

EFM- Data rate analysis

Part I: upper-bound channel capacity

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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
 - Using the Spectrum up to 12 MHz



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

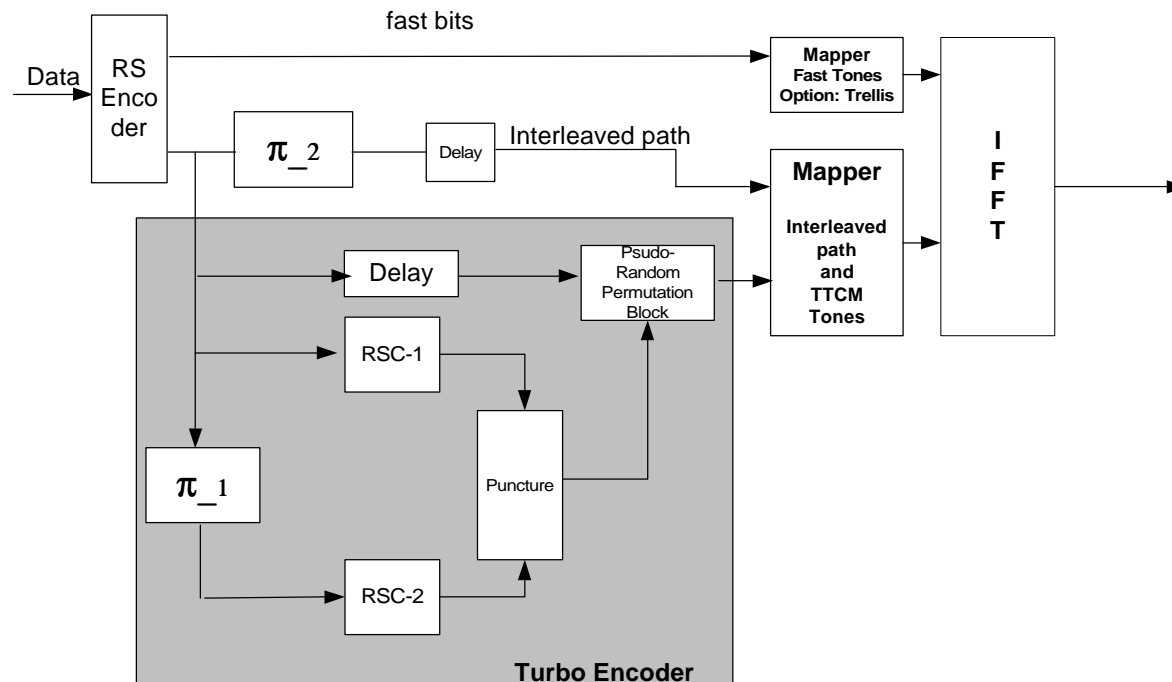
- Compatibility below 1.1 MHz: T1.417
 - POTS and Voicegrade services, EBS, DDS
 - ISDN
 - HDSL, HDSL2, SHDSL
 - ADSL
 - 2B1Q SDSL
- Compatibility beyond 1.1 MHz
 - Different frequency plans have been approved by standards bodies: 998, 997.



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

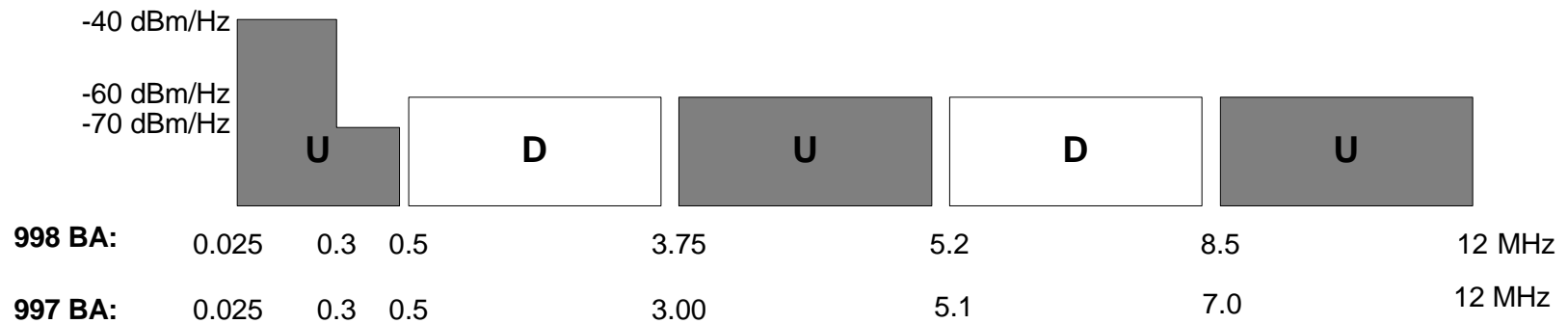




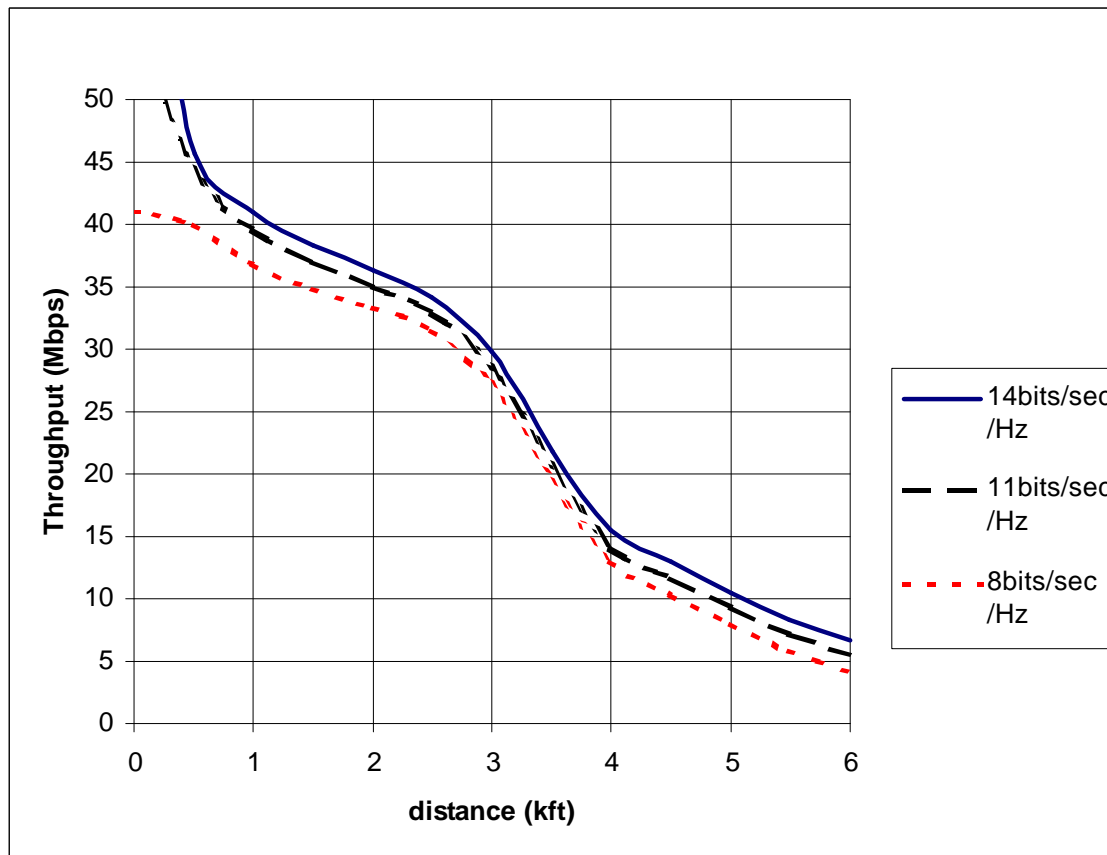
Proposed EFM System

- 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



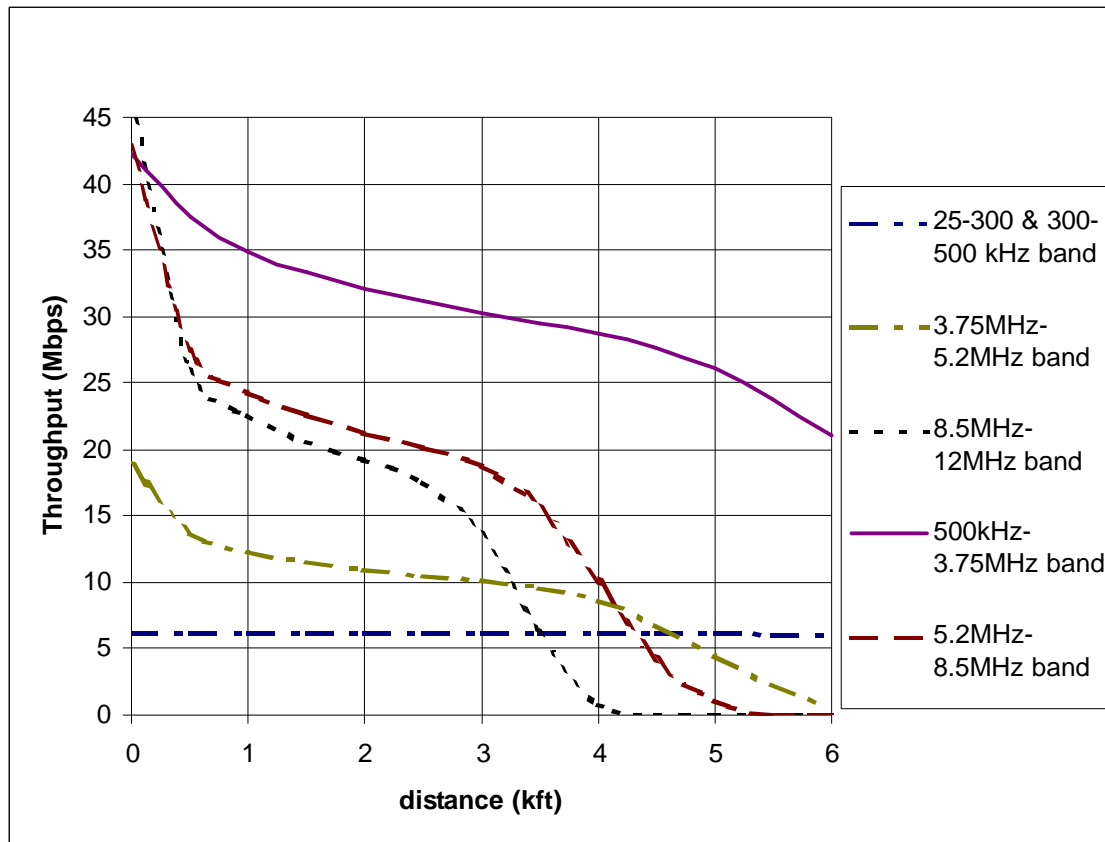
Symmetric rate vs. distance with 14, 11, and 8 bits/sec/Hz maximum



- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 7 dB coding gain
- 24 awg

Rate vs distance for separate bands

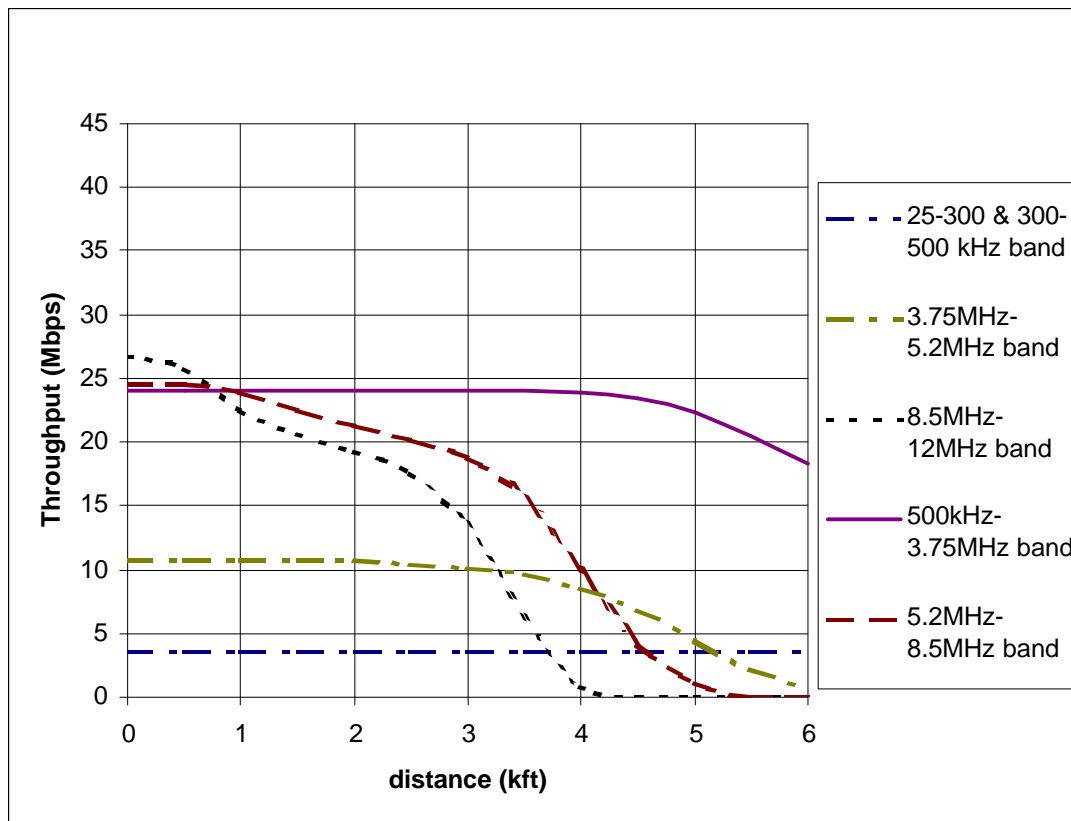
Maximum of 14 bits/sec/Hz



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

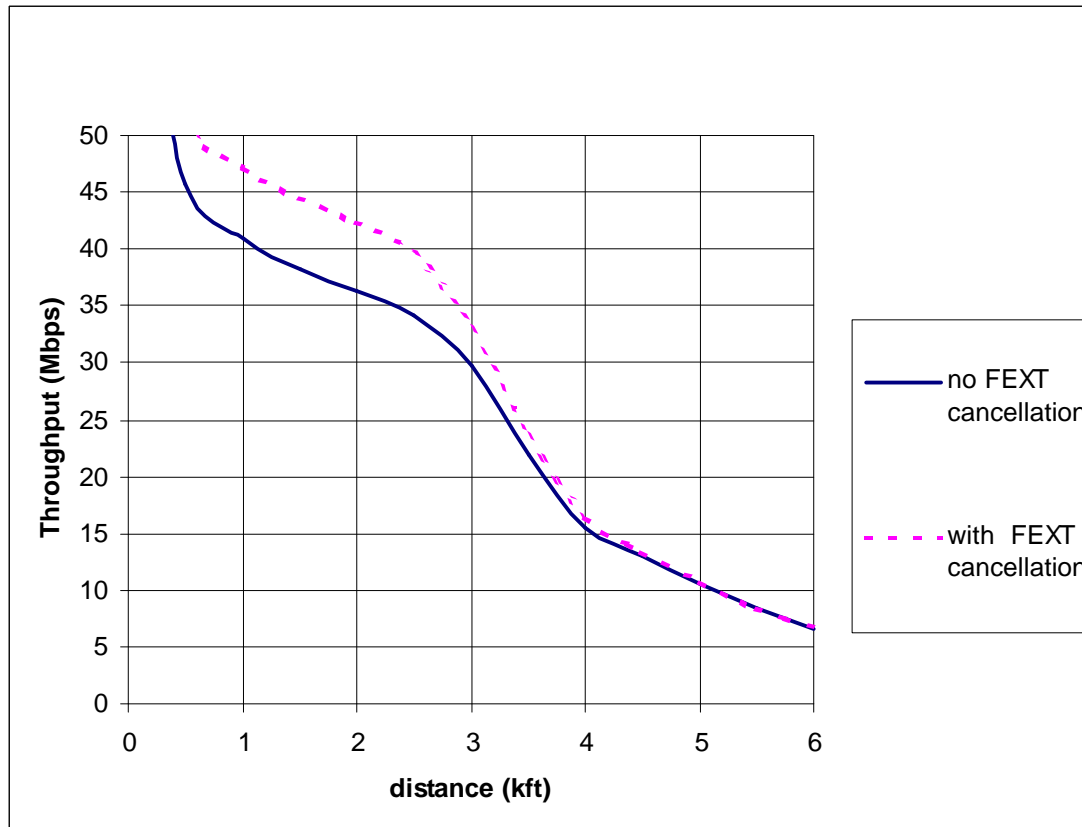
Rate vs distance for separate bands

Maximum of 8 bits/sec/Hz



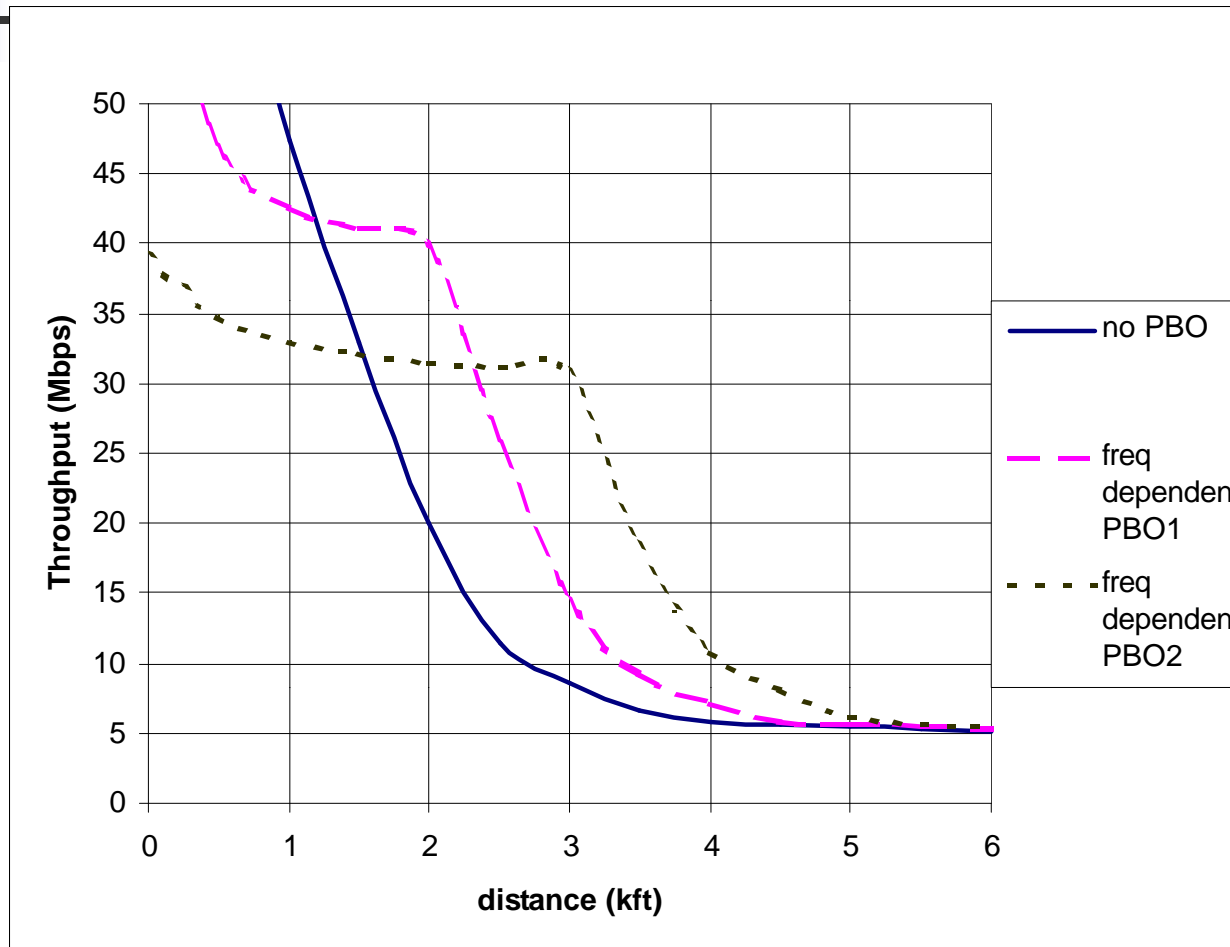
- -140 dBm/Hz
AWGN
- 20 equivalent
length self FEXT
- 7 dB coding
gain
- Maximum of 8
bits/sec/Hz
- 24 awg

Symmetric rate vs distance for cancellation 4dB of FEXT cancellation



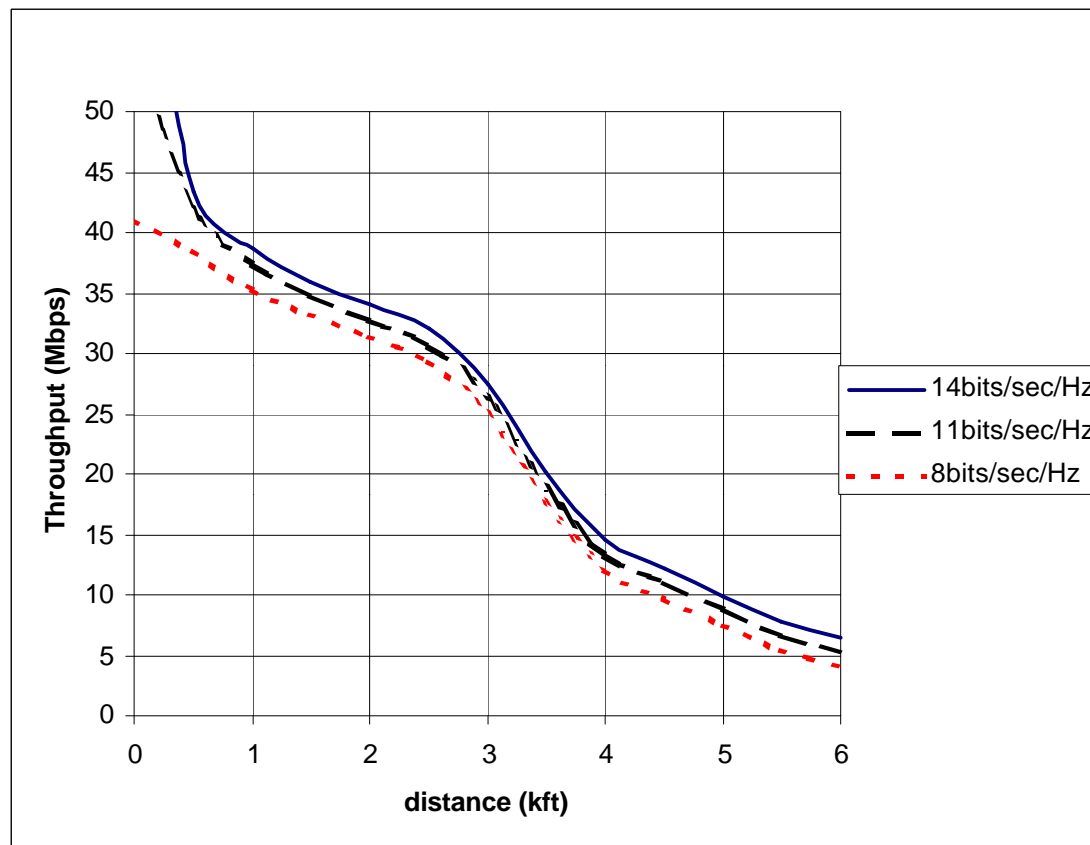
- -140 dBm/Hz
AWGN
- 20 equivalent
length self FEXT
- 7 dB coding
gain
- Maximum of 14
bits/sec/Hz
- 24 awg

Upstream rate for 2 different methods of UPBO



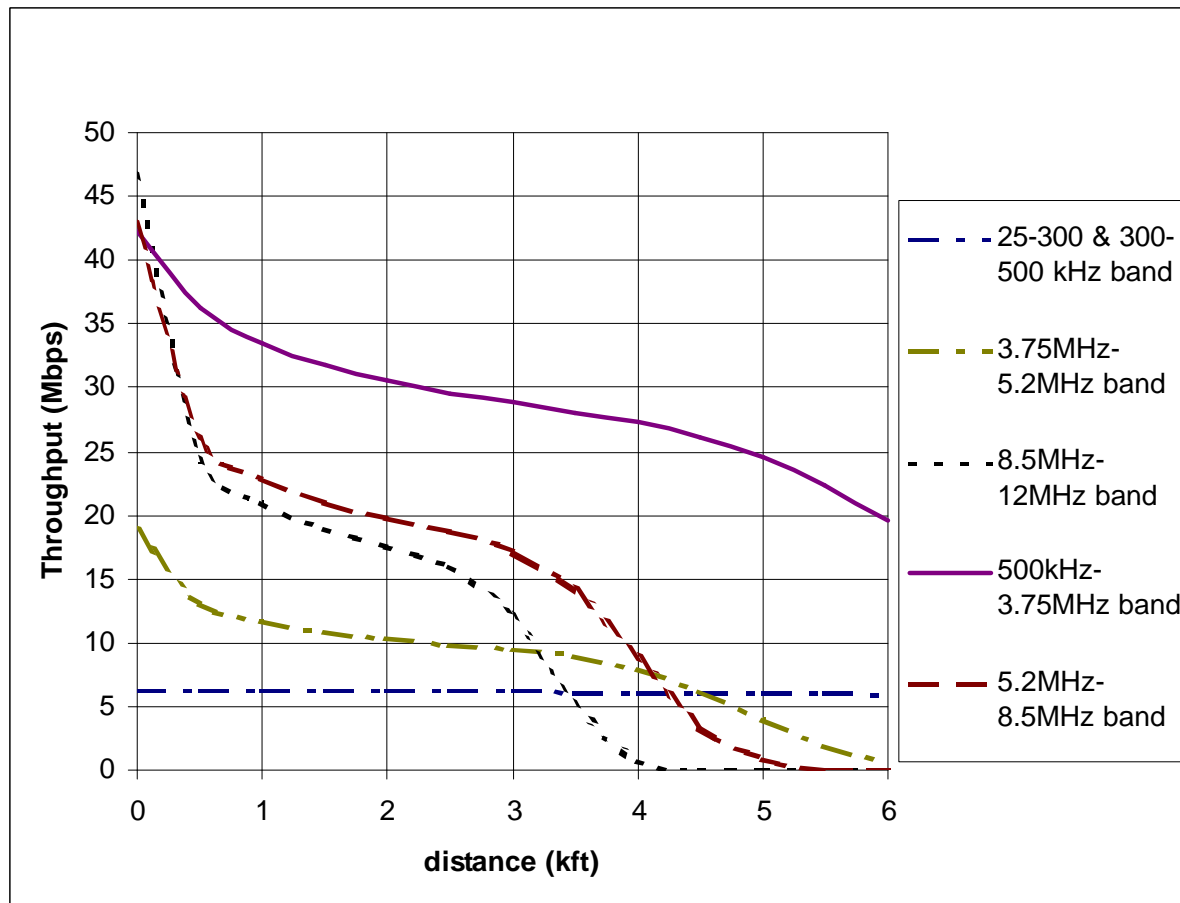
- -140 dBm/Hz AWGN
- Uniformly distributed FEXT disturbers
- 7 dB coding gain
- Maximum of 14 bits/sec/Hz
- 24 awg

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



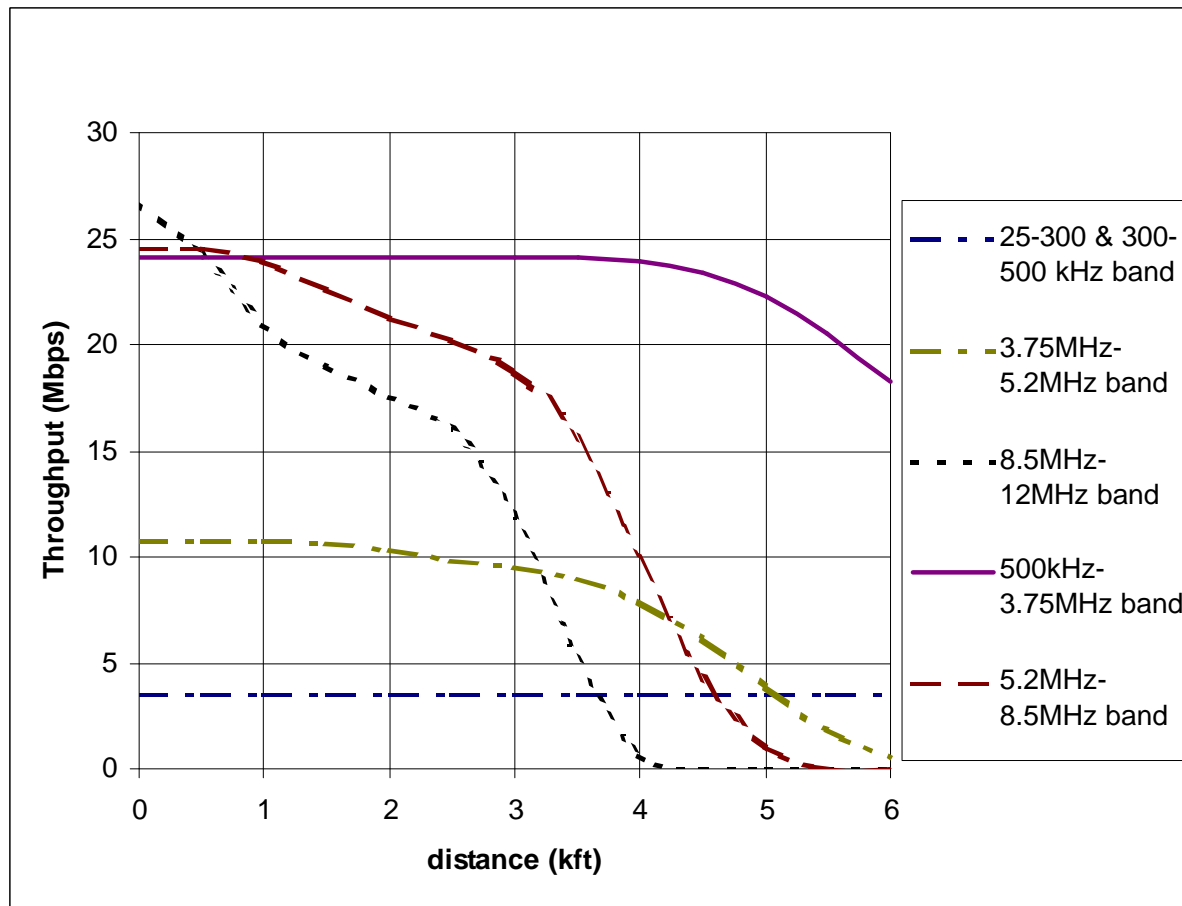
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 5.5 dB coding gain
- 24 awg

Rate vs distance for different bands



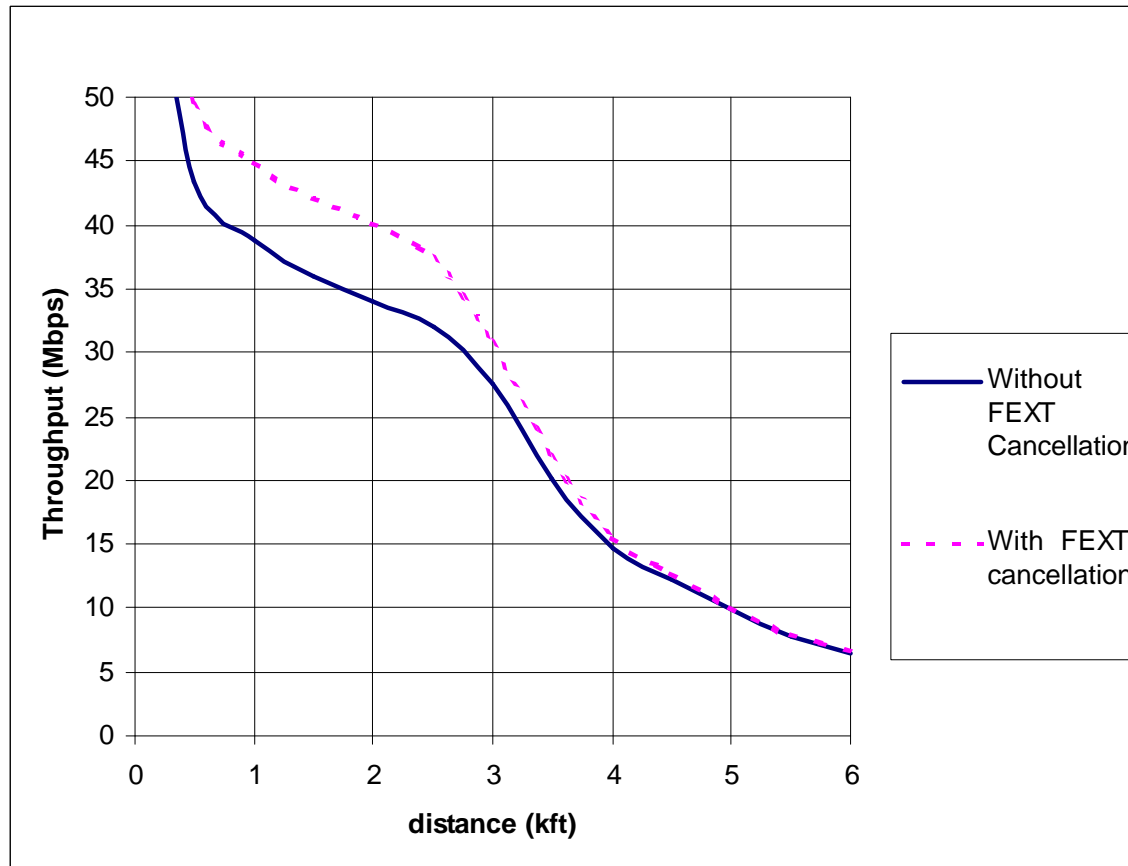
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 5.5 dB coding gain
- Maximum of 14 bits/sec/Hz
- 24 awg

Rate vs distance for different bands



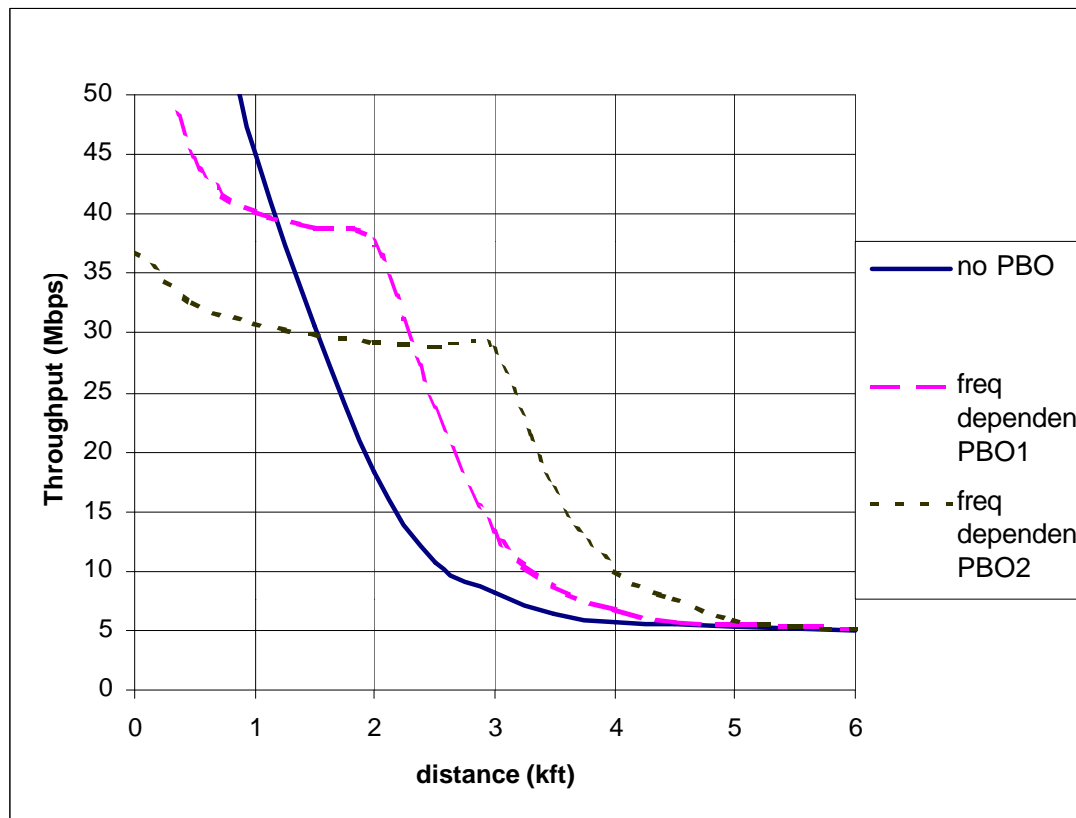
- -140 dBm/Hz AWGN
- 20 equivalent length self FEXT
- 5.5 dB coding gain
- Maximum of 8 bits/sec/Hz
- 24 awg

Symmetric rate with 4dB of FEXT cancellation



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

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
- 24 awg



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 $N \in \{1, \dots, n\}$

k: FEXT constant

f: frequency in Hz.

And

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

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

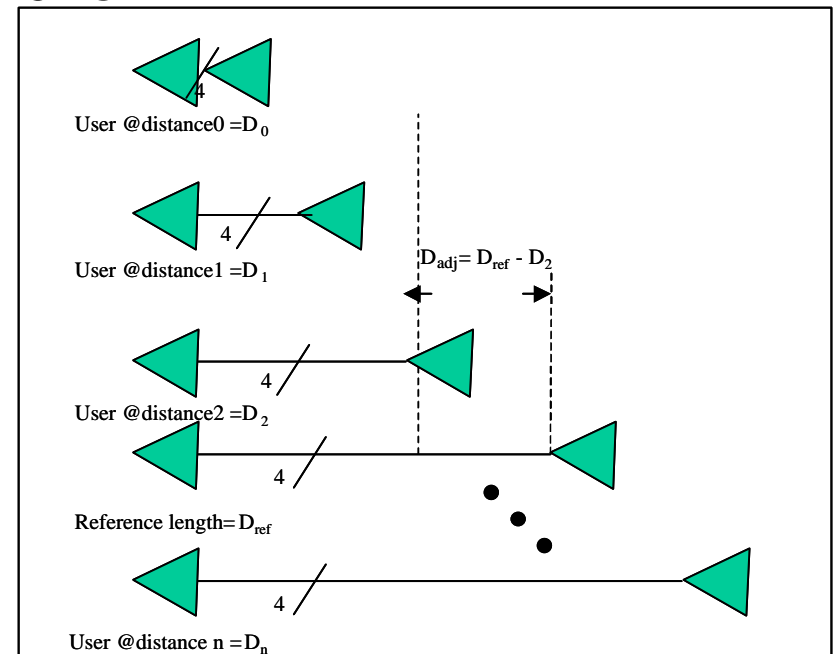
Where,

PSD_{max} is given as -60 dBm/Hz

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 10+ 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