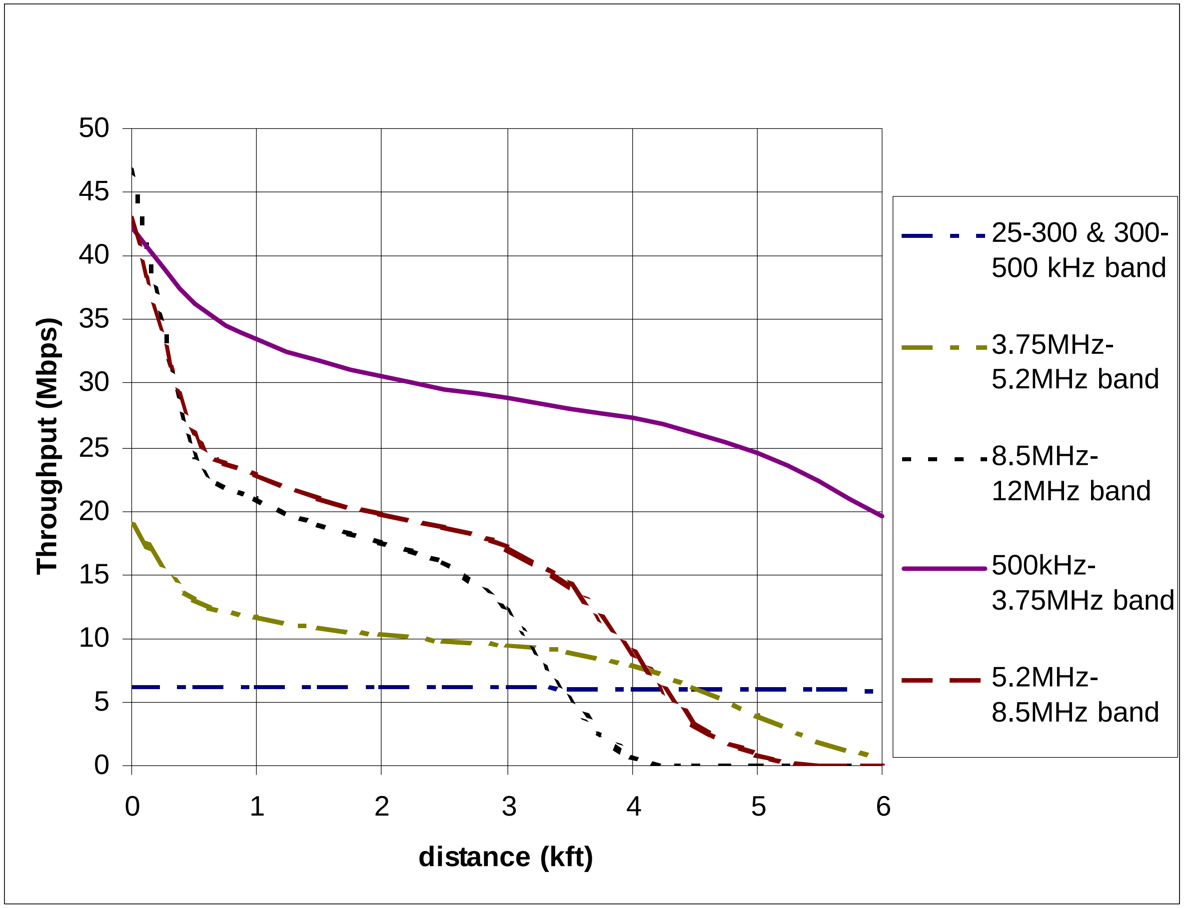
- -140 dBm/Hz AWGN
- Uniformly distributed FEXT disturbers
- 7 dB coding gain
- Maximum of 14 bits/sec/Hz

Symmetric rate vs. distance for various maximum bits/sec/Hz



- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 5.5 dB coding gain
- Maximum of 14 bits/sec/Hz

Rate vs distance for different bands



- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
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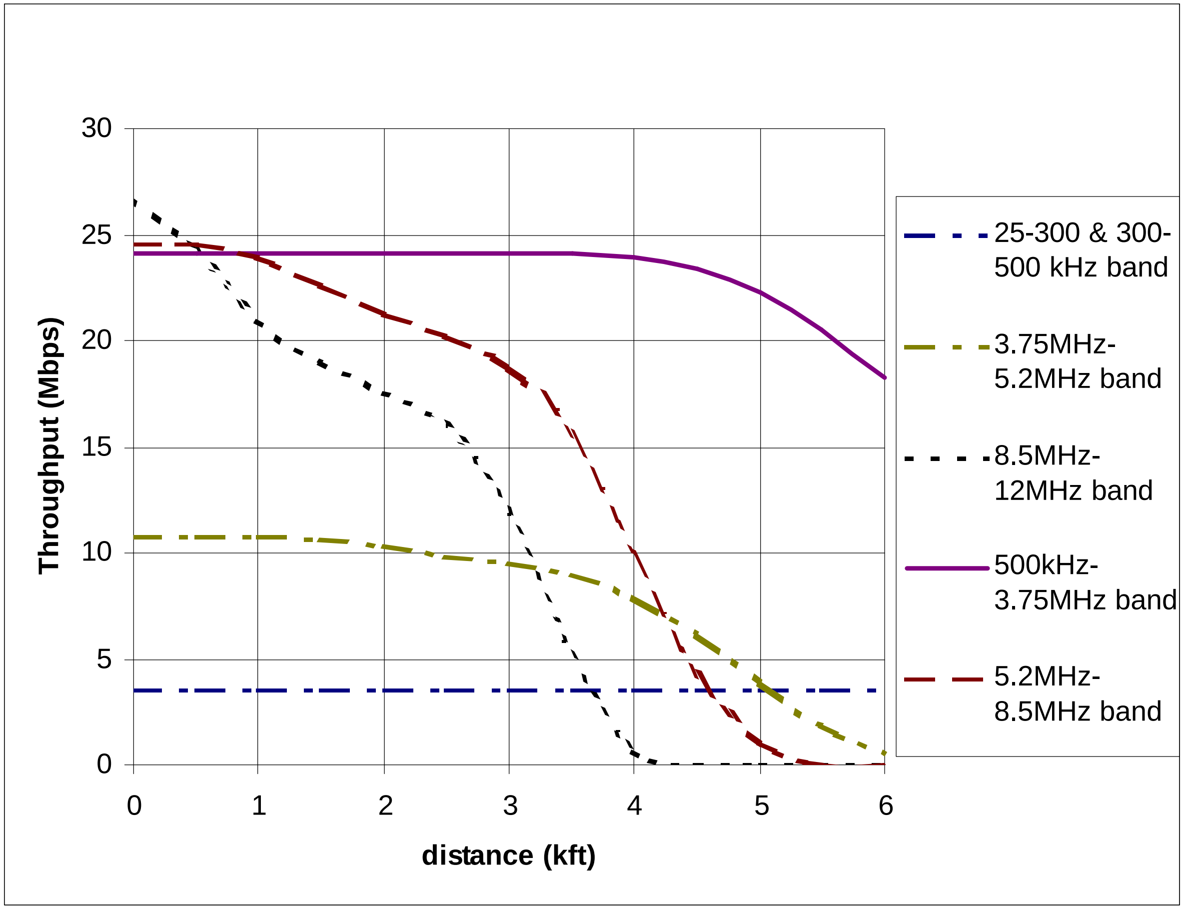
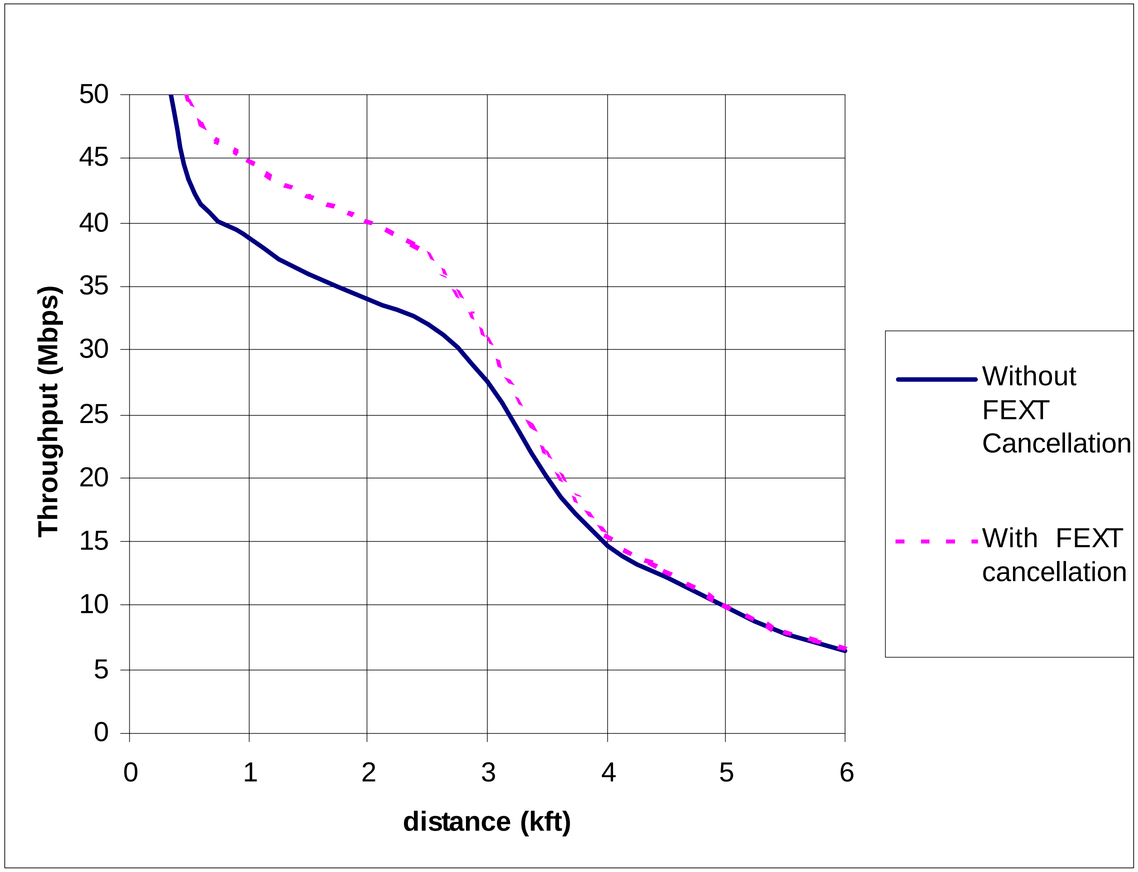
Rate vs distance for different bands



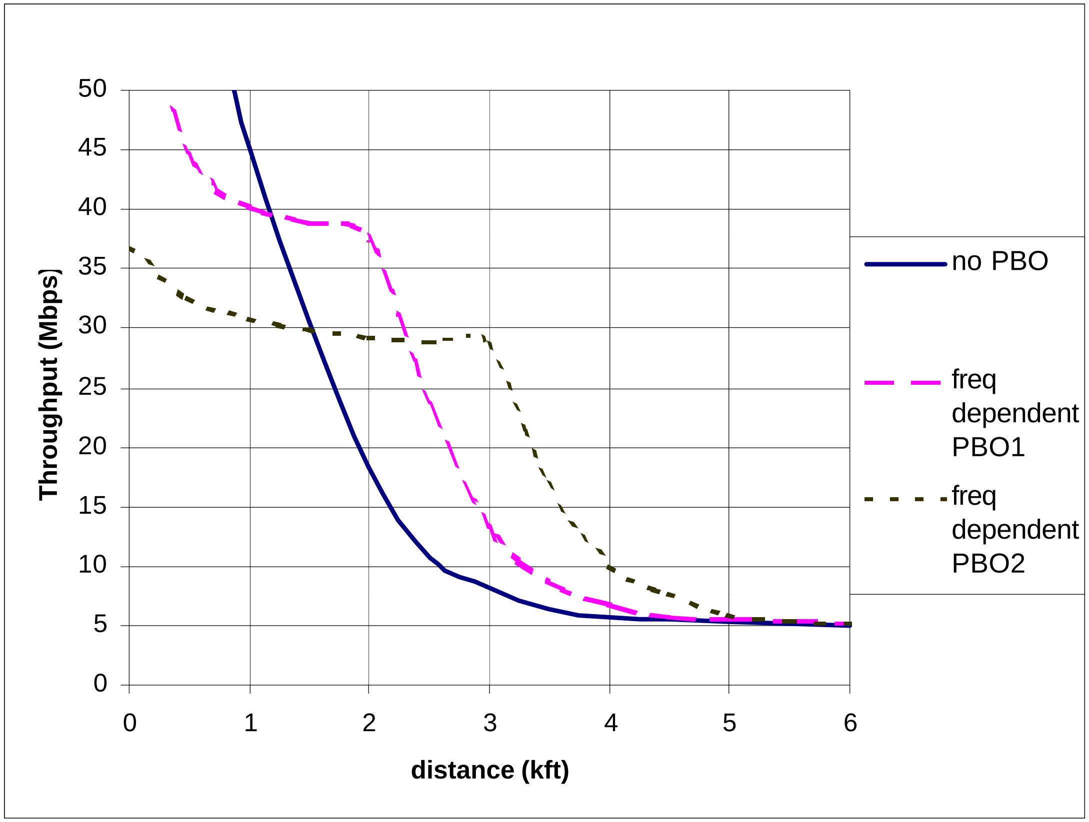
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 5.5 dB coding gain
- Maximum of 8 bits/sec/Hz

Symmetric rate with 4dB of FEXT cancellation



- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 7 dB coding gain
- Maximum of 14 bits/sec/Hz

Upstream rate utilizing 2 different methods of UPBO



- -140 dBm/Hz AWGN
- Uniformly distributed FEXT disturbers
- 5.5 dB coding gain
- Maximum of 14 bits/sec/Hz

Non-stationary noise and Network capacity, FDD Vs TDD

- TDD must Synchronize the frames across all systems in a cable
- TDD is more vulnerable to the effects of a single line losing sync
- TDD has more latency (delay for buffering data until next ping-pong cycle)
- TDD signal is cyclo-stationary
- TDD is less flexible for Symmetric vs Asymmetric services co-existence.

Power Back-Off (PBO)

- UPBO is employed to provide spectral compatibility between loops of different lengths deployed in the same binder
- Equations used in PBO are as follows:

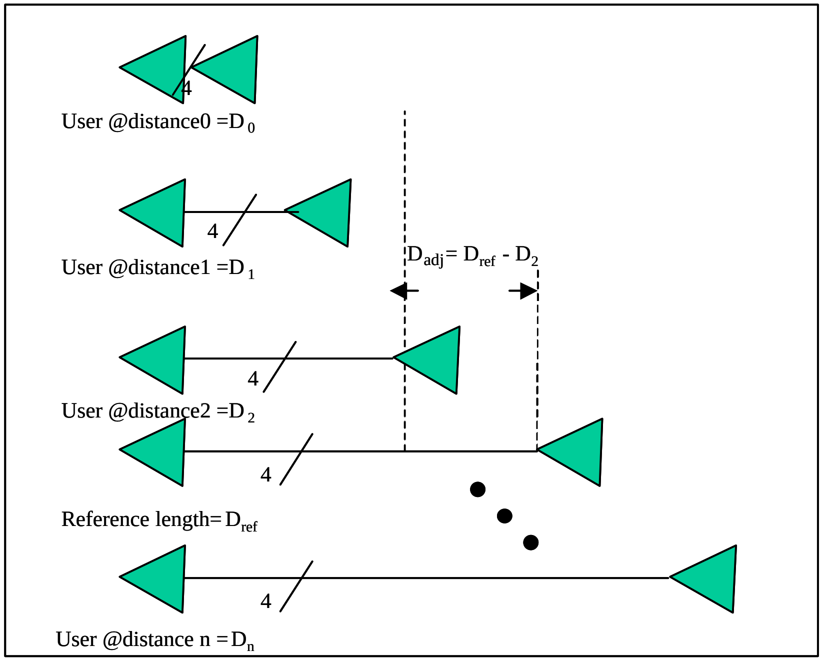
$$PSD_{FEXT_N} = PSD_{D_N} * IL(f, D_N) * D_{coup} * k * f^2$$

Where,
D_N is the disturbers distance and N= 0, 1, …, n
k: FEXT constant as defined in the standards
f: frequency in Hz.

And

$$PSD_{D_N} = \begin{cases} PSD_{\max} * IL(f, D_{adj})^2, & D_N < D_{ref} \\ PSD_{\max}, & otherwise \end{cases}$$

$$D_{coup} = \begin{cases} D_{UOI}, & D_N \geq D_{UOI} \\ D_N, & otherwise \end{cases}$$



Where,
PSD_{max} is given as –60 dBm/Hz for DataXpress applications.
D_{adj} is $D_{ref} – D_N$. Note that D_N could refer to a user or a disturber
D_{coup} is the effective coupling path between the UOI and the disturber who is causing the FEXT.
D_{UOI} is the user of interest distance.

COST: One Line card, all PSD band options.

- One linecard supports all frequency plans
  - Simple or no discrete front-end filtering
  - Programmable Frequency or Time domain multiplexing
    - FDD – allocate bandwidth to upstream and downstream by use of provisioning software for each application

Recommended Specification based on current state of technology

- Long Reach and High performance EFM with maximum data-rate of 100 Mbps total
  - Maximum reach of 6 kft and minimum data rate of 15+ Mbits total
  - Maximum bandwidth of 12 MHz with option to support up to 14 bits/sec/Hz capacity
- Flexible spectral shaping with variable bandwidth for downstream and upstream band allocation
  - Utilizing most of the existing VDSL standards
  - Well understood
  - Faster Time to Market
  - Programmable Frequency Plan, Spectrally compliant with:
    - In public network, all existing systems including VDSL 998/997
    - In MxU applications, with services below 1.1 MHz
- Low complexity discrete front-end
  - Will reduce cost
  - Allows flexible spectral shaping
- Turbo and or trellis coding in conjunction with RS coding
- Frequency dependant PBO for maximum bundle capacity is preferred