Local Loop Spectrum Management

Report prepared for

The Commerce Commission of New Zealand

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Preface

Layer 10 has prepared this report for the Commerce Commission to assist it in evaluating a Spectrum Management Plan for the copper local loop network in New Zealand.

This report and the observations it contains were commissioned by and are intended solely for the Commerce Commission.

In preparing this report, Layer 10 has relied on information supplied to us by the Commerce Commission, and information available from publicly accessible sources. Unless otherwise indicated, we make no comment on material that is not explicitly referenced, and offer no warranty, express or implied, as to any information that is contained in this report.

This report is subject to the limitations, assumptions and qualifications referred to in the body of this report.

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Revision Log

Issue Number	Date	Affected Sections	Reason for Change
0525	25 May 2006	All	Initial Draft
0531	31 May 2006	All	First draft to client
0620	20 June 2006	All	Second draft to client
Final	29 June 2006	Exec Summary	Comments from client

Executive Summary

Background

Telecom New Zealand have referred to a form of spectrum management throughout regulatory matters during 2005 and 2006 that they name “bit-rate limiting”, and have proceeded to formalise the principle within a draft industry Spectrum Management Plan known as “bit-rate limiting PLUS”. By limiting ADSL services to a data-rate of no more than 3.5 Mbps, instead of the maximum rate of the technology of up to 7.5 to 8 Mbps, they believe other adjacent services will benefit from increased reach or increased performance. Much of the rest of the industry is looking to access wholesale DSL services without any such performance constraint. Telecom has repeatedly asserted that a spectrum management regime must be in place before significant numbers of unconstrained services are deployed.

Methodology

I have reviewed the submissions provided to the Commerce Commission during the Unbundled Bitstream determination proceedings with TelstraClear in 2005 and for ihug and CallPlus in 2006, where they contain material relevant to the topic of “DSL Spectrum Management” and related topics of cross-talk interference between adjacent services. I have also reviewed the 17 – 19 May High Speed Internet Service Customer Briefing , and attended briefings with Commission staff and Telecom New Zealand staff to go through the material presented and underlying assumptions, and obtain clarification to questions. I have also undertaken extensive modelling of various scenarios to determine the likely effect of these measures in reducing cross-talk interference, and conducted a literature search for recent publications relating to the future of Dynamic Spectrum Management.

Conclusions

Telecom New Zealand is developing a spectrum management regime ‘from scratch’, and appears to date to be operating without any clear engineering guidelines or deployment rules that might protect operating services from being degraded due to new services being commissioned nearby.

A spectrum management (or more correctly, an Interference Management) framework is crucial to prudent network operation, and I demonstrate through simulations that services may be at immediate risk by virtue of Telecom not having a coherent management plan, through natural interactions between nearby services as their signals are carried throughout the copper local loop network. I recommend the New Zealand telecommunications industry should commence the construction of a management framework while the broadband subscriber density is still relatively low, recognising that completion and implementation of such a plan may require more than a year of elapsed time, during which the level of broadband subscription will likely increase and the degradation of operating services will become more and more apparent.

While there may be a reduction in the time required through adopting the relevant parts of other jurisdiction's management processes, care must be taken to ensure that the results are applicable to the New Zealand network and service mix. In particular, the Australian ACIF framework may provide a workable model, however the specific 'benchmark curves' and derived deployment limits for each technology should be recalculated to suit the New Zealand network characteristics of technology mix and loop length distribution.

After investigating the likely effect of "bit rate limiting" as a form of transmission power control for ADSL, and the effect of such reduced power on other services, I conclude that the notion of using "bit rate limiting" as a form of transmission power control for ADSL to reduce interference appears to have little merit. While such a technique will indeed reduce transmission power for isolated services, there is no evidence that the reduced power will have significant benefit in reducing detrimental interference to neighbouring ADSL services, or produce significantly improved broadband speeds than unconstrained services.

In particular, it will have absolutely no benefit in improving the reach of services on very long lines. There is no significant difference between interference from unconstrained full-power ADSL services and from reduced power ADSL services, and no benefit for long lines in introducing a reduced power or bit-rate limiting regime. Any reduction in data-rate or any long line service which becomes inoperable completely is caused by simply adding new services into the network, not by whether its data rate is constrained or not.

Where there are adjacent services that might benefit from the reduced cross-talk interference brought about by the reduced transmission power, I have found that the cross-talk interference back into the bit-rate limited service will cause it to increase its transmission level to compensate, thus largely counteracting much of the perceived benefit from the reduced transmission power.

Simulations show that the degree of impairment on legacy systems and ADSL-based systems alike does not increase greatly for each technology as the number of interfering lines extends beyond approximately 4 lines. For a service operating in an otherwise clean environment with no crosstalk interference and only the normal background noise, even a single interfering adjacent line will have a significant effect on rate, reach, or tolerance to further interference. Beyond that point, however, the incremental degradation caused by modelling 2, 3, 4 and more adjacent lines of the same technology becomes smaller and smaller. Under standard cable manufacturing techniques, each service will have (statistically) on average a single additional adjacent service interfering with it when ADSL broadband subscriber penetration reaches approximately 20%. Each additional 'adjacent line' represents a further approximate 10% increment in ADSL penetration. Different international jurisdictions have varied approaches to the maximum number of interfering lines – where the number is higher than 4 it tends to be to enable simulations regarding multiple interfering technologies, rather than larger numbers of the same technology. ACIF uses 8 interferers (4 of the interfering technology, 4 of the same type as the victim), while the North American ANSI approach uses 25 lines, with a specific mix of ISDN, HDSL, SHDSL and ADSL interferers to construct a worst-case model noise environment. The service mix and number of each type of service should be chosen to be representative of conditions in the area of interest, and this is one of the areas that should be investigated in order to build an interference management regime suited to the New Zealand network.

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1. Introduction

This report is to assist the Commerce Commission in evaluating a Spectrum Management Plan currently under development by Telecom New Zealand Limited (Telecom) to manage the potential for interference between services on the local loop copper access network. This plan and related matters including DSL line-rate, reach and interference has been the subject of considerable debate during the determination for Bitstream Access for TelstraClear Ltd (Decision 568) throughout 2005, and continuing in further current applications for Bitstream Access determinations in 2006 for CallPlus Limited (Callplus) and ihug Limited (ihug), culminating in the Commission's Decision 582.

Mutual interference between adjacent services within the local loop cable plant is a complex technical topic that is the subject of ongoing basic research and development in universities and vendor laboratories worldwide in order to minimise the impact of interference on operational services. In parallel, telecommunications regulatory bodies and standards bodies around the world have been building frameworks for managing and reducing the levels of interference being generated, to ensure that operating services remain operating reliably as more wideband services are commissioned and newer technologies are deployed.

A number of independent issues have been raised and debated in the regulatory debates over Unbundled Bitstream Access that are directly related to the management of local loop spectrum and the mutual interference of services of varied technologies:

- The nature and implications of the Australian ACIF interference management regime;
- The effect of mass-market ADSL services on symmetric and legacy business-grade services, and vice versa;
- The possible effects of crosstalk interference on service reach;
- Methods of mitigating mutual crosstalk interference, such as limiting bit-rates; and
- Dynamic Spectrum Management.

These are discussed in this report.

Although the issue of Spectrum Management (or more correctly, Interference Management, see later) is important to manage interference between all types of services, where this paper focuses on particular technologies it will necessarily focus mainly on ADSL interference management, due to the context of the Bitstream Access Determinations.

1.1. A note on terminology

This report, as an outcome from the terminology used by all parties in the ‘UBS’ debates to date, has been termed a report on copper loop ‘spectrum management’. This is a misnomer, as the debate is really about managing interference, not spectrum – and this loose terminology has allowed a number of questionable points to be raised in the debate. The ‘spectrum’ or range of frequencies used by each technology (ADSL, HDSL, SHDSL, ISDN, etc) is largely fixed by the relevant ITU standards, and is not amenable to being changed. Further, each technology of interest covers a very wide range of frequencies overlapping with the spectrum used by other technologies. This is in contrast to the more traditional radio situation, where each service occupies a single very narrow portion of the frequency range, and management of transmission frequency (true ‘spectrum management’) is the method for separating services and preventing mutual interference.

The copper loop situation is more akin to the management practices required within the specific ISM radio ‘shared use’ bands, such as the 2.4 GHz band used by spread-spectrum wireless LAN technologies, cordless phones and so forth (including the aspect of being subject to interference from external non-communications-related sources such as microwave ovens). Within this band, each device or service overlaps its spectrum usage with other devices and services to a large degree, and the focus is not on managing use of spectrum as such, but on techniques and rules that minimise interference to allow multiple services to operate while sharing the same frequency spectrum.

In this report, we will tend to use the term ‘interference management’ more than ‘spectrum management’ for this reason, as the prime goal of a management regime is to optimise performance through management of interference. Static Spectrum Management - determining ‘deployment limits’ for static technologies – and Dynamic Spectrum Management for adjustable technologies such as ADSL2/2+ - are tools deployed in order to achieve interference management.

Telecom uses an analogy of a cake – “In very simple terms spectrum resource in the cable sheath … are finite. A cake can be divided in many ways. If a large piece is taken by one customer there is less left for other customers. The size of the cake does not change."[1] This imagery in my opinion is flawed and has more in common with the allocation of radio frequencies in radio spectrum management than with the use of copper resources. Unlike dividing a cake, dividing cable sheath spectrum is not a one-time process and spectrum is never consumed – while one service uses a portion of spectrum for transmission capacity, it is still available to all the other services. Slice sizes can be re-allocated and re-divided, as more slices are required. Mandating a limited resource allocation to the first comer on the basis that the un-used remainder forms a pool for subsequent subscribers ignores the fact that the first subscriber might as well be using all the resources until the next subscribers come along. Nothing in the UBS service description prescribes that a line rate, once provisioned, can not reduce gracefully over time as more and more subscribers are provisioned in the binder and the 'spectrum' or more correctly 'tolerance to interference' is re-allocated across an increasing number of services.

Indeed, a better analogy is the management of water or air pollution. There is no finite limit to the number of people or processes that can coexist within a given volume of air or water, however the more participants or users there are, the dirtier the resource becomes. Whether this is actually a problem or not for any class of users depends largely on the degree of tolerance they have for a degree of pollution, and it is the degree of tolerance for some pollution, rather than the fact that some pollution inevitably occurs, that determines whether any mitigating activities should be considered. In the same way, it is the degree of tolerance (or not) that technologies such as ADSL have to some background crosstalk interference that should dictate whether any special interference management techniques should be put in place, rather than whether or not such interference actually occurs.

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[1] Telecom, TCL01, Para 73.

2. Information Sources

The following documents have been considered during the preparation of this report.

Table 1 - Documents considered in preparing this report

Ref	Document Title	Organisation	Date
TCL01	Submission in respect of the Commission's draft determination on the application for access to and interconnection with Telecom's fixed PDN service ("Bitstream Access")	Telecom NZ	20-May-05
TCL02	Cross Submission in respect of the Commission's draft determination on the application for access to and interconnection with Telecom's fixed PDN service ("Bitstream Access") (public version)	Telecom NZ	8-Jun-05
TCL03	Report on Technical Issues Concerning the Draft Determination for UBS (Annex E to TCL submission)	AAS	1-Jun-05
TCL04	Knossos Networks Report	Knossos Networks	8-Jun-05
TCL05	Crosstalk Effects on Loop Reach for ADSL	Lee Garth	21-Jul-05
TCL06	Workshop 21-22July Transcript	(Various)	21-Jul-05
TCL07	Workshop additional info request	Commerce Commission	3-Aug-05
TCL08	Response on workshop new material	TelstraClear	5-Aug-05
TCL09	Response to workshop info request	Telecom NZ	16-Aug-05
TCL10	Response to workshop info request	TelstraClear	16-Aug-05
TCL11	Bitstream technical specification	Commerce Commission	30-Aug-05
TCL12	Comments on Proposed Technical Specification	TelstraClear	12-Sep-05

Ref	Document Title	Organisation	Date
TCL13	e-mail from V Oakley to CC.pdf	Telecom NZ	3-Oct-05
TCL14	UBS Consultation document (REVISED PUBLIC version) 12 October 2005.pdf	Commerce Commission	12-Oct-05
TCL15	(various parties)	(various parties)	27-Oct-05
TCL16	Telecom's response to Commerce Commission Statement for Consultation in respect of TelstraClear's bitstream application	Telecom NZ	27-Oct-05
TCL17	Bitstream Determination Decision 568	Commerce Commission	20-Dec-05
IHCP01	Submission in respect of ihug's application on access and interconnection with Telecom's fixed PDN service ("Bitstream Access")	Telecom NZ	12-Apr-06
IHCP02	(various parties)	Federated Farmers (+various parties)	1-May-06
IHCP03	Cross Submission in respect of Applications by CallPlus and ihug for Access and Interconnection with Telecom's fixed PDN service ("Bitstream Access") (public version)	ihug & CallPlus	9-May-06
IHCP04	Technical Expert Report on ADSL Transmission over Copper	Gibson Quai-AAS on behalf of ihug & Callplus	9-May-06
IHCP05	Cross submission in respect of ihug's and CallPlus' joint submission on Callplus' application on access and interconnection with Telecom's fixed PDN service ("Bitstream Access")	Telecom NZ	9-May-06
SM01	High Speed Internet Service Customer Briefing	Telecom NZ	17-19 May-06

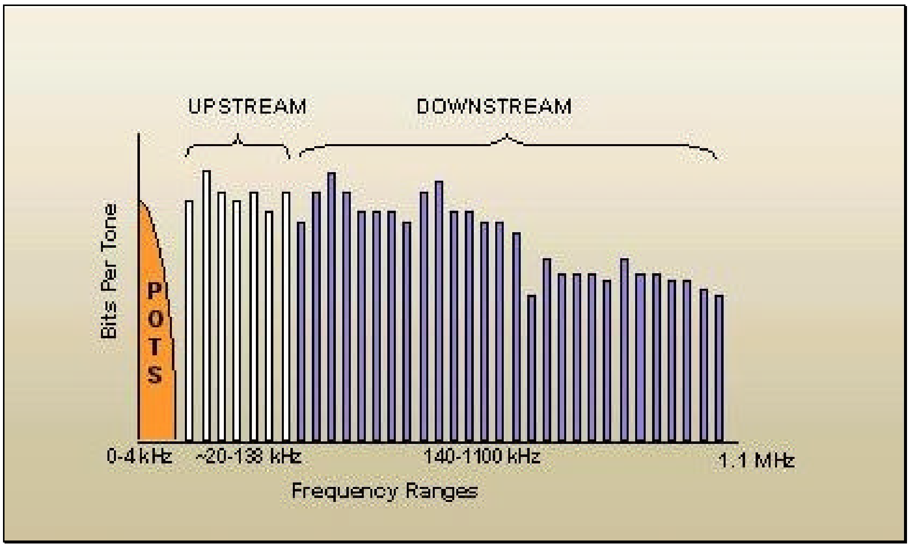
3. ADSL Spectrum Utilisation

Several submissions have covered basic principles of ADSL technology; however some fundamental aspects with deep implications on the effect of cross-talk interference have not been sufficiently explored to date. In this section we outline these extra aspects, and then use them to explain the fallacies of some of the claims made in a number of submissions in the various determination submissions.

3.1. Discrete Multi-Tone (DMT) primer – ADSL1

All ADSL variants achieve high transmission line rates by splitting the data to be transmitted across hundreds of low speed channels operating in parallel at equally spaced frequencies, as shown in Figure 1. This is termed 'Discrete Multi-channel Transmission', or DMT.

Figure 1 - ADSLv1 DMT channels



Each single channel operates very similarly to a conventional dial-up modem, with similar data rates – and similar techniques for dealing with line-noise. ADSL can be regarded to a large part simply as hundreds of conventional modems operating in parallel on different carrier frequencies.

For ADSLv1 there are 255 defined channels (sometimes referred to as sub-carriers) in total. The six lowest frequency channels correspond to the POTS/PSTN baseband signals, and are not used for ADSL. The next 26 channels are used for 'upstream' data, transmitting from the subscriber towards the DSLAM port, and the highest 216 channels are used for 'downstream' data, transmitting from the DSLAM out towards the subscriber (the remainder are used for synchronisation or separation and are not used for user data transmission).

They all transmit at once, in parallel, each carrying a small fraction of the total information, at a rate of 4000 'symbols' per second. Each channel can carry between 2 and 15 bits per 'symbol' depending on how strongly the signal is being received, as illustrated by Dr Lee Garth[2] - when the received signal is strong and clearly detectable above the noise, more bits can be sent per time period. In channels where the signal is difficult to detect against the background noise, the receiver can elect to tell the transmitter to reduce the number of bits sent per symbol to reduce the chance of errors occurring.

Figure 2 - ADSLv1 achievable line rate

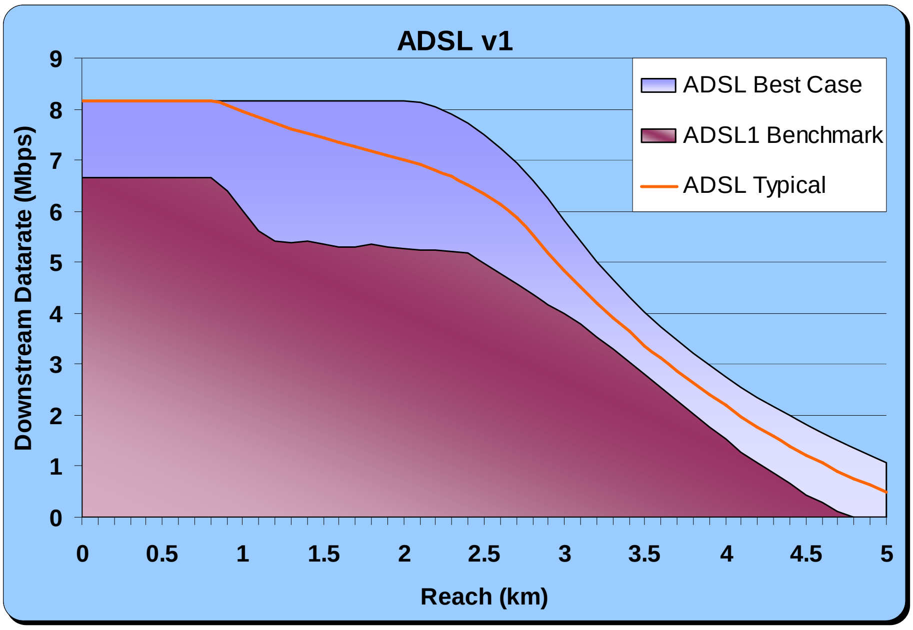


Figure 2 shows the theoretical 'Best Case' performance curve of achieved line-rate as a function of distance (assuming 0.40PIUT cable, standard -140dB background noise, and no other interference). It also shows the ACIF performance benchmark curve for ADSL1, which is the expected worst-case performance. All operating ADSLv1 services are expected to fall within the blue area, demonstrated by the 'ADSL Typical' line. (Note that in this chart the 'Data-rate' is the synchronised ADSL line rate. Telecom uses 'IP payload' data-rates in their submissions, which is approximately 85% of the ADSL line rate.). The 'ADSL Typical' line is the expected performance of a 'victim' ADSL service with two adjacent ADSLv1 interferers,

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[2] TCL02, p81

corresponding to an ADSL subscriber penetration of approximately 33%, or roughly three times the current level. Figure 9 and Figure 11 later in this paper show how this curve might vary slightly in degradation under other numbers of interfering services.

Key observations from this discussion are:

- Any discussions of excessive interference need to consider precisely which frequencies or channels are being interfered with. Interference, crosstalk, or discussions of excess power can only affect a channel if it is present at the same frequency as the channel. Interference generated at one frequency cannot affect a transmission channel of a different frequency.
- ADSL in particular has been specifically designed to operate in the presence of significant background noise, and can 'avoid' or work around frequency bands with relatively high interference, and still maintain a usable signal level.

3.2. ADSL initialisation and synchronisation

ADSL initialization is required in order for a physically connected modem and DSLAM pair to establish a communications link. The task of the initialization process is to maximize the throughput and reliability of the link. When first connected, each end briefly transmits a maximum-strength signal towards the other end in each channel. Each receiving channel measures the received signal strength (and when compared with the transmitted signal level this produces the attenuation of the wire at that frequency), the noise level in that channel, and the received signal-to-noise ratio for that channel. During the exchange process each receiver shares with its corresponding far-end transmitter certain transmission settings that it expects to see, and the characteristics of the signal it receives. The number of 'bits per symbol' to be used in every channel are calculated in each receiver, and sent back to the transmitter at the other end.

If a receiver channel cannot determine any signal, this also is communicated to the transmitter, and the transmitter turns off that channel and transmits no energy at that frequency.

In this way, the pair of devices negotiates and finds the optimum method of information transfer between themselves, adjusting dynamically to the surrounding noise and attenuation environment, allowing ADSL to be extremely resilient in achieving at least some minimal line rate in the presence of even severe interference. The degree of effectiveness of this process is somewhat constrained by the capabilities of the individual modem and DSLAM manufacturer, and in how many characteristics are opened for tweaking – this depends greatly on the actual capabilities of the modem, the DSLAM and the DSLAM line card.

Many early ADSL1 DSLAMs do not have capabilities for restricting transmission power, other than a flat ‘power cutback’ across all frequencies activated automatically on extremely short lines to prevent overloading the receiving circuitry. Regardless of how low the line-rate is set, these ADSLv1 systems may transmit at the maximum power permitted by the PSD in every channel that can be received at the far end. For this equipment, statements from Telecom such as “Higher downstream speeds create greater noise interference. This is because the DSLAM is required to transmit at a much higher power in order to achieve the necessary speed”[3] are false – regardless of the downstream speed selected, the noise interference will be the same.

3.3. Attenuation of signal

As a signal travels along a twisted-pair wire, the energy is dissipated somewhat within the wire and the signal reduces in strength through attenuation until eventually at some distance it becomes so weak that a receiver cannot pick the signal out of the background noise. This is the basis of the distance limitations for DSL systems.

Higher frequency signals experience higher attenuation, and become fainter over shorter distances than low frequency signals. This is demonstrated in the following diagram:

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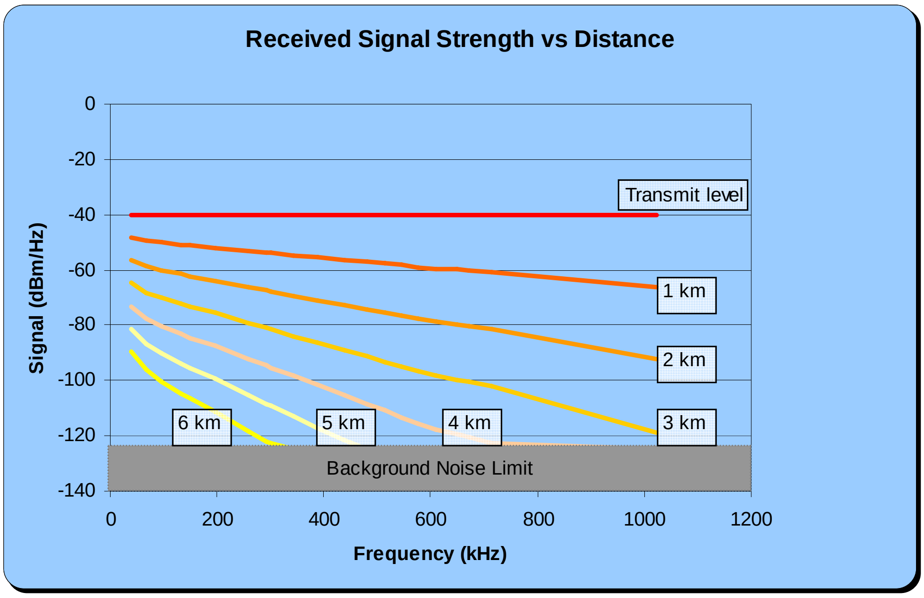
[3] TCL01, Para 76

Figure 3 - Attenuation of signal with distance



Referring to Figure 3 above, we assume the signal at the transmitter (the DSLAM port) is being transmitted at the maximum power of -40 dBm/Hz in each frequency – the top line. By the time the signals have arrived at a receiver (the DSL modem) – say 4 km along the wire – all frequencies are received with lower power, however all channels with frequency higher than around 700 kHz have become so faint that the modem will not be able to detect the signal through the background noise.

A key observation from this discussion:

- On long lines, the higher frequency channels encounter so much attenuation that no signal can punch through - these channels are turned off at the transmitter. The remaining (lower frequency) channels will be transmitting at full power. On longer and longer lines, the aggregate power will reduce as the number of channels that are transmitting at full power contracts towards the low frequency end of the downstream band.

The implication for an Interference Management Plan is that, to maximise the reach of ADSL service, it is the low frequency end of the downstream band that needs to be protected in some fashion – the frequency range from approximately 200 kHz to 450 kHz or so. Frequencies or channels at the high frequency end play no part in long reach services. If restrictions on transmission power are found to be necessary in this range to preserve the long distance services (and it is not yet shown that it is required) then a compromise solution may be, for example, to artificially restrict the PSD for short-range services only in this frequency band. This would cause short lines that would otherwise achieve line rates above seven Mbps to achieve a slightly lower rate, inconsequential in percentage terms, while maximising reach of the long lines. This is the basis of Dynamic Spectrum Management, covered later, and is possible only with the more recent DSL variations, ADSL2 and higher – but not ADSLv1.

3.4. ADSL2

ADSL2 was ratified in July 2002. In ADSL2, the same number and spacing of channels is used, and so ADSL2 uses precisely the same frequency bands or spectrum as ADSL1. Modest downstream capacity increases were included, largely through introducing more complex encoding. The major set of improvements over ADSL1 are in the form of vastly improved line diagnostics measurement, reporting and control of the link and the behaviour of individual channels. Improvements that relate to Spectrum Management (as extracted from G.992.3, the ADSL2 specification) include:

- New line diagnostics procedures available for both successful and unsuccessful initialization scenarios, loop characterization and troubleshooting;
- Enhanced on-line reconfiguration capabilities including bit swaps and seamless rate adaptation;
- Improved transceiver training with exchange of detailed transmit signal characteristics;
- Improved SNR measurement during channel analysis;
- Improved transmit power cutback possibilities at both CO and remote side;
- Improved channel identification capability with spectrum shaping during Channel Discovery and Transceiver Training;
- Mandatory transmit power reduction to minimize excess margin under management layer control;
- Power saving feature for the central office ATU with new L2 low power state;
- Power saving feature with new L3 idle state;
- Spectrum control with individual tone masking under operator control through CO-MIB;

Many of these new capabilities could be used to implement Dynamic Spectrum Management (see Section 8 below) through a sufficiently advanced external management system, or through sophisticated DSLAM equipment without an external management system. The latest research on DSM, however, appears to indicate that a centrally controlled management system is not necessary, and autonomous procedures that can be executed within each transmitter-receiver pair will achieve an almost optimum result without the costs of central management. As the older ADSLv1 equipment and line-cards are retired and replaced by ADSL2+-capable equipment which incorporates the improved management and reporting functions, better performance in practice should be obtained.

3.5. ADSL2+

ADSL2+ was ratified shortly after in January 2003. It doubles the frequency band used, essentially extending the 'downstream' channels with another 256 downstream channels in the space between 1.1 MHz up to 2.2 MHz. This allows ADSL2+ to achieve up to 24 Mbps or more downstream capacity (line rate) on short lines. All the ADSL2 management improvements remain the same, as does the upstream capacity.

Figure 4 - ADSL2+ Performance Curves

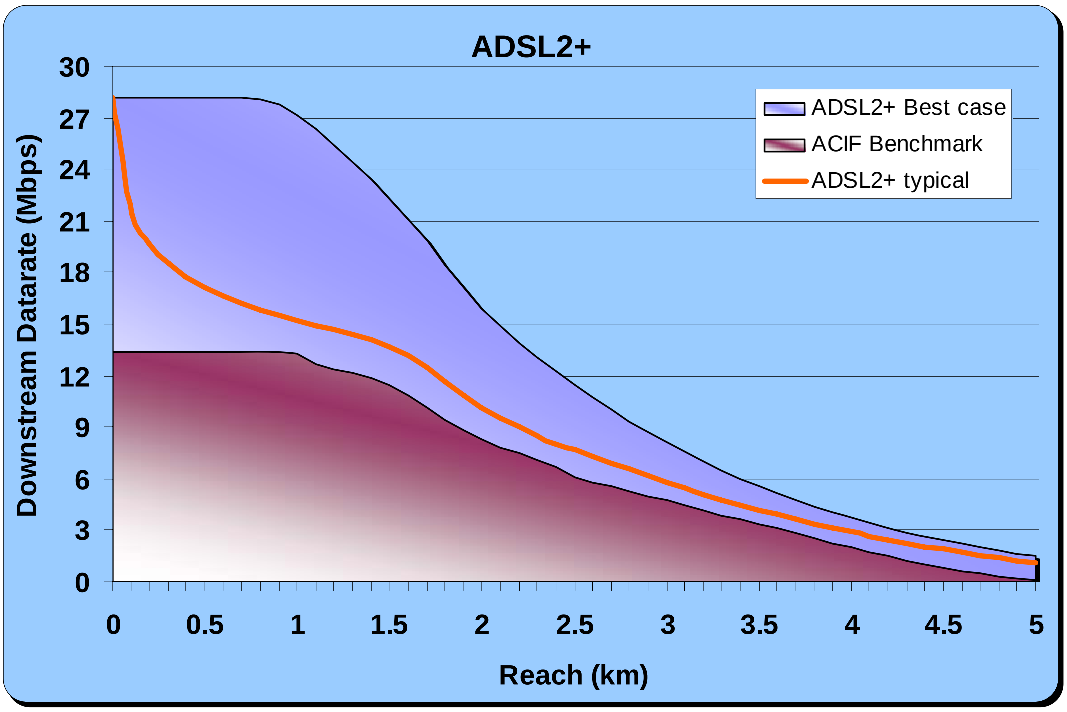


Figure 4 shows the theoretical 'Best Case' ADSL2+ performance curve of achievable line rate as a function of distance (assuming 0.40PIUT cable and standard -140dB background noise). It also shows the ACIF performance benchmark for ADSL2+, which is the worst-case expected performance. As with ADSL1, all operating ADSL2+ services are expected to fall within the blue area. The 'ADSL2+ typical' line is the expected performance of an ADSL2+ service under the influence of cross-talk from two other similar services – again, corresponding to an ADSL subscriber penetration of approximately 33%. Note that while at short distances there is a significant reduction due to cross-talk, at long distances (5km) the expected performance is very close to the maximum predicted speed. This reflects the observation that for long-range services, interference from adjacent ADSL systems has very little effect, and the low ACIF benchmark curve in this region is dominated by interference from non-ADSL systems such as ISDN.

3.6. VDSL2

VDSL2 was ratified in 2005, after a long drawn out battle with opposing factions helped ensure the original VDSL standard was never standardised enough for widespread adoption.

VDSL2 in many respects is essentially ADSL2+++++ - the DMT system and channel coding is retained, however additional upstream and downstream bands are defined using frequencies up to 30 MHz. This allows VDSL2 systems to gracefully degrade to be the same as ADSL2+ over long lines as the higher frequencies are progressively attenuated by distance.

VDSL2 is designed to provide 100Mbps symmetric capacity over very short wires (~500 metres), and asymmetric capacity up to around 50 Mbps down, 3 Mbps up over longer wires (~1500 metres). It is of most utility in the in-building wiring of a Fibre-to-the-building scenario, such as for hotels and apartment blocks when a DSLAM is installed in the basement.

Figure 5 - Summary of current xDSL technology

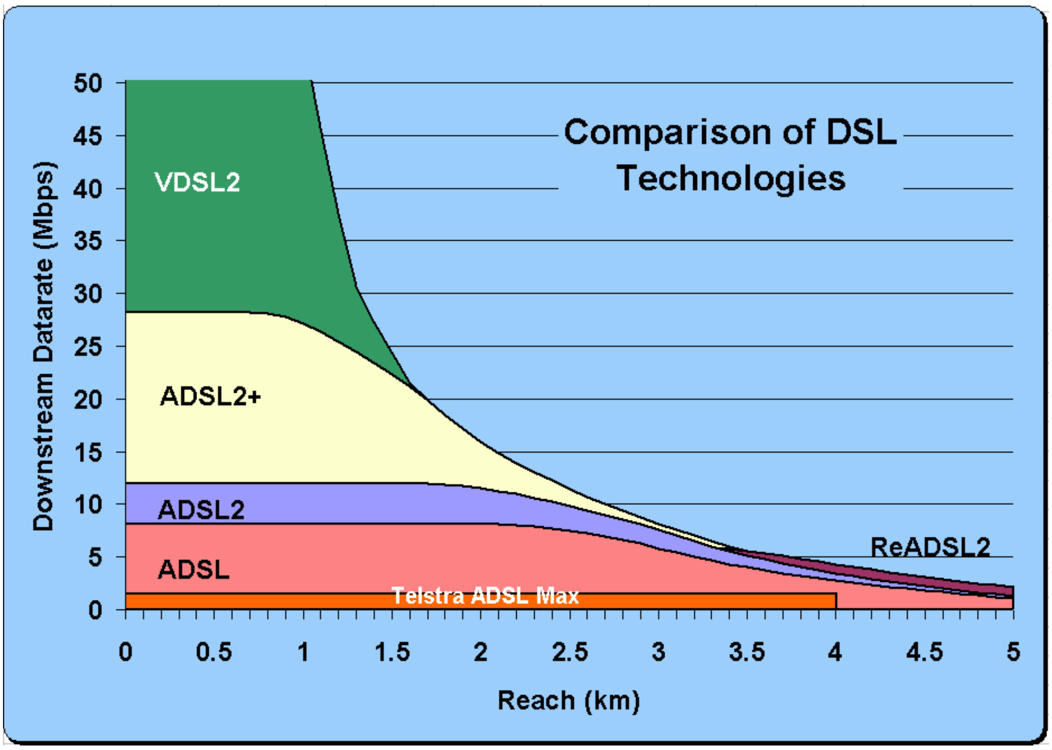


Figure 5 shows the maximum achievable line rate of several DSL technologies. Note that at long distances (around 5km at the nominal attenuation rate) the technology that provides the best solution for long lines and rural services is a variant known as “Reach Extended ADSL2”, described in Annex L of the ADSL2 specification, which is specifically designed to maximise service reach at the expense of line speed. Telecom NZ has included this in their list of ‘Primary Base Systems’[4] of their spectrum management draft presentation, however it has not been discussed in the UBS process – possibly because, as an ADSL2 variation, Telecom believes it to be out-of-scope for a process revolving around access to ADSL1 equipment.

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[4] Telecom, CC01, slide 17

4. The Australian ACIF spectrum management regime

One of the central themes of the spectrum management portions of submissions surrounds the Australian regime, and whether or not it is applicable or a desirable model for use in New Zealand or as a base on which to build a New Zealand-specific regime.

Telecom New Zealand, and in particular its expert Dr Lee Garth, appear to believe the ACIF approach is flawed and a completely new approach is required[5],[6]. Other parties have produced submissions supporting the ACIF approach in NZ.

In this section, we outline the essential characteristics of the ACIF approach, and then comment on a number of Telecom's misconceptions of the ADSL benchmark.

4.1. Jurisdiction and structure

The Australian approach is embodied within two main specifications:

ACIF C559 *Unconditioned Local Loop Service (ULLS) Network Deployment Rules Industry Code* (last updated 2005)

AS/ACIF S043 *Requirements for Customer Equipment for connection to a metallic local loop interface of a Telecommunications Network— Part 2: Broadband*

C559 is an Industry Code that has been registered with ACMA and therefore compliance is mandatory for service providers. It governs transmission by DSLAMs and other 'network end' equipment (including those housed in remote cabinets) in the 'downstream' direction.

AS/ACIF S043 is registered with Standards Australia as an Australian Standard, which mandates compliance by all equipment manufacturers and end-users. It governs transmission by the CPE operated by the subscribers – essentially the 'upstream' direction.

While one is an Industry Code and the other an Australian Standard, in practice, both are tightly coupled and it is the ACIF working groups that have drafted and revised both documents, with largely congruent membership of the two working groups. The distinction is mainly due to jurisdiction issues, including legal jurisdiction as to which laws govern the

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[5] Telecom NZ, IHCP01, Para 7

[6] Dr Lee Garth, TCL02, Annex C

activities of licensed telecommunications carriers and service providers compared to the laws that govern end-users.

4.2. Objects and Aims

As noted in the C559 Explanatory Statement:

> “The increased use of wideband services has increased the risk of interference occurring between them. The nature of the interference varies from a reduction in the data rate on the service to effectively rendering the service unusable.
>
> Minimising this risk requires a coordinated approach to the operation of services over the affected access networks. This Industry Code offers that coordinated approach and defines the “technical and network rules dealing with spectral compatibility and the operation of services using xDSL technology on the local loop” identified as key areas of work in the ACCC report. It is imperative that network performance requirements and rules relating to operation of services are formally agreed upon and adhered to by all relevant industry players.”

The ACIF approach is pragmatic, in that it recognises that interference is a fact of life for wideband services in metallic cables, and the issue is not to eliminate it, but rather to manage and limit the degree of impairment and the expectations of operators (and through them their subscribers).

The Australian approach is very similar to the approach taken in North America, with the ANSI T1.417-2003 *Spectrum Management for Loop Transmission Systems*.

Key features include:

- Key technologies are designated as ‘Basis Systems’, which must be protected from interference from other technologies so as to achieve at least a minimum benchmark performance.
- Reference Architectures and Reference Cables are defined to closely match real deployment situations
- Benchmarks provided of the lowest or minimum acceptable performance expected from Basis Systems, to assist in determining if interference from another technology is excessive. Note that there is no requirement for a service provider to take account of the benchmarks in determining their product specifications or offers to the market, as real service deployments are expected to (almost) always exceed the benchmark.

- Specification of classes of technologies in ways that permit non-standard new technologies to be classified within classes according to the nominal transmission spectral profiles;
- A computer-based interference modelling package and process that permits any arbitrary transmission spectral profile to be checked as to the degree of interference it will likely cause, and hence determine any limitations that should be applied to ensure the basis systems are not unacceptably degraded.
- Includes procedures for dealing with and specifying deployments in remote cabinets and other situations there the transmitters are not co-located (which is particularly relevant in the current FTTN debate in Australia, however is not relevant as this situation does not occur in NZ)
- Where limitations must be applied, preference is given to limits that are applied by the operators themselves using standard-compliant equipment, and do not require customised versions of equipment or software to be developed and offered by vendors. Any mandated requirement for a special customisation on the part of equipment manufacturers (such as supporting a customised spectral transmission profile for example) would likely have the effect of raising prices and reducing the availability of compliant equipment. This is one reason why the limits applied within the Australian regime are deployment distance limits (specified in dB attenuation) – they are under the control of the service provider, and do not need to be controlled by the equipment.

The primary method of demonstrating that a new technology is compliant with the ACIF interference management plan is through fitting entirely within the PSD of an existing deployment class (and accepting any deployment limits attaching to that class) or through independent modelling of potential interference with each of the basis systems.

The computer modelling tool was developed within Telstra Research Labs. Independently, NEC developed a tool for making similar calculations as a means of crosschecking the results obtained using the TRL/ACIF system. In the revisions that culminated in the 2005 update, including ADSL2 and ADSL2+ for the first time, three completely independently developed interference modelling tools were used to cross-check each scenario. Any disagreements in results permitted the divergent system to be checked for errors, and results were accepted only when all three systems produced substantially the same predictions for the level of interference. This high level of independent verification provides confidence that the tool and its predictions are correct and valid.

4.3. Spectrum assumptions and PSDs

Relevant to the discussion of Telecom's approach is the fact that all interference calculations are performed assuming the interfering lines are all operating at full power up to the PSD limit as specified in the relevant technology standard. While it is possible for some technologies such as ADSL2 and 2+ to scale back their transmission power, this is not modelled to ensure that the degree of interference is calculated pessimistically (some term it conservatively) and ensure that as far as possible the real-world network services will therefore operate well in excess of the modelled limits.

This approach is entirely the opposite of the "WCSM" characterisation by Dr Garth as it pertains to ADSL. This approach is used to determine the limits that should be placed on the other technologies that are being modelled to interfere with ADSL, not on ADSL itself. The ACIF approach allows ADSL (the most common variations at least, some rare variants have limits applied) to operate completely unrestricted, at full power across the entire permissible spectrum. This is set out in Figure 7 .

4.4. Technologies Addressed

This section outlines the specific requirements for the technologies included within the ACIF codes as they pertain to spectrum management.

4.4.1. Basis Systems

Figure 6 - ACIF Basis System Table

Name	Description	Relevant Standard
Symmetric Systems		
Voiceband		
ISDN-BR	2B1Q	ITU-T G.961
E1-HDB3	2048 kbit/s	ITU-T G.703
SHDSL 576kbit/s	16-TCPAM, f_{sym}=194.67	ITU-T G.991.2
SHDSL 1160 kbit/s	16-TCPAM, f_{sym}=389.33	ITU-T G.991.2
SHDSL 2312 kbit/s	16-TCPAM, f_{sym}=773.33	ITU-T G.991.2
ESHDSL 3840 kbit/s	16-TCPAM, f_{sym}=1282.67	ITU-T G.991.2 Annex F
ESHDSL 5696 kbit/s	32-TCPAM, f_{sym}=1426	ITU-T G.991.2 Annex F
Asymmetric Systems		
ADSL	Reduced NEXT option	ITU-T G.992.1
ADSL2+	Non-overlapped spectrum mode	ITU-T G.992.5

Figure 6 shows the ACIF 'Basis Systems', which are considered the most important systems that must be protected from excessive interference when proposing new systems for use on the copper loop network.

4.4.2. Specific restrictions for each technology

Figure 7 - Table of ACIF classes and restrictions

Deployment Class	Typical Technology	Deployment Limits
1b	E1 (G.703 HDB3)	HDB3 systems generate a large amount of interference. Further HDB3 systems are discouraged; SHDSL systems should be installed instead. For other technologies C559 assumes HDB3 systems are operated only in separate cable binders – other technologies can assume physical cable separation from HDB3 systems, and so they are not used as interferers when modelling benchmarks.
3a	PSTN Baseband Audio	No restrictions
4a	ISDN (Basic Rate 2B1Q)	No restrictions
5a, 5b	Proprietary low-rate symmetric system similar to SHDSL	No restrictions
6a, 6e, 6f	ADSLv1 FD (Non overlapped) – Annex A	No restrictions
6c	ADSL over ISDN (Annex B)	Deployment Limit 18.2 dB (1.3 km)
6d	ADSL (overlapped EC) – Annex A	Deployment Limit 30.8 dB (2.2km)
6g	ReADSL2 – Annex L	MINIMUM deployment limit 35.9 dB (2.6 km) – not to be deployed on shorter loops.
6h,6i	ADSL2, ADSL2+ (non overlapped) – Annex A	No restrictions
8b	HDSL (2B1Q 1168kbps)	Deployment Limit 22.2 dB (1.6km)
9a	SHDSL (up to 576 kbps)	No restrictions
9b	SHDSL (low power up to 776 kbps)	No restrictions
9c	SHDSL (full power up to 776 kbps)	Deployment limit 30.2 dB (2.8 km)
9d to 9g	SHDSL (various speeds up to 2312 kbps)	Deployment limit varies from 32.1 dB (2.7km) to 29.3 dB (1.9 km)
9i to 9q	ESHDSL (various speed up to 5696 kbps)	Deployment limit varies from 27.8 dB (1.7km) to 22.7 dB (1.1 km)

4.4.3. Cable Attenuation

In the table above deployment limits are specified as 'dB attenuation'. Distances corresponding to that attenuation on a nominal 0.4mm PIUT cable are informative only, and the actual distances could be longer or shorter than this depending on precisely what mix of cable gauges are involved for the specific line. Specifying all limits and key characteristics in 'dB attenuation at frequency X' permits the limits to be translated directly to any cable plant, including that in NZ, simply by knowing the scaling factors applied to attenuation of unit lengths of the cables used in the NZ network. The ACIF C559 Part 1 document includes a table (Table A-2) of line attenuation characteristics for different types of cable at different frequencies for this purpose, which amongst other uses allows the 'dB attenuation' figures used by Telecom NZ (specified at 1024kHz) and the figures used by ACIF (specified at 300 kHz) to be inter-converted.

The 'Deployment Limits' in permitted lengths of line were determined using the interference modelling tools, so as to not cause any of the basis systems to drop below its performance benchmark in subscriber line-rate at any point along the range of line lengths.

4.5. Misconceptions Corrected

4.5.1. ACIF model mandates a WCSM

Telecom's expert Dr Lee Garth outlines an Australian ADSL downstream transmission mask which he states is restrictive compared to the ANSI mask, and asserts that this conservative mask is a strategy currently used in Australia as a result of applying a Worst Case Spectral Mask to ADSL systems[7].

This assertion is false – ADSL systems in Australia use the full PSD provided in the ITU-T G.992.1 standards for ADSL. There is no artificial constraint on data rate or access loop length, and hence none of the claimed advantages in later calculations of restricted loop reach, line speed or efficiency of the BRL scheme are valid.

4.5.2. Bit-rate Limiting is not applicable to ADSLv1

Dr Garth outlines a scheme he calls 'bit rate limiting'[8] where the ADSL modem uses the minimum amount of power so as to achieve the desired bit-rate, thus reducing cross-talk signals and using power/bandwidth more efficiently.

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[7] Telecom, TCL02, Appendix C, Paragraph 3a

[8] Ibid, Paragraph 3b

This technique of managing power output by specifying a line rate and a minimal desired Signal-Noise Ratio was introduced into the G.992.3 ADSL2 specification, and does not exist in the ADSL1 specification. It appears Dr Garth has confused the ADSLv1 network capabilities that were the subject of the access determination request with the newer capabilities of ADSL2 and ADSL2+ systems – this is confirmed with the graph in Figure 13, where he shows the BRL curves have a maximum data rate around 12 Mbps and references the ITU-T ADSL2 specification in the Simulation Parameters. ADSL2 runs at 12 Mbps maximum, while ADSLv1 has a maximum user data rate around 8.1 Mbps.

It is unsurprising therefore, that he can show in Figure 14 that a full-speed ADSL2 service achieves better loop reach than the benchmark 1% worst-case expectation for an ADSL1 service in an invalid comparison.

4.5.3. Benchmark is not a Deployment Limit

Much of the criticism by Telecom of the ACIF model compared to Telecom's 'bit rate limited' model, and the modelled results which shows that a 'bit rate limited' regime provides superior line reach, appears to be based on the erroneous premise that the ACIF 'ADSL benchmark' is a form of restriction on ADSL deployment.

In the latest proceedings, Telecom states "As explained at length in the Decision 568 proceedings, if New Zealand moved to an ACIF mask as in Australia, reach would be reduced and approximately 70,000 lines may be unable to obtain broadband in the future."[9] This appears to be a reference to the ACIF ADSL1 benchmark, which cuts out at around 4.5 km, and the statement is simply false. There is no 'ACIF mask'. There is an ACIF performance benchmark, which is not a spectral mask at all. This is a minimum expected worst-case performance; all real services are expected to exceed the benchmark, in rate as well as reach. Long lines continue to receive the best performance that the technology can support. The ADSL benchmark is a '1% worst-case' expectation of the minimum performance under maximum cross-talk interference. Any actual service set up will still extend to the maximum distance the technology will support, well beyond the 4.5km benchmark in 99% of cases.

The ACIF benchmark is an administrative construct with only two purposes – firstly, to help set appropriately conservative deployment limits on other non-ADSL technology, and secondly as a trigger for identifying genuine requests for investigation of excessive interference. It plays no

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[9] Telecom, IHCP01, Para 7.

part whatsoever in determining if a subscriber will be able to obtain broadband, and what line-rate they will actually get in practice. The only way the ACIF benchmark could prevent those 70,000 lines from obtaining broadband is by Telecom using the 4.5km cut-off as an administrative limit in their order acceptance system and not attempting to connect them when they apply for a service.

Further, as outlined in Section 5.6 below, the Australian benchmark curve is not valid in New Zealand, and a New Zealand specific curve should be determined, which is likely to have a much longer cut-off.

5. Telecom's 'Bit-rate Limiting PLUS' regime

Telecom has released a high-level overview of a copper loop interference and performance management regime it is currently developing titled 'Bit-rate Limiting PLUS', which appears to build upon the 'Bit-rate Limiting' approach it developed through the TelstraClear UBS Determination process. Telecom referred to Bit-rate Limiting in its Callplus and ihug UBS submissions[10]. The High Speed Internet Service Customer Briefing presented to the industry in May expanded upon Telecom's earlier views. In this section we comment on aspects contained in the briefing slides provided to the industry and then the Commission.

5.1. New Plan

Telecom NZ is developing a completely new copper loop spectrum/interference management plan from scratch, and appears not to have had any formal or even informal internal engineering guidelines for managing wideband copper loop interference prior to the development of this new plan[11]. Telecom is of the opinion that a new spectrum management regime should be put in place before higher (ADSL) speeds are offered[12]. I strongly agree that a plan should be put in place as soon as possible - in my view the same holds for the initial introduction of ADSL and like services. I would have expected a prudent network operator should have had a spectrum management regime in place well before this period, to ensure that important business services were not adversely impacted by the introduction of widespread consumer wideband services such as ADSL1, and to ensure that legacy HDB3-based systems were not adversely impacted by the introduction of SHDSL-based systems for example. That Telecom has not referenced any previous engineering standards or guides is surprising for a carrier of Telecom's size and incumbent stewardship of the copper loop plant asset.

What has not been demonstrated is whether there is any significant value in putting a plan in place now that significant ADSLv1 services are already deployed in service. The main result of such a plan will be to determine the likely reduction in performance that ADSL services cause to symmetric services – but those effects will already be being experienced where they are

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[10] Telecom NZ, IHCP01, Para 8.

[11] Telecom NZ, TCL01, Para 63 – "A non rate limited configuration raises technical and operational issues…..that require careful consideration as discussed below. Telecom's comments are necessarily preliminary given that such matters have not been fully investigated before."

[12] Telecom NZ, IHCP01, Para 6.

significant – that horse has already bolted. A suitable investigation and plan should be developed before other new technologies, such as ADSL2 and ADSL2+, are deployed on the copper loop network.

A number of submissions in the UBS determinations have outlined that a Spectrum Management Plan is a requirement arising from the introduction of Local Loop Unbundling[13]. While it is international best practice that Local Loop Unbundling requires a spectrum management plan to be in place, the opposite does not hold – that without Local Loop Unbundling there is no need for a spectrum management plan. As AAS noted in June 2005 "Telecom also needs to manage the spectrum in its cable sheaths, and this will become more important as the number of different types of DSL systems proliferate,..... Management is always required because every digital system running in a cable sheath will induce crosstalk into every other system running in that cable sheath. The only difference from the environment created by LLU is that Telecom is the only installer and operator of digital transmission systems"[14].

The introduction of LLU (or in this case UBS) does not, in itself, generate the need for a spectrum management plan. The introduction of LLU or UBS simply brings visibility of what would have been internal deployment rules into public visibility, and that the spectrum management should move from being an internal engineering function to a transparent, open function with shared responsibility.

5.2. Objectives

In Slide 22 of the May briefing Telecom state that the objective of cable spectrum management is to improve the net bit rate performance for all users of the asset.

I observe that an additional objective should be to ensure reliable and continued service for all users of the asset. Indeed, Telecom appears to share this objective, evidenced by their concern for the continued service of existing subscribers on very long loops.

During the briefing[15] Mr Kevin Mason outlined that the general goal of the spectrum management regime was aimed at reducing transmission power, and that 'bit rate limiting' was a means of encouraging the DSLAM port to use reduced power for those services where

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[13] Gibson Quai-AAS, ICHP04, Para 3.4

[14] AAS, TCL03, Para 3.1.2, pp5

[15] SM02, June13 2006

the modem was on a line short enough that the nominated bit-rate could be easily achieved – that is, those lines where the maximum possible bit-rate was significantly higher than the nominated limited bit-rate. On longer lines where the technology could not achieve the nominated bit-rate the DSLAM port would be transmitting at full power in any case in order to achieve the best performance the line could provide.

The main effect of this power reduction was expected to be an increase in performance for 'mid-range' services on lines between 2 to 3 km long – the focus has shifted away from preserving services on extremely long lines, as Telecom now has experience to show that such services are not as affected by full-power ADSL interference as they had initially feared.

5.3. Service Performance Management

In the context of the Ministerial announcement of the introduction of Local Loop Unbundling it is conceivable that each service provider network using LLU may choose or be required to implement a performance measurement and/or management system, and possibly coordinate or share data formats in a central database repository to build a database of line characteristics. In practice, each network operator will tend to collect these statistics in any case, for their own internal baseline modelling and to provide some performance history of each line to use during subsequent fault-finding.

Measurements that are typically collected for each line by network operators of DSLAM equipment include:

- Line synchronisation rates – upstream and downstream
- Transmission Power – upstream and downstream
- SNR Margin – upstream and downstream
- Calculated line attenuation
- Calculated maximum attainable line synchronisations rates – upstream and downstream
- Number of retrains
- Number of errored frames/coding violations

5.4. Spectrum Management

Telecom outlines a number of techniques for dealing with Spectrum Management (or more accurately handling or reducing interference)

- Physical Separation to deal with external noise sources and legacy highly-interfering services such as E1-HDB3;

- Noise Cancelling is not feasible currently, so they propose to ignore this method;
- Deployment Limit (line length limits) used for fixed spectrum systems
- Frequency and Transmission Power management for technologies (ADSL, VDSL) that allow these to be adjusted – typically the asymmetric technologies.

The first three are not controversial, and correspond to practices in other regimes. Noise Cancellation is a current hot research topic within the various vendors and institutions, with a primary focus on implementing it in VDSL2 systems to achieve yet higher speeds such as 100Mbps symmetric over kilometres of copper loop. Many of these exist only as mathematical formulae in research papers, a few may be experimentally deployed in lab environments, and none of these techniques are currently commercially implemented – however over time some may be implemented in updated DSLAM software and hardware.

'Frequency and Power management' at its most powerful is the practice referred to as Dynamic Spectrum Management (DSM), also a hot research topic, again primarily in the context of VDSL2 – it refers to systems selectively modifying their transmission profiles to actively avoid transmissions in specific frequency ranges that would interfere with adjacent services. Commercial systems with some rudimentary support for altering the shape of the transmission spectral profile should appear on the market within the next few years. Certainly ADSL2 and ADSL2+ systems provide significantly better management information to allow some of these ideas to be implemented, although currently the platform management systems do not implement the latest techniques, and today the systems can implement 'flat power adjustment' where the transmission profile maintains the same shape, and the same relative power reduction occurs over the whole frequency range. ADSL1 has rudimentary support for flat power adjustment, but this is not standardised and the degree of control is very dependent on the vendor and the capabilities of the device at the other end.

. See Section 8 "Dynamic Spectrum Management" below for a current review of DSM.

DSM is a laudable goal in terms of implementation, however it is debatable whether it is appropriate or necessary to mandate support for DSM to some degree within a formal spectrum/interference management plan. It is still reasonable to build the plan on worst-case scenario (especially in a LLU environment, where some operators may not have the resources to implement DSM) and operators that can exceed the base requirements through investing in DSM will reap the benefits in significantly improved service speeds and options.

In any case, conventional Static Spectrum Management is required for all the systems that cannot adjust their spectral profile, such as all the symmetric systems such as SHDSL and E-SHDSL, G.703 HDB3, ISDN Basic Rate and to determine the effect of each of these systems on the adaptable systems.

In particular, SSM must be used to model the worst-case effect of each technology on the other non-adaptable technologies, in order to determine what is a safe deployment length. The deployment limit for SHDSL services (as an example) is typically not set to limit the impact of SHDSL on other technologies, but rather is determined by the impact of the other technologies on SHDSL, and simulations indicating that SHDSL services attempting to operate on lines longer than the limit may receive enough interference to prevent them from operating. This is highlighted in the ACIF case by the simulations in Figure 14.

5.5. Primary and Secondary Services

"Principle 2" on Slide 33 of the May briefing outlines an approach of designating certain services as 'Primary services' (listed in Appendix 1), and proposes these should be given higher priority than other services should a significant risk of excessive interference be determined. In general this is consistent with most other interference management approaches, where Telecom's 'Primary Services' correspond with the term 'Basis systems' used in Australia, USA and other jurisdictions.

It is surprising to see ReADSL2 (ADSL2 Annex L, known as 'Reach Extended ADSL2') listed as a potential 'Primary Service', as to date neither Telecom or any other contributor has raised ReADSL2 as a service option, and Telecom confirms there is not a significant installed base. ReADSL2 for rural or other long-loop subscribers is certainly a probable solution to extending service beyond the limit where conventional ADSL2 Annex A becomes unreliable. It would require minimal resources to deploy as it is essentially forwards and backwards compatible with standard ADSL2, and would be turned on automatically and seamlessly whenever a ReADSL-enabled modem and DSLAM pair determined that they would be able to achieve a higher line rate using the ReADSL2 profile than if they used the conventional version.

A possible issue for further exploration is the notation in Appendix 2 (Slide 37) that a Primary System "Can be deployed unrestricted". Even amongst certain combinations of the listed Primary Systems it is possible for significant service degradation to occur through cross-talk, such as ADSL services degrading a SHDSL business service, and restrictions may still be required so as not to unduly impact other Primary Systems.

5.6. Loop Lengths and Benchmarks

Slide 'Appendix 4' in the Telecom NZ briefing refers to the New Zealand line length distribution, and states "there are a material number of lines well beyond the Australian benchmark maximum range of 4.5km for a 320Kb/s linerate (256k service range)". Possibly this is raised to indicate that lines beyond 4.5 km would not achieve a minimum service if the Australian model was adopted. In my opinion, even if the Australian ACIF process and framework was adopted in New Zealand, the benchmark performance curves should be recalculated to suit the mix of services specific to the New Zealand network. The performance benchmarks are determined from the expected level of interference from all the surrounding mixture of services, including E1-HDB3, ISDN Basic Rate, G.SHDSL and so forth, and so the curves in the current Australian specifications are specific to the Australian adoption of technologies. Telecom has indicated that the mixture of services on the New Zealand copper network is different from the mix in Australia, with lower numbers of ISDN and other symmetric DSL services[16] - on this basis, the benchmark curves for ADSLv1 and ADSL2+ are not applicable in NZ and should be recalculated to suit the New Zealand situation. As Dr Potter outlined during the technical workshop and in TelstraClear submissions[17], without the significant degradation caused by services in the frequency band most used by long-distance ADSL services, the New Zealand specific benchmark should be considerably higher than the Australian benchmark at long ranges. The benchmark curves may also need to be adjusted periodically as the relative proportions of interfering services in the overall mix of potential interferers changes over time.

Figure 8 demonstrates this effect – the orange line indicates the 320kbps line-rate situation that Telecom requires to deliver a 256kbps service. As Telecom note, the Australian ADSL1 benchmark effectively only guarantees this rate will be achieved on lines up to 4.5 km long. This is misleading however as when the ISDN, SHDSL and other potential interferers are removed and the only substantial interference comes from surrounding ADSL services, under the 1% worst-case cross-talk conditions (and with eight other ADSL services running at full power – that is, close to 100% broadband penetration) ADSL can still provide this service on lines up to 5.1km. Also shown is the extra reach provided through deploying ReADSL2

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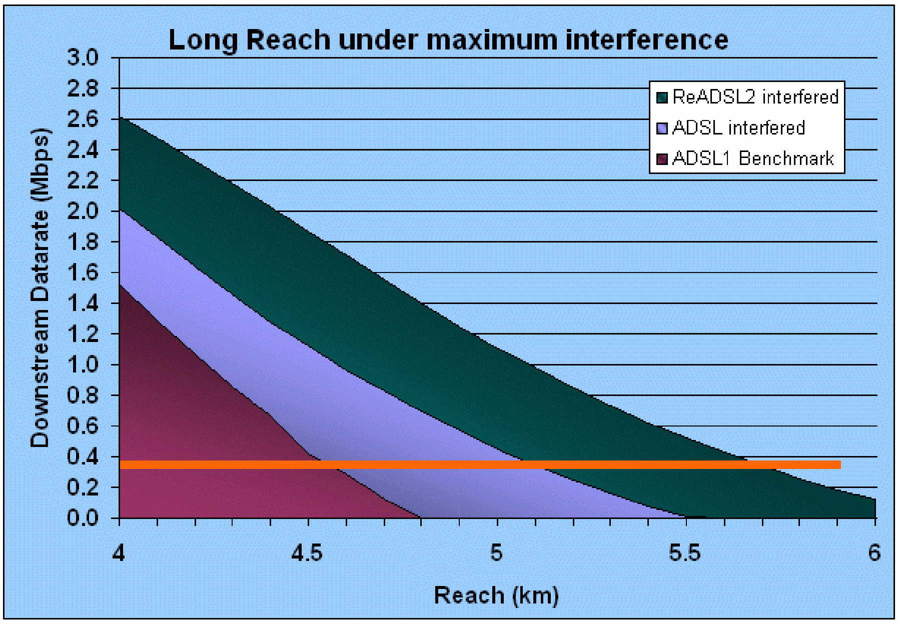
[16] Telecom, TCL09, Section III – "New Zealand has relatively low penetration of ISDN and other DSL services"

[17] TelstraClear, TCL08, Paragraph 4 – "the worst case interferer that determines the ADSL Benchmark at long range is not FEXT from adjacent ADSL systems, but NEXT from ISDN and low rate SHDSL. This is demonstrated in the slides 8-11 presented by TelstraClear at the recent Workshop; those slides show that the ISDN interferer case has lower rate, because ISDN causes considerably more interference…."

services, which even under maximum interference will manage to push this out to 5.7km, well beyond the distance that Telecom deploys services today.

Figure 8 - Maximum range ADSL services



Referring to the loop length distribution graphs on this slide, Telecom shows that approximately 3% of lines are longer than 4.5 km, which is indeed a significant proportion. In my view the more likely appropriate distance that a 256 kbps service can be provided that would correspond to a New Zealand ADSL1 benchmark is approximately 5.1km, which would be approximately 1.5% of lines. Under the ACIF assumptions of all interferers running at full power/full speed, and 1% worst-case cross-talk, approximately 1% of lines at this range would not be able to obtain ADSL service – around 0.015% of lines in total – and ReADSL2 can take care of the majority of those.

6. Spectrum Modelling

This section includes graphs and figures demonstrating the effects of crosstalk interference on DSL services under a variety of scenarios and service penetration proportions, based on DSL simulation software.

The software package used for these calculations was developed by Telstra Research Labs, and the methodology and results of this package have been compared and confirmed with results produced by two other independently derived software packages from NEC Australia and Adtran Inc of Alabama, USA.

Key parameters of the simulations include:

- Arbitrarily defined PSD profiles can be built for victims and interferer technologies, with separate transmission profiles for 'upstream' and 'downstream' communications.
- All four forms of cross-talk are individually modelled (upstream FEXT, upstream NEXT, downstream FEXT, downstream NEXT) and then combined with the industry agreed -140 dBm/Hz background noise floor to determine the overall noise background level at each channel frequency.
- Line attenuation is simulated with varying attenuation level by frequency, based on measurements of line characteristics in field installations.
- The level of cross-talk coupling uses the 1% 'worst case' coupling profiles measured for the cable type, and combined using the FSAN model described in detail in ANSI T1.417-2001 *Spectrum Management for Loop Transmission Systems* and T1E1.4/98-189.[18]
- For ADSL technologies, information bits are variably allocated to channels based on the computed Signal-Noise Ratio (SNR) as would be calculated by a DSL modem/DSLAM pair during re-training.
- For ADSL technologies, a signal in any channel is taken to be undetectable at less than 9.75dB SNR margin, incorporating 3dB of gain through error correction

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[18] Note there is ongoing fundamental research into crosstalk models and there are alternative models for combining complex multiple cross-talk situations – see for example Galli & Kerpez (2002), *Methods of Summign Crosstalk From Mixed Sources – Part 1* (IEEE), viewed online at http://www.argreenhouse.com/papers/sgalli/XtalkSum1.pdf

coding. For symmetric systems, the system is deemed unusable at less than 6dB SNR margin, incorporating 5dB gain through error correction coding.

The modelling tool and these simulations are generalised simulations of DSL systems compliant with ITU-T specifications, and are applicable in general to all networks. While the tool was developed for the Australian regime, only the derived network deployment rules and limits are specific to the Australian context.

The distance and ‘reach’ scales may vary slightly between different countries due to variations in cable gauge. The tool performs calculations and infers distances in terms of ‘dB of attenuation’, which is converted to a distance in kilometres using a measured attenuation factor at a reference frequency. The distances and reaches presented here are for the Australian network reference of 0.4mm PIUT cable, with conversion factor of 13.81 dB/km at 300 kHz. Telecom New Zealand performs its calculations at 1024 kHz, at which the attenuation is 26.20 dB/km. The ratio between these two figures permits the Telecom calculations and distances expressed in ‘dB’ units to be directly converted to ACIF calculations and distances.

6.1. ADSL Degradation from increasing service numbers

A single service, in the absence of any nearby interferers, will achieve a maximum rate at the receiver that is limited only by the attenuation of the signal is it travels along the cable until it is reduced to a level near the natural background noise on the cable. As more and more nearby services are added, each will introduce some additional interference through cross-talk into the ‘victim’ wire, and the achievable transmission rate will be reduced to some degree.

Figure 9 - Effect of increasing service numbers

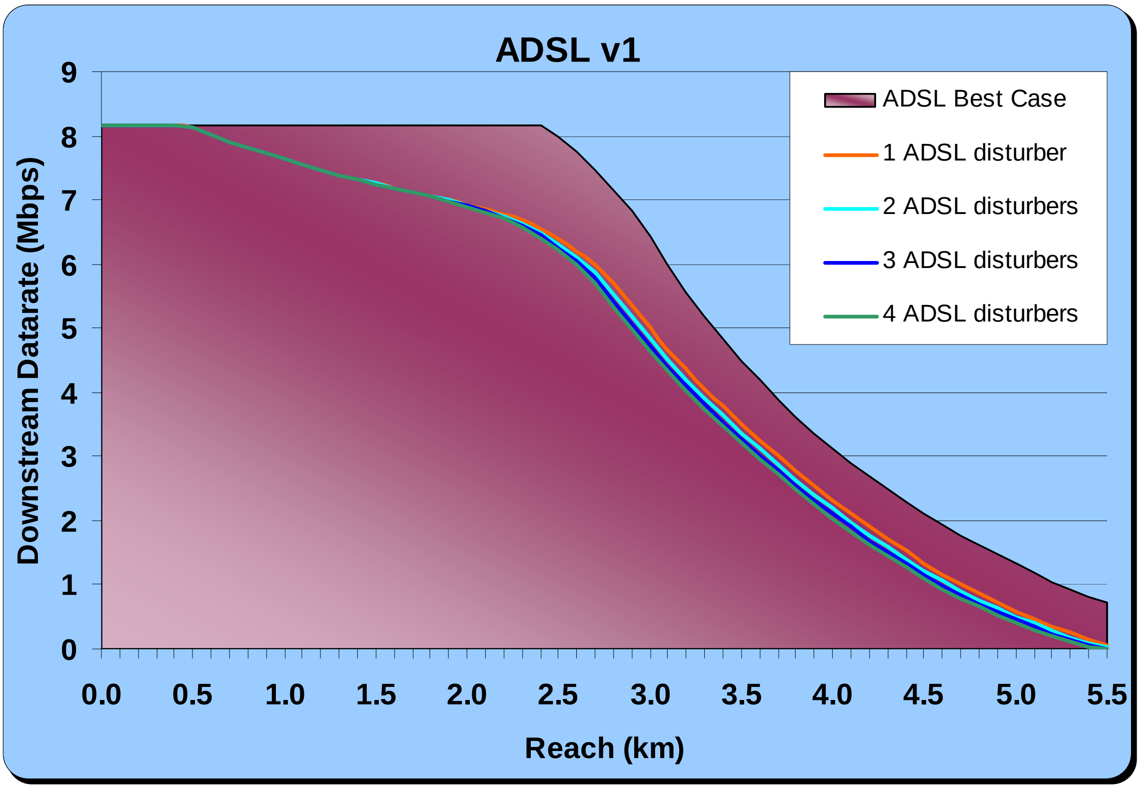


Figure 9 demonstrates that significant degradation does occur to an ADSL service, previously operating without any cross-talk interference at all, when a single additional ADSL service begins operating on an adjacent pair. Beyond the first disturber though, as each additional service is introduced the additional degradation from each additional service is relatively minor – most of the degradation caused through increasing take-up of ADSL occurs early in the take-up cycle, and then adding more and more services has little impact.

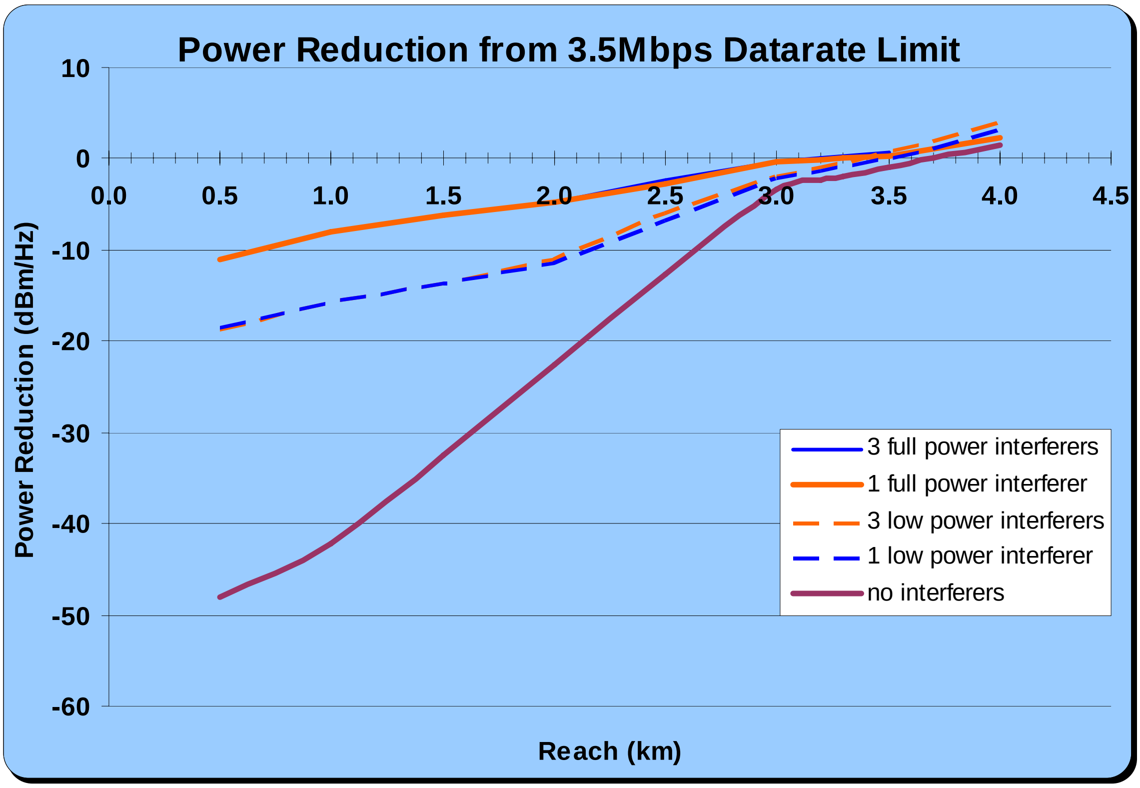
6.2. Power Reduction for 'constrained services'

Telecom is proposing to constrain or limit the bit-rate of ADSL services as a method of reducing the transmission power of short-range services. Where an ADSL service could, if unconstrained, achieve a bit-rate significantly above 3.5 Mbps, then Telecom believe that constraining the data-rate will allow the DSLAM and modem to negotiate a reduced transmission power such that the 3.5 Mbps data rate is only just achieved.

Telecom's 3.5 Mbps data-rate corresponds to a negotiated line rate of approximately 4.1 Mbps, which from Figure 9 occurs on lines shorter than 3.6 km (if no other interfering service is nearby), or approximately 3.2 km in the presence of other interfering services.

The following chart is derived from simulations of the average SNR across all channels that are being used to achieve the desired line rate. The SNR average at the distance where the service can only just achieve a linerate of 4.1 Mbps is set as the 'baseline' or minimum SNR. At shorter distances, the service will achieve a better or higher SNR on average. The difference between the two is the extra headroom or 'SNR margin', and it is this margin that the DSLAM could trade-off by reducing its transmission power - this is plotted as 'Power Reduction'.

Figure 10 - Power reduction from bit-rate limiting



The average loop length in Australia is approximately 2.2km. In New Zealand it is likely to be similar or slightly shorter, judging from the distribution graph of loop lengths[19] in the Telecom briefing slide Appendix 4.

Figure 10 shows that an isolated service limited to 3.5Mbps data-rate can achieve significant power reduction on short lines – between 20 to 30 dBm/Hz reduction on 2km lines. However, once even a single low power service (10 dBm/Hz lower than standard is modelled) is activated on an adjacent pair, the level of increased interference requires the data-rate limited

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[19] SM01, Appendix 4, graph "Cumulative Loop Length Distribution". 50% of lines are shorter (or longer) than approximately 1.73 km.

service to increase transmission power to compensate – and the result is that the data-rate limited service can only achieve a more modest average power saving of approximately 10dBm/Hz. If the adjacent service is instead a full-power service (including a “bit-rate limited” service longer than around 3km) then the level of power reduction is even further reduced to a modest 5 dBm/Hz on average.

In general, this shows that, even if a ‘bit-rate limited’ regime were put in place, the practical effect as more and more services were deployed is that any benefits from the resultant reduced transmission power would slowly evaporate as each service raised its transmission power to cut through the increased noise level. The system overall would approach an unconstrained transmission power regime in any case, with an average transmission power reduction for shorter-than-average lines settling somewhere between 5 to 10 dBm/Hz. This would produce an inconsequential reduction in cross-talk on adjacent services, negating the point of the “bit-rate limiting”.

In subsequent analysis we assume a ‘bit-rate limited’ regime could result in an average transmission power reduction of 10dBm/Hz for ‘low power’ ADSL services.

6.3. Long Lines

In this section we simulate the effect of increasing numbers of both full-power unconstrained services and reduced power bit-rate limited services on services at the extreme margins of line length around 5km. Within Telecom’s regulatory submissions, they outline their concern regarding existing services operating at this distance[20]. The ‘victim’ line is operating at full power.

To achieve the lowest base service of 256kbps downstream data rate, the line must synchronise at a line rate of approximately 310 kbps – this level is also shown on the diagram, along with the line length limits that are implied by a line speed of this level.

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[20] TCL06, pp66, “DR MILNER: ….we have customers out up to the - in fact beyond the 130 dB at 1024 Khz range today and we need to be able to make sure that they continue with service”. 130dB loss at 1024 KHz on 0.4mm guage cable is a line length of 4.96km

Figure 11 - Maximum range ADSL Services

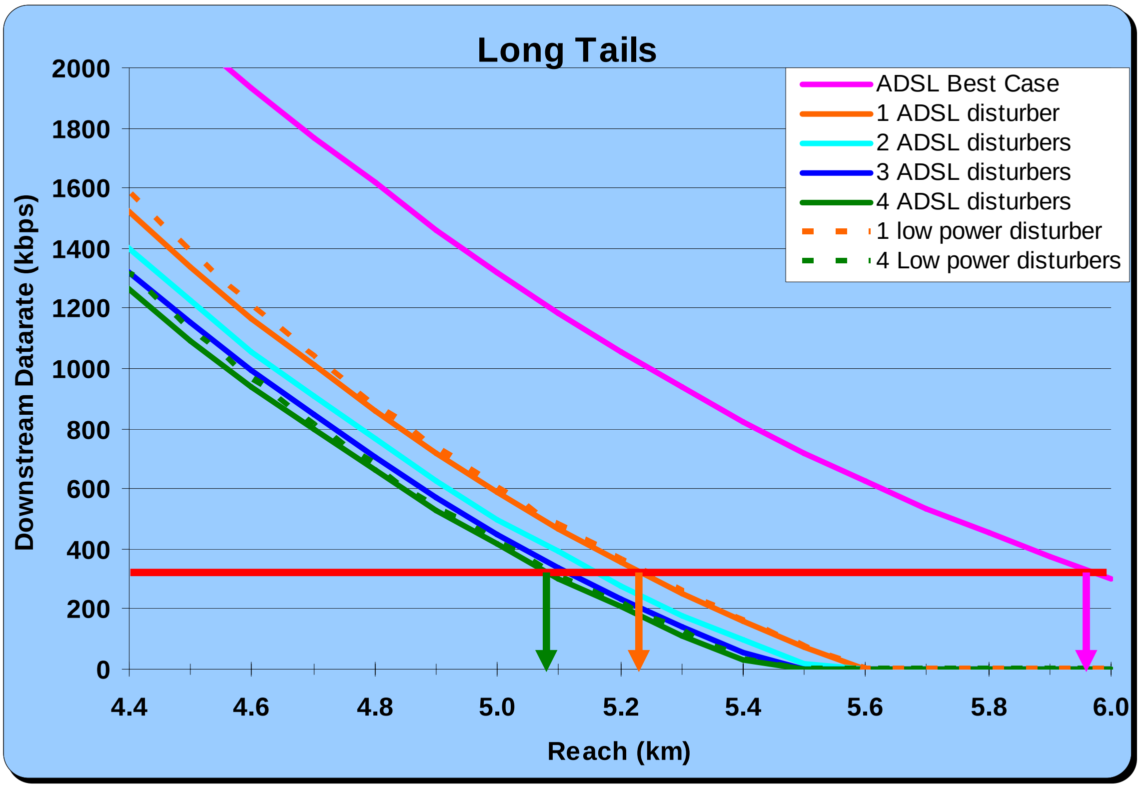


Figure 11 shows that an isolated ADSL service on a good quality line can deliver this service to almost 6km, and at 5km may be able to deliver up to 1 Mbps data-rate – however, this contracts to distances of around 5.1 to 5.2 km for a 256kbps service once one or more neighbouring lines begin to cause interference.

More importantly, it shows there is no significant difference between interference from unconstrained full-power ADSL services and from reduced power ADSL services, and no benefit for long lines in introducing a reduced power or bit-rate limiting regime. Any reduction in data-rate or any long line services which becomes inoperable completely is caused by simply adding new services into the network, not by whether its data rate is constrained or not.

Services that have been provisioned with 256 kbps in the ‘danger zone’ between 5.1km and 6km (i.e. beyond the expected performance of ADSL once interferers become more common) demonstrate the need for a spectrum management plan and initial simulations before the ADSL1 network was deployed.

Figure 12 - Maximum range ADSL services

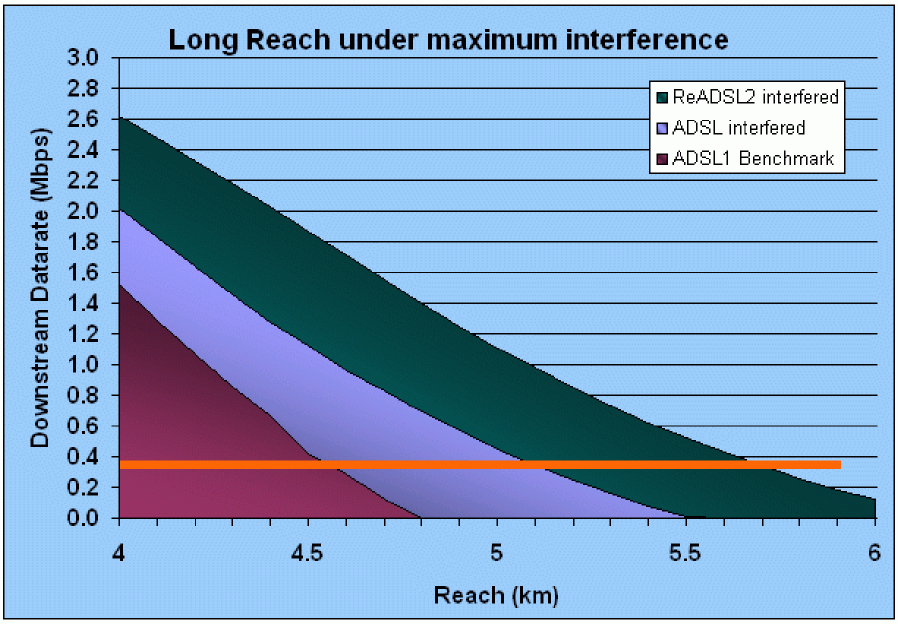


Figure 12 demonstrates the same situation with reference to the Australian ACIF principles. Compared here is the ADSL1 ‘benchmark’ – the minimum expected performance under worst-case cross-talk and maximum number of interferers, which for 256kbps data-rate services extends only to 4.5 km. The benchmark is determined by all possible interfering technologies, and when the worst-case interference due to ADSL only is used (the blue area) then ADSL service can be assumed out to 5.1km. Thirdly, the newer ‘Reach Extended ADSL2’ variation is shown – also under worst-case cross-talk interference – and it promises to provide service out to 5.7km, well beyond the maximum limit of Telecom’s services today.

For any service at large distances where increased interference has caused the service to cease functioning, Telecom should deploy ReADSL2 to restore service, as it has been specifically designed to provide the best results on long lines.

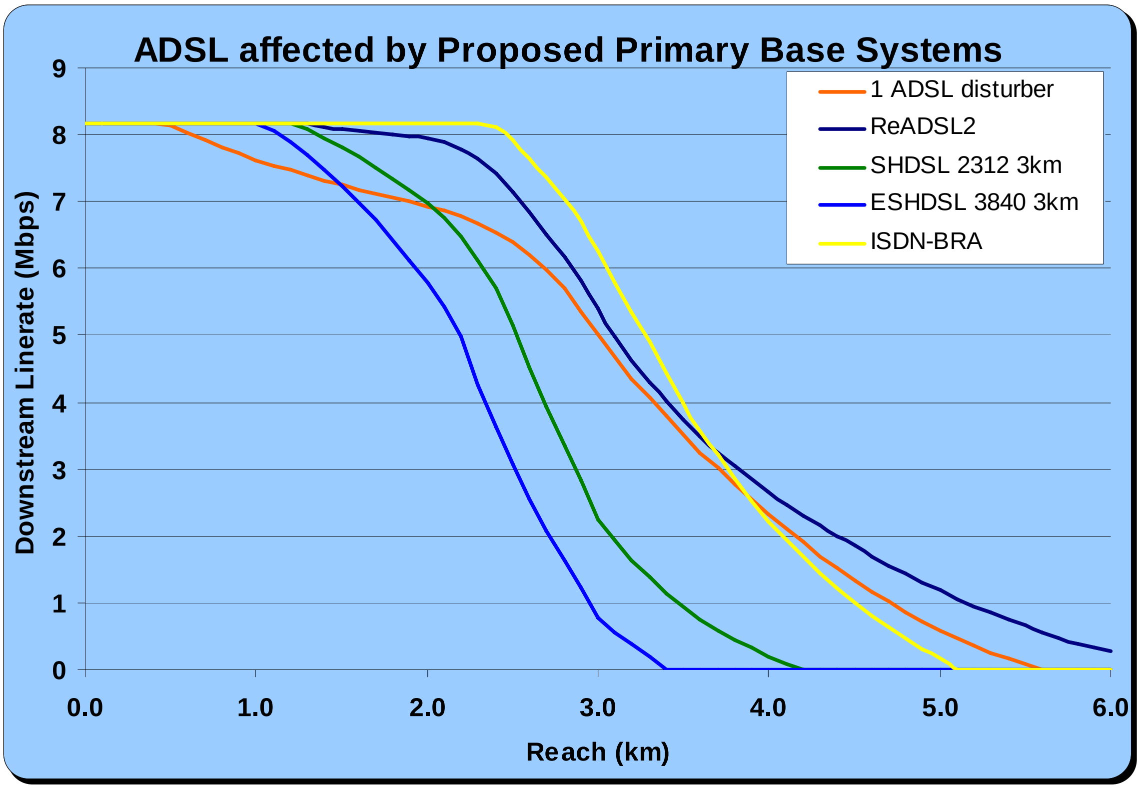
6.4. Telecom’s Proposed Primary Systems

Within the section of their May briefing document dealing with Telecom’s Draft Spectrum Management Approach (Slide 20) they propose several ‘primary systems’ – technologies that provide (or will provide) key services, and should be protected from other systems if undue interference would occur.

Previous charts have demonstrated that mutual crosstalk amongst ADSL systems does not lead to significant impairment, however each of these ‘Primary Systems’ can cause significant impairment to other primary systems unless extensive modelling is undertaken and suitable deployment rules, restrictions or other measures are introduced.

As Telecom have indicated they are looking to develop a plan that permits symmetric business services to be deployed to significantly longer distances than the ACIF plan allows, the symmetric SHDSL and ESHDSL systems are modelled with a length of 3km, while the other ADSL variations and ISDN systems are modelled as unrestricted lengths. The following chart shows the relative impairment of a single adjacent service of each type on a full-power ADSL1 service:

Figure 13 - Primary Systems interfering with ADSL



Notable from Figure 13 is that the only technology that does not impede the farthest reaches of ADSL more than ADSL itself is the Reach Extended ADSL2 variant.

All other Primary Systems significantly degrade ADSL – in the case of the SHDSL and ESHDSL systems, a ‘business line’ of 3km has a dramatic adverse affect on adjacent ADSL services longer than about 2km – which will be more than 50% of services. Clearly, some other form of management will need to be developed if 3km long business symmetric services are to be retained – possibly they will need to be separated into different cable sheaths, or a shorter length restriction will need to be determined.

Figure 14 – Primary Systems interfering into SHDSL

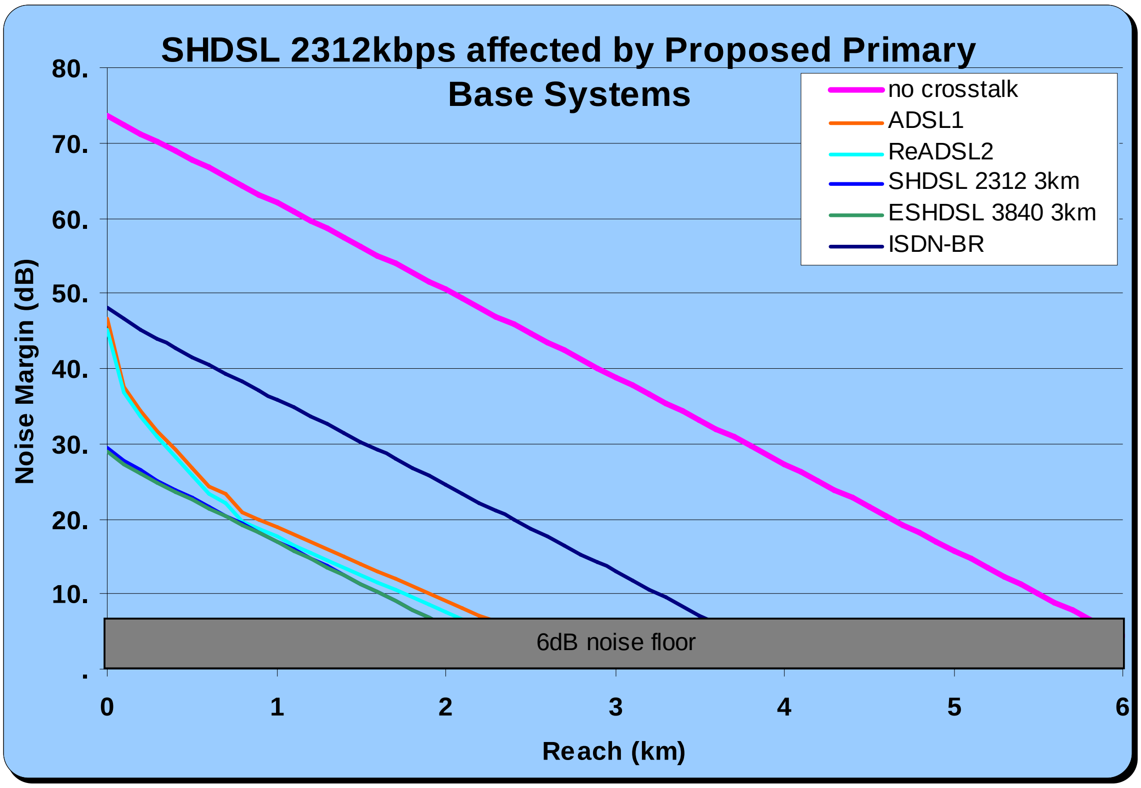


Figure 14 demonstrates the very significant effect that just one adjacent service could have on a SHDSL 2312 kb/s service, also a proposed Primary System. In the absence of any cross-talk interference, on a good line SHDSL can extend to almost 6km before being subject to so much attenuation that the service cannot work.

Add an adjacent service though and the attainable range reduces dramatically. An adjacent ADSL or ReADSL2 service may degrade the SHDSL service until it will not operate beyond approximately 2.2km, and a neighbouring SHDSL service will degrade it even further, establishing a maximum working distance of less than 2km.

These effects will no doubt be experienced in the access network now, in the absence of any other rules governing the deployment of each transmission system. As the penetration of mass consumer broadband continues, the statistical likelihood of an existing service being impacted by a new ADSL service is increased – a spectrum management plan is urgently required to prevent ADSL and business services from being detrimentally affected by other services,

7. Factors to consider in a NZ spectrum management regime

When developing New Zealand's future Interference Management Plan the following points should be considered:

- Any mandated requirement for a special customisation on the part of equipment manufacturers (such as supporting a customised transmission spectrum profile for example) would likely have the effect of raising prices and reducing the availability of compliant equipment. Mandated special PSD masks, different from those specified in the relevant international technology standards, would have this effect. Limits that are applied by the operators, but can be accomplished by standards-compliant equipment (such as limits on deployment distance, or separation of services on different cable binders, or a mandatory or prohibited use of a feature that would otherwise be optional) are preferred;
- The standards must have a revision process, and will likely need to be updated periodically as new technologies become available and old ones obsolete;
- Some technologies may be deemed to have priority over others, whether by virtue of their widespread use (such as ADSL) or class of subscriber (symmetric services for business that require reliability). These are Telecom's proposed Primary Systems;
- The requirements should not, as far as possible, limit the commercial arrangements possible from service providers. Spectrum management is a technical process, addressing a technical issue of crosstalk.
- All technologies used on the network should be considered, not just ADSL.
- Pragmatically, it may happen that some currently operational services on the network will not comply with the new requirements. This situation may need to be recognised as exceptions, and rely on natural attrition to remove the exceptions over time, or a work-program to rectify the non-compliant systems may be desired or required.
- While Dynamic Spectrum Management (DSM) is a desirable goal, at best this will be incremental to a Static Spectrum Management process, as most of the technologies to be considered on the copper network have static profiles, including all the symmetric technologies. DSM is possible only with DMT-based systems, essentially only the ADSL family and VDSL family.

- If the ACIF approach is adopted, the minimum performance 'Benchmark curves' for ADSL variants should be re-calculated, based on the expected disturbers in the NZ network. The ACIF benchmark includes contributions from technologies such as Basic Rate ISDN that may not be as widespread in the NZ network, and so the NZ 'benchmark' may have a different shape to the Australian benchmark. This may have particular consequence with the long-distance tail for ADSL in the 4 – 5km range as it is ISDN that is the greatest disturber in the 130 – 250 kHz portion of the spectrum that is the most important for ADSL service reach. Eliminating ISDN from the benchmark calculation may raise the benchmark at long distances.
- Consider that interference management is all about the achieved performance (in rate and/or reach) of the transmission system – not of any higher-order services. It should possibly be specified in terms of actual line bitrate or the transmission user data bitrate. It should not make any assumptions as to what layer2 or later3 protocol is operating over the transmission (i.e don't try to account for ATM or IP headers). The accounting of an 85% reduction to allow for packet or cell header overhead is only appropriate for a retail subscriber service description, not for technical transmission systems. (example – spectrum management rules should also be easily applied to networks running Voice-over-DSL or video-over-ATM, not necessarily IP packets).

8. Dynamic Spectrum Management

This section provides a short review of the current state of Dynamic Spectrum Management, and summarises research papers published over the past five years.

8.1. Stages of Dynamic Spectrum Management

Dynamic Spectrum Management refers to the ability for technologies such as ADSL2, ADSL2+ and VDSL2 to modify the size and shape of their spectral transmission profile while still maintaining connectivity with the corresponding receiver at the other end of the line. This modification may occur autonomously, with the two devices agreeing between them on their spectral profile and transmission levels, or directed under external management control.

DSM is deployed on a DSL service to achieve two simultaneous outcomes:

- Optimise the performance of the technology in the presence of external cross-talk interference; and
- Reduce its own impact on nearby services that may or may not be able to adjust their own profile.

DSM coordination is thought to evolve in three phases:

Stage 0: Uncoordinated, current practice – DSL capable of reaching ~ 1 Mbps. Some improvement may be possible by using measured crosstalk instead of always assuming worst-case.

Stage 1: Autonomous Spectrum Balancing – DSL capable of reaching ~ 10 Mbps. Transmit PSDs of DSLs are jointly or autonomously optimized to lower crosstalk. For example, two DSLs could use distinct frequency bands, eliminating crosstalk entirely, particularly in common fed remote cabinet situations.

Stage 2: Coordinated Spectrum Balancing – spectrum management under control of a centralized management system.

Stage 3: Vectoring, from a fiber-fed remote terminal – VDSL capable of reaching ~ 100 Mbps. Multi-user techniques (MIMO) are used to jointly optimize all transmit symbol streams and joint receiver structures. DSM operates in real time

Much of current DSM research is oriented to maximising line rates in a 'CO/RT' situation, where a given distribution area is served by copper loops of which some are driven from equipment housed in an exchange building, and others are driven from remote cabinets located much closer to the subscriber premises. Under these conditions the stronger signals from the closer cabinets can dramatically interfere with the exchange-originated signals, as seen from the viewpoint of the subscriber modem receiver. This form of access network deployment is not prevalent in New Zealand, so it is possible that algorithms designed to optimise line rates in these scenarios will be only marginally applicable in New Zealand.

Most deployed networks around the world would be characterised as being in Stage 0, where adjacent lines are essentially uncoordinated, and subscribers are offered products and line-rates that are known to be able to be achieved under conservative noise and interference assumptions. Few carriers have completed the task of mapping out the cross-talk coupling factors between each line and its neighbours throughout the access network, which is required for Stage 2 to be accomplished.

The newer variations of ADSL – ADSL2 and ADSL2+ - include much more extensive diagnostic capabilities and statistics gathering, including recording and reporting the received spectral energy profile in each channel, so carriers can now use ADSL2 modems to build a database of line characteristics.

An example of a carrier using Stage 1 techniques would be characterised through deploying ADSL2+ technology, but deliberately not using the upper frequency band for services originating from an exchange-based DSLAM. Instead, the upper frequency band would be reserved for cabinet-based DSLAM ports, and the lower traditional ADSL downstream band not used at all from the cabinet. In this way the two systems will not interfere with each other as they are both transmitting in different frequency ranges out to the subscriber – however, it also implies that the significant speed increases that other jurisdictions are offering through ADSL2+ is not available.

8.2. Current State of DSM standardisation

The following section is quoted from the latest published status report on formal standardisation of DSM capabilities[21] in August 2005, concerning updates to the North

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[21] ETSI GSC10ATIS Status Report of DSL work GSC10, August 2005. Viewed online at http://portal.etsi.org/docbox/workshop/gsc/GSC10_RT_Joint_Session/gsc10_joint_26%20ATIS%20DSL%20Work.doc

American spectrum management stanadards document T1.417 Spectrum Management for Loop Transmission Systems:

"The work on Dynamic Spectrum Management (DSM) continued this past year with the goal of a ballot in 1Q06. The goal of DSM is to enhance spectrum-management value by improving reliability and increasing data rates through measurement and/or dynamic management of DSL spectral compatibility. Dynamic management incorporates parameters of the loop plant environment and loop transmission systems that are time or situation dependent and which are not incorporated in the current issue of T1.417 Spectrum Management for Loop Transmission Systems. Using physical-layer performance information provided to the service provider's maintenance entity, the service provider may use this information to improve service provisioning, reliability, and/or data rates. DSM defines methods and/or tests that determine the spectral compliance of dynamic-spectra DSL systems with themselves and with the static DSL systems of T1.417. Specifications may thus allow situation-dependent (i.e., adaptive or dynamic) assignment of lines, signals, spectra, and operation of DSL modems that are found spectrally compliant. For example, there were a number of contributions to Annex E on compliance criteria for ADSL and VDSL."

Practical and agreed DSM methods and equipment that can implement DSM is still a year or two from being commercial reality.

8.3. Evolution of algorithms:

(Summarised from "DSL Spectrum Management", Dr. Jianwei Huang (Princeton University), March 13, 2006)

A number of theoretical approaches to multiple line DSM have been developed over the past few years – these are known as:

- Iterative water-filling (IW)
- Optimal spectrum balancing (OSB)
- Iterative spectrum balancing (ISB)
- Autonomous spectrum balancing (ASB)

Iterative Water Filling (IW)

The IW algorithm was developed and published by Yu, Ginnis and Cioffi in 2002, and is essentially an extension of the standard method for allocating information bits to ADSL channels based on the SNR of each channel that was built into the ADSL standard specification. Each line maximizes its own rate by varying the shape of its PSD, while maintaining a total overall power constraint assuming fixed interference plus noise.

It has the advantage of being autonomous – it does not require any central coordination, however it fails to deliver an optimal mix of solutions when the actual interference on lines does not match the assumed interference and noise model.

Optimal spectrum balancing (OSB)

OSB was developed in 2004, and uses a central database of the current spectral profiles of each line and its cross-talk coupling to adjacent lines to calculate centrally the optimal profile for each line through a joint exhaustive search of optimal spectra of all users at each channel frequency. The optimised spectrum is then downloaded to each DSLAM port, where the DSLAM port must then re-synchronise the new profile with the modem. This is supported only from ADSL2 onwards.

While OSB can achieve better results over all lines than IW, it is very computationally intensive, and requires the central coordination system to continuously upload the spectral profile of each port, compute an optimal balance, and download the new profile.

Again, the main problem being solved is the coordination of shared CO and RT deployments.

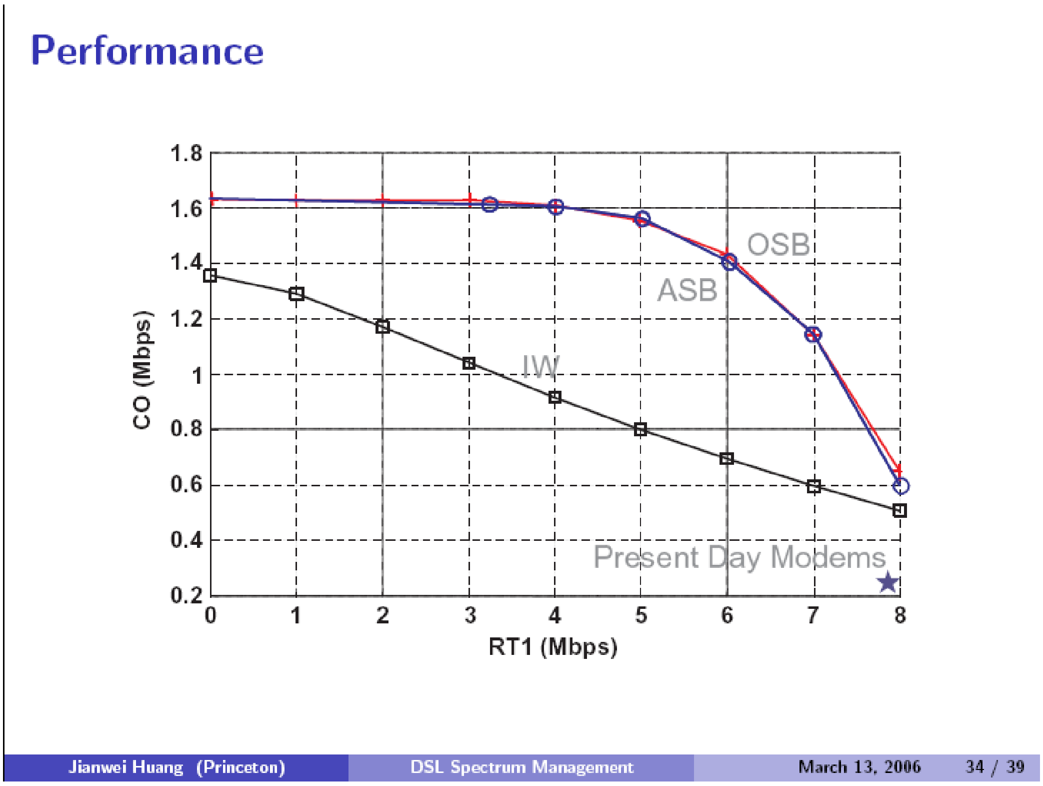
Iterative spectrum balancing (ISB)

ISB was developed soon after, as a centralised system that combines the central optimisations of OSB, and the iterative nature of IW. Under ISB, the central system does not attempt to simulatenously optimise each line’s transmission spectrum. Instead, it optimises one line while holding all the others steady, and then steps to the next line. The system as a whole is proven to approach an optimal steady-state situation after a few iterations through the collection of lines, without requiring the raw computing horsepower required to perform simultaneous optimisation, reportedly producing 100% - 150% better line conditions than the earlier IW algortithms

Autonomous spectrum balancing (ASB)

The latest algorithm – Autonomous Spectrum Balancing – was developed in 2006, and is a return to a system that does not require centralised computation. Under ASB, each line attempts to optimise its line rate by modifying its own spectrum, however it does so against a model reference line, and attempts to jointly optimise both its own line rate and the line rate of the fictitious reference line – in essence, it is an extension to the ‘selfish’ IW algorithm that attempts to optimise or reduce the damage caused on the other system. By measuring the actual SNR margins at each tone the DSLAM can iteratively step through a number of optimisation steps, measuring the effect on the noise environment of all the other lines performing the same algorithm – and the system as a whole converges to an almost optimum solution for each line extremely close to the solution obtained through the centralised ISB algorithm.

Figure 15 - simulations of DSM techniques



Performance

Jianwei Huang (Princeton) DSL Spectrum Management March 13, 2006 34 / 39

Figure 15 shows simulated results of the various DSM techniques listed, while attempting to optimise the line rates achieved when an exchange-based DSL line and a cabinet-based DSL line are causing mutual interference. The latest ASB technique produces an extremely close to optimal solution without requiring a central management system.

Which approach should be put into practice in the New Zealand network will depend largely on the extra capabilities that might be built into newer generation DSLAM, line-cards and DSL management systems over the next several years as these techniques discussed above move from the theoretical realm to commercial implementation.

All approaches require, as a first step, that each line in the NZ network is characterised, measured and its characteristics recorded, which cannot realistically commence until ADSL2 is widespread, as it is through the enhanced diagnosis and line characterisation and reporting built into the ADSL2 and ADSL2+ standard that forms the most cost-effective method of gathering the required data.

9. Project Brief from the Commerce Commission

I was asked by the Commerce Commission to review submissions received by the Commission in the ihug/CallPlus Bitstream Application, specifically to assess Telecom's proposed spectrum management plan currently under development (due to be released to the industry in late 2006) against other jurisdiction's approaches to spectrum management, and alternative spectrum management approaches.

Material to have regard to included:

- Relevant material presented by the parties in Decision 568 (the TelstraClear Bitstream decision);
- Material submitted by the parties in the ihug/CallPlus Bitstream Application; and
- Telecom's High Speed Internet customer briefing 17th-19th May 2006.

10. CV for Dr Paul Brooks

Dr Paul Brooks

Technology Director

BSc (Hons) Physics & Computer Science, University of Adelaide
PhD Astrophysics & Optics, UNSW
Foundation Member, Internet Society of Australia

Competencies

Paul's expertise in telecommunications design, planning and operation has been forged through a number of executive and consulting appointments within the Australian Internet and telecommunications industry. His practical and pragmatic knowledge of communications protocols, leading equipment suppliers, carriers & service providers and the Australian regulatory environment has assisted many organizations build critical services.

Paul has extensive hands-on experience in Broadband Access and data networking, having designed and built networks based on ATM, Frame Relay, Gigabit Ethernet, IP, either directly or through wholesale/other carrier services and lead implementation teams for carriers and ISPs. In Australia most of these have also been based on Wholesale products from other carriers such as Telstra Unconditioned Local Loop (ULLS) and various DSL flavours, and included negotiating access conditions and working through regulatory concerns.

He has been involved in a diverse range of projects, from small, such as assisting a leading Australian DSL network builder in its early days to understand the options and intricacies of deploying telephony services over broadband networks – to large - engaged by Telstra's NDC division to work on very dense broadband network designs in China and India, and developing a national $130 million DSL network architecture.

Experience

Founding an independent consulting practice in 2004, Paul's project leadership has encompassed:

- Assessing operational and cost aspects of ULLS & LSS undertakings and access disputes – ACCC
- ADSL2+ spectral modelling - ACIF
- WAN Strategic Planning/Analysis – Southcorp, Flowcom
- Voice Telecoms Strategic Planning/Analysis – Southcorp
- RFP generation, evaluation & vendor selection – Flowcom, Southcorp
- Remote & Rural Telecoms – Macrocom

- Carrier Network Redesign & Operations – Flowcom, Macrocom, NTLT, Digital Distribution Australia
- Training – Central Queensland University
- Network/Service Audit – Flowcom, NewSat, NTLT

Before consulting, Paul's career encompassed executive management roles in a number of influential firms. Sample projects and career highlights include:

- **CTO, TransACT Communications:**
  As Chief Technology Officer for TransACT in Canberra, Paul had overall responsibility for expansion design and planning the "triple-play" voice/data/video integrated broadband FTTC/VDSL network and the internal IT infrastructure, including vendor selection, management of equipment, and the technical/IT support of service development. He designed and led the trials for the first commercial TV over ADSL services in Australia outside Telstra.
- **CTO, eCom Communications:**
  With this seed-stage start-up telco Paul covered the evaluation, selection and deployment of a planned national broadband network and organisation to design and operate the network. Providing strategic direction on current and future technologies and business practices to Board members, Investors and other executives, and hands-on selection of equipment, transmission, services and management/billing systems suppliers to build underlying infrastructure to support the business.
- **Director, Asia-Pacific Network Engineering, Global One:**
  A core Executive Management role in Global One Australia/New Zealand (now Equant / France Telecom), providing strategic technical leadership and responsible for network planning, design and deployment of the ATM, Frame Relay and Internet backbone networks throughout the APAC region, with personal involvement in pre-sales complex network designs for large customers, and expansion projects within the global backbone networks.
- **Windows Sockets Team Leader:**
  In the infancy of the Internet, Paul was a leader in the global Windows Sockets (WINSOCK) software standardisation effort, which opened up the use of MS Windows PCs to run TCP/IP-based applications, helping enable the explosion of the World Wide Web.

Paul is an active participant within ACIF, ATUG and the Australian ISP community, is a Foundation Member of the Internet Society of Australia, and is regularly invited to present at industry conferences and seminars.

Technical

Paul has the benefit of exposure to most aspects of telecommunications and IT, having worked with many data and voice technologies as both service provider and customer. He is familiar with most communications technologies and protocols including:

- LAN – Ethernet, Fast Ethernet, Gigabit Ethernet, FDDI
- WAN – Frame Relay, ISDN, DDS, ATM, X25, MPLS
- Metro – SDH, PON, xDSL
- Internet Protocols and operation – DNS, BGP-4, OSPF, ISIS, SNMP, etc, VoIP, VoATM, VoDSL, Video, troubleshooting, IP-VPNs
- OSS/BSS – Network/Service Management, Operational Processes, Billing, Provisioning – eTOM and FCAPS models
- Capacity Planning & Modelling

Summary

Paul is a senior consultant, respected internationally through his various roles and activities on industry panels such as ACIF and ATUG. He personally assisted many of the leading Australian ISPs in the early 90's with designing their global Internet backbone connectivity.

Paul is able to liaise at all levels of an organisation, from Board and executive management to technical staff. He has the competency to work on virtually any IT&T consulting assignment from high-level strategy to technical design and specification.