A New Penalty Based Algorithm For Multi-User Spectrum Balacing in xDSL Networks

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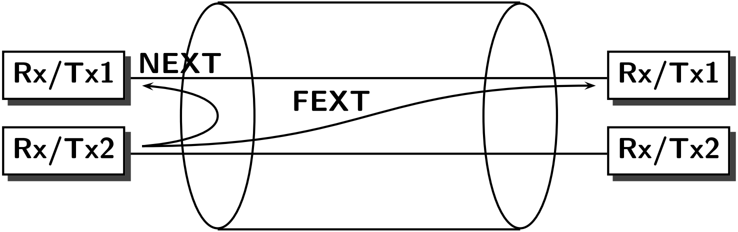
Transmission Impairments in xDSL

- Telephone loop plant only designed to carry voice at bandwidth 4kHz
- At higher frequencies (i.e. xDSL) strong noise and attenuation
  - Near End Crosstalk
  - Far End Crosstalk
  - Narrow-band Interference (e.g. A.M. radio)
  - Impulse Noise

NEXT and FEXT

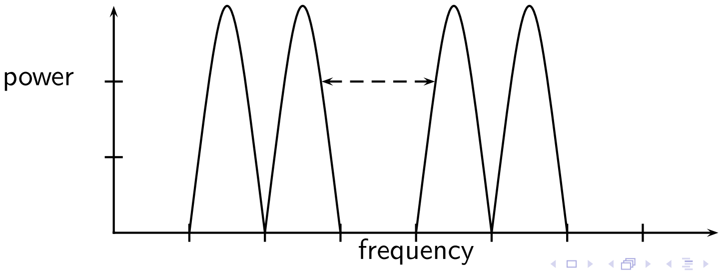
- Bundles typically consist of 50-100 lines
- NEXT and FEXT vary with line length and frequency



- Crosstalk is the dominant noise source in xDSL

Discrete Multi-Tone Modulation

- Frequency Spectrum is split into discrete bands
  - ADSL freq. band: 25kHz-1.1MHz
  - 255 4.3125kHz channels
  - VDSL2: Up to 30MHz
- Each band is an independently modulated QAM channel
- Transmit spectra adjusts to channel characteristics



Discrete Multi-Tone Modulation

- DMT Frames have a variable number of bits depending on data rate
- Sub-carriers within DMT frames are assigned a number of bits and transmit power depending on the CNR (channel-noise ratio)
  - Allows better use of channel than single-carrier QAM
- This process of assinging power to DMT channels is known as **Bit or Power-Loading**

Bit Loading

- Objective to maximise bit rate for a given power budget

$$\text{Rate} = \sum_{k=1}^{K} b_n(k)$$

- Subject to power constraints on each line

$$\sum_{k=1}^{K} p_n(k) \leq P_{budget}$$

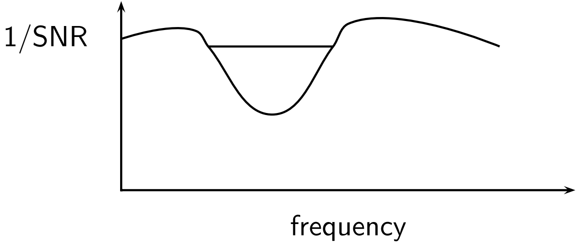
- The number of achievable bits on a particular line/tone

$$b_n(k) = \log_2 \left(1 + \frac{SNR_n(k)}{\Gamma} \right)$$

- Γ is the "SNR-gap" or "Shannon-gap" related to target symbol error and line coding

Single-User Bit Loading

- Optimal bit loading for a single user is known as a "waterfilling" solution



- Discrete version of waterfilling is known as the Levin-Campello Algorithm
- This is only optimal from the perspective of a single user

Multi-User Bit Loading

- Known as "Dynamic Spectrum Management"
- Large performance gains over current methods

$$b_n(k) = \log_2\left(1 + \frac{p_n(k)|h_{nn}(k)|^2}{\Gamma\left(\sigma_n^2(k) + \sum_{m \neq n}^{N} p_m(k)|h_{jm}(k)|^2\right)}\right)$$

- The objective is now non-convex in p and exhaustive search is prohibitively expensive
- Many algorithms exist with varying performance and complexity
  - Iterative Waterfilling, Multiuser Greedy
  - Optimal Spectrum Balancing (OSB), ISB, SCALE
  - ASB, Band preference, SBLC

Multi-User Greedy Bit Loading

- Originated from Stanford
  - John Cioffi's group
- Conceptually simple algorithm
- Calculate cost to add a bit on each line/tone
  - Total power required to add a bit to tone in question
  - Includes extra power required by increased crosstalk
  - Choose the bit with the minimum cost until power constraints are met
- Problems:
  - Does not consider fairness
  - Favours shorter lines
  - Very suboptimal performance which strong assymetric crosstalk
- Advantages
  - Significantly lower complexity than many other methods

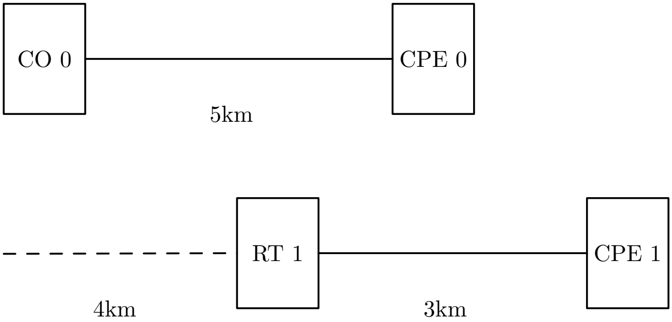
Improved Multi-User Greedy Loading

- Revised cost function
- Two new heuristic metrics
- Crosstalk Penalty Term
  - Indication of crosstalk incurred by loading a bit
  - Based on how many bits were potentially lost on other lines
- Relative Usefullness Adjustment
  - Indication of how useful a tone is to a particular line

$$\gamma_n(k) = \frac{b_n(k)^{ref}}{\bar{b}_n}$$

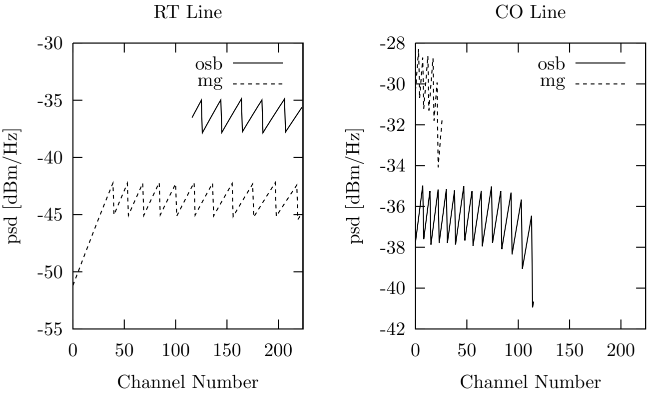
- Cost Matrix Re-intialisation
  - Re-intialise costs when a line has met rate target or used all power
  - Purpose is to not unneccesarily penalise other lines

Scenario 1



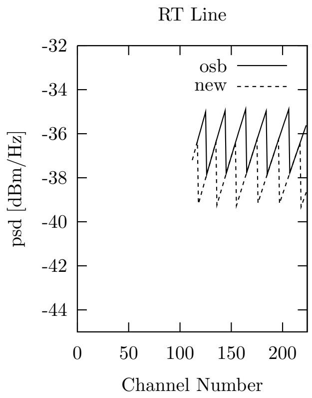
- One modem located is located in the Central Office, another in a Remote Terminal
- This configuration exhibits the near-far effect
- Highly assymentric crosstalk

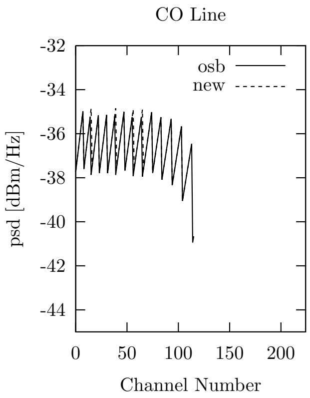
Optimal Spectrum Balancing vs Multi-User Greedy



	OSB	Multi-User Greedy
CO Line	3.496Mbps	1.084Mbps
RT Line	4Mbps	4Mbps

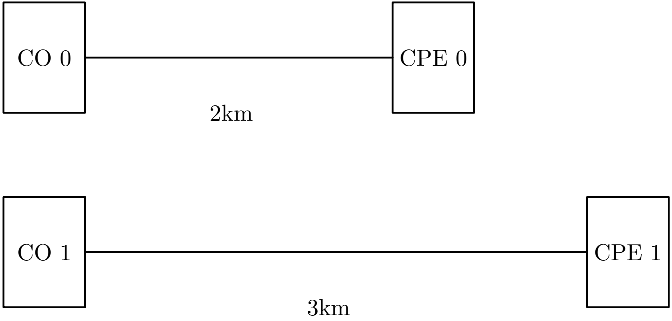
Scenario 1 Results





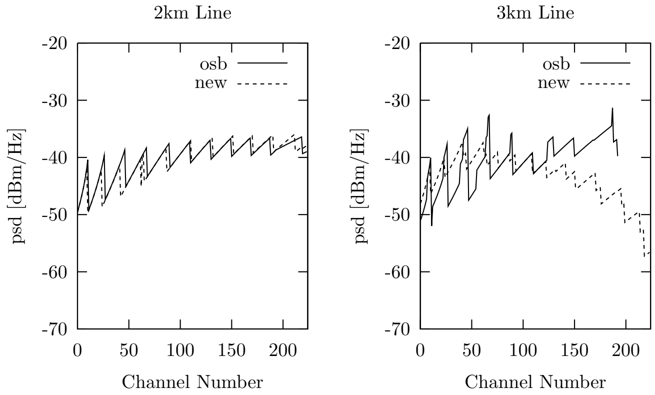
	OSB	Improved Multi-User Greedy
CO Line	3.496Mbps	3.48Mbps
RT Line	4Mbps	4Mbps

Scenario 2



- Two CO located modems

Scenario 2 Results



	OSB	Improved Multi-User Greedy
2km Line	7.672Mbps	7.632Mbps
3km Line	8.8Mbps	8.8Mbps

Conclusions

- A new algorithm for spectrum managment based on a greedy algorithm with new heuristic adjustments
- The new algorithm achieves excellent performance for the two scenarios tested
  - Further research has shown that ther performance is also good for larger bundles (8-10 lines)
- Computational complexity is very low, making it tractable for spectrum balancing in large bundles