# Zero-touch VDSL2 vectoring

## Copper broadband performance

**Copper broadband plays a key part in New Zealanders' broadband experience. The introduction of new technologies such as vectoring and G.INP continue to improve and maximise the performance of our copper network.**

The majority of New Zealanders continue to use and benefit from broadband (xDSL) services over our ubiquitous copper network. Investment in evolving copper broadband technologies ensures copper broadband speed and stability continue to improve, to meet growing customer demand.

With more than 150 million customers worldwide on xDSL technologies, vendors are continuing to look at ways to get the most from copper networks. This paper looks at two of these new technologies, vectoring and G.INP, which we are investigating as part of our copper broadband strategy.

## Key copper broadband performance inhibitors

One of the biggest inhibiters of xDSL performance is interference or 'noise' from external sources. This noise makes it more difficult for the receiving modem to differentiate between the transmitted signal and the noise, forcing the modem to reduce the throughput rate to compensate.

There are two types of noise that affect xDSL performance:

- Sustained, which is dominated by crosstalk or 'leakage' from other services, mainly xDSL service, in the same cable bearer; and
- Impulse noise, generated by external sources to the cable such as electrical network switching, poorly shielded electric motors, radio transmitters, poorly maintained electric fences and similar devices.

As part of our broadband technology life cycle management, we are investigating the deployment of VDSL vectoring and G.INP to improve copper broadband performance.

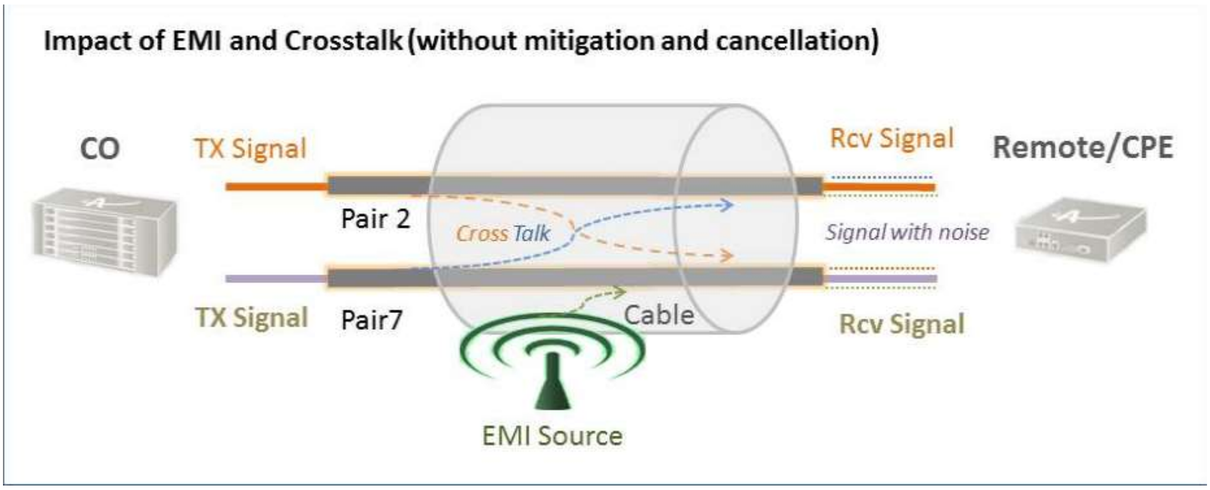
# What is VDSL vectoring?

**VDSL vectoring configures broadband VDSL lines dynamically and automatically to cancel interference due to xDSL crosstalk. It significantly increases performance.**

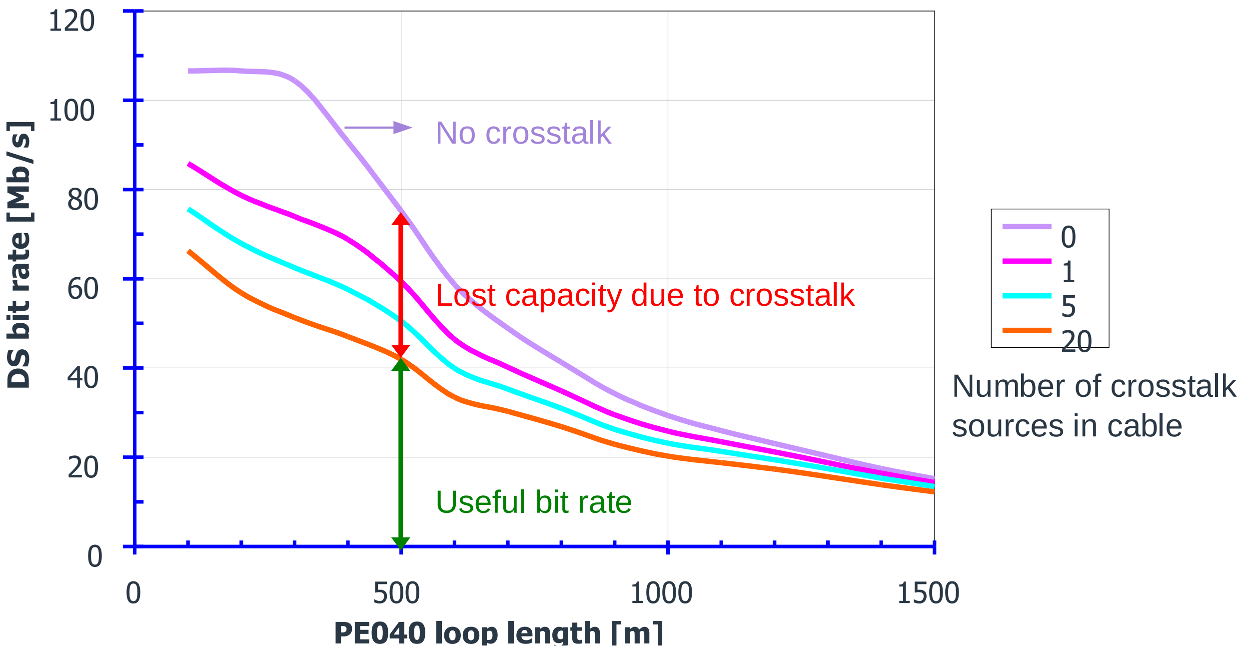
VDSL vectoring is a feature of the new generation Nokia ISAMs, which uses line monitoring information to maximise the data rate by cancelling interference caused by cross talk. This improves the signal to noise ratio and therefore connection speed.

## What is crosstalk?

Crosstalk is the inductive leakage of signals between adjacent copper pairs.

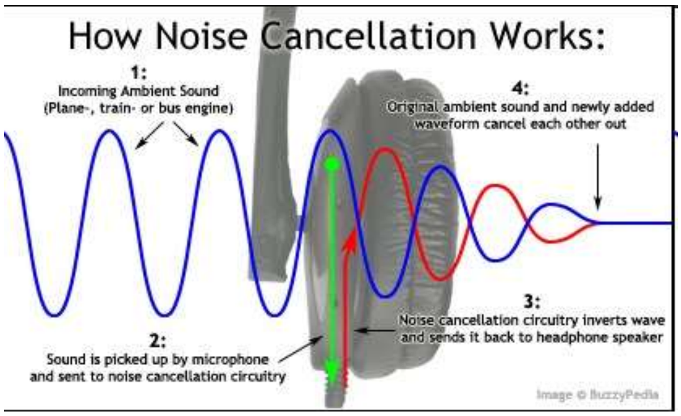



This crosstalk is influenced by the proximity, level and number of adjacent signals. VDSL2 is particularly susceptible to far end crosstalk due to its higher frequencies resulting in greater signal loss over shorter transmission distances. This higher attenuation of the signal causes VDSL2 bandwidth decreases significantly the more VDSL2 services there are in a common cable sheath.



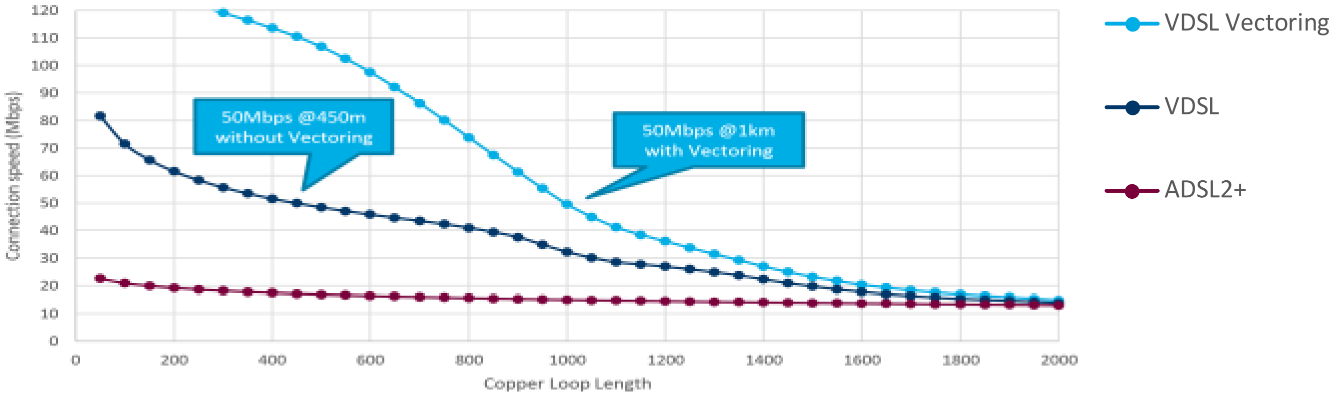

## How vectoring works

In concept, vectoring is comparable to the noise-cancelling technology used in headphones. It produces a clean signal for each line by measuring the crosstalk from all other lines and generating anti-phase signals to cancel the crosstalk signals out, resulting in almost zero noise. This concept sounds simple, but its execution can be highly complex, depending on the environment in which it is deployed.




The noise cancellation technology in headphones, for example, has few variables to address as it suppresses interference in the audio band (20 kHz). They pick up ambient noise (via an external-facing microphone) and generate an anti-noise signal that compensates or neutralises the ambient noise at the ear.

Vectoring does exactly the same thing, by deploying multiple noise cancellers per VDSL2 line. But as it increases performance for everyone vectoring often deals with the crosstalk generated by a few hundred VDSL2 lines and signals that span a wide frequency band (e.g. 17.6 MHz for 17a VDSL2). Nokia "real world" modelling suggests 50Mbps can be attained at 1km. Maximum performance at distances less than 600m can exceed 100Mbps.




Vectoring relies on interaction between our DSLAM and Customer CPE. For example, downstream vectoring works as follows:

1. The DSLAM inserts a known probe signal on a VDSL2 line;
2. VDSL2 modems on different pairs in the same cable bundle measure the error or cross talk induced by the probe signal;
3. This error feedback is forwarded back to the DSLAM by the VDSL2 modem;
4. The DSLAM correlates the error sample with the probe signal to derive the relevant crosstalk coefficient which is then fed into a crosstalk matrix;
5. This process is applied across all lines in the same cable bundle at the same time, providing a complete matrix of crosstalk; then
6. The DSLAM uses this matrix to create a combined noise cancelling signal for each line.

# Modem vectoring capability

There are four levels of VDSL modem vectoring capability:

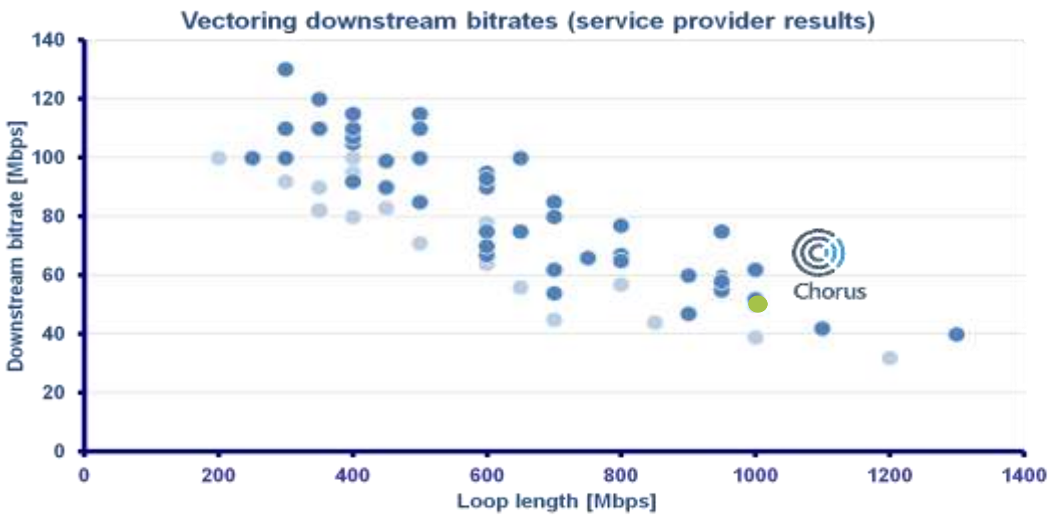
**Full vector-capable CPE**: VDSL modems that fully comply with G.993.5 standards. This type of CPE allows full vectoring gain in both upstream and downstream directions.

**Full Vector-friendly CPE**: VDSL modems that comply with G.993.2 Annex Y standards. While these types of modems receive little benefit from vectoring, they do allows a reduction in crosstalk in upstream and downstream direction. This enables full vectoring capable lines to benefit from noise reduction in both downstream and upstream direction.

**Downstream vector-friendly CPE**: VDSL modems that comply with G.993.2 Annex X standards. While these types of modems receive little benefit from vectoring, they do allows a reduction in crosstalk in downstream direction only. This enables full vectoring capable lines to benefit from noise reduction, but only in downstream direction.

**Legacy VDSL2 CPE**: VDSL modems that do not support G.993.5, G.993.2 Annex Y or Annex X standards. While these legacy CPE lines will not benefit from any vectoring gain, nor do they allow a reduction in electrical noise. Service Providers will still benefit from their customers with full-vector capable lines gaining some downstream vectoring gains on vectored lines. By implementing zero-touch vectoring Chorus ensures the lines with legacy modems are unaffected by implementation of vectoring.

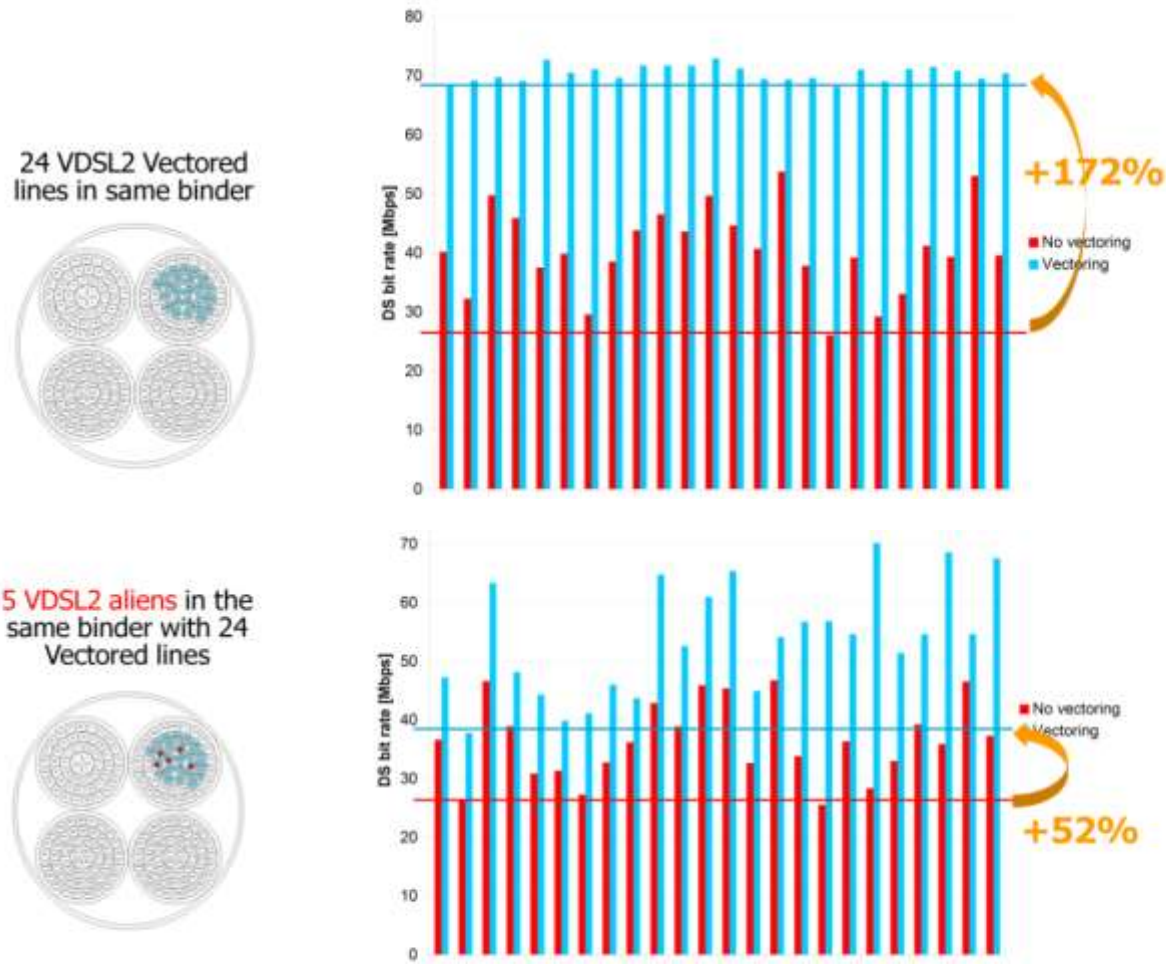
Testing has shown that most modems in New Zealand that support the 998 Band plan can already support vectoring, as illustrated by the following test results:




Vectoring is only effective if all lines in a cable bundle are fed by the same DSLAM. This makes vectoring unsuitable for unbundled areas or where cable pairs are spread across multiple DSLAMs.

# Zero-Touch vectoring

Large scale deployment of vectoring could be delayed by challenges that arise when vectored lines are mixed with legacy VDSL2 lines. Just one non-vectoring compliant CPE operating in a vectored cable binder can create cross talk, which drastically reduces gains on vectored lines. However, we understand that it is very difficult for service providers to upgrade all of its customers to vectoring in a single step, as they will need to replace all legacy VDSL2 CPEs with G.vector capable CPEs, or at least vectoring friendly CPE.




**Impact of legacy CPE on VDSL Vectoring2**

Zero-Touch vectoring solves this problem by enhanced DSLAM software capability automatically handling all legacy VDSL2 CPEs. Firmware upgrades are not required, so legacy VDSL2 CPEs will effectively be vectoring-friendly without needing to be touched. However only those lines with vectoring capable CPE will receive higher bandwidth vectoring services. This provides a quick and easy way for service providers to introduce vectoring in their network, without having to worry at all about legacy VDSL2 CPEs.

## What does zero-touch vectoring mean for SPs?

Zero-touch vectoring minimises (almost eliminates) crosstalk from legacy CPE to G.vectored lines in downstream direction. However, there will be no vectoring gain achieved in upstream direction.

With zero-touch vectoring, we can enable vectoring on an existing network and see an increase in downstream sync rate on vectored lines.

- Legacy VDSL2 lines will not be impacted by zero-touch vectoring.
- Existing ADSL lines will not be impacted by zero-touch vectoring.

For vectoring to provide the full benefit on connections, CPE needs to support all of the following requirements:

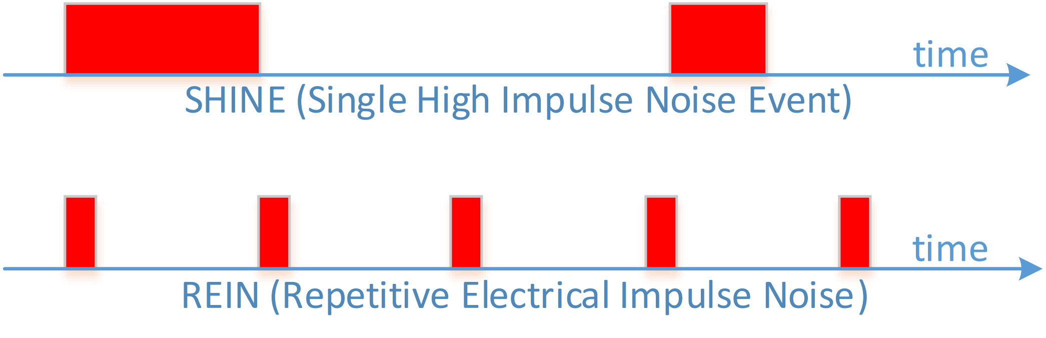
- G.993.5 and its corrigenda
- G.vector (G.993.5) minimises crosstalk impact;
- G .993.2 and G .998.4 Amd 1 - Seamless Rate Adaption - adapts a steady line rate to the signal to noise ratio (SNR) without the line needing to be re-synched.
- G.inp Amd 1 and 2 (G.998.4) - minimises impact noise impact.
- TR-249, Section 8.9 - Protection against connection on one wire and disorderly leaving from the user.

## G.INP

G.INP provides an improved mechanism for dealing with impulse noise.

Impulse noise is short or long pulses of interference from external sources and comes in two types:

1. Single High Impulse Noise Event (SHINE), as generally the result of on/off switching of appliances in the home; and
2. Repetitive Electrical Impulse Noise (REIN), as generally the result of motor controllers, electrical fences or older dimmers.



xDSL has traditionally used Interleaving Forward Error Correction (I-FEC) to compensate for impulse noise, but this has several disadvantages:

- I-FEC introduces a constant delay to all frames;
- This delay overhead is always on, even when no impulse noise is on the line;
- I-FEC is best suited for REIN and is not as effective against SHINE events

G.INP (G.998.4) specifies the use of physical layer retransmission to enhance INP. It provides enhanced protection against impulse noise and increases the efficiency of Impulse Noise Protection (INP).

The approach is similar to the retransmission method used in TCP/IP. Instead of IP packets, however, data transfer units (DTU) are sent between transmitter and receiver. When packets get corrupted during transmission, the transmitting peer is informed and the DTU is resent.

In addition, the round-trip time - i.e., the (minimum) time required for retransmission - is very short in case of G.INP because the DTU error detection and retransmission occurs at the physical layer. TCP/IP retransmissions often take 50 milliseconds or more, while G.INP only takes a couple of milliseconds (4 milliseconds is typical). The result is that G.INP achieves enhanced INP with good efficiency at shorter delays compared to I-FEC.

Another key advantage is that G.INP only transmits when required, i.e. noise is detected on the line. This minimises latency impacts when there is no impulse noise, but it also means the bit rates are not fixed anymore, depending on the number of retransmissions.

Reducing latency is important even when retransmission is not required, providing better the end-to-end communication between the server and the client, as having faster responses reduces the amount of time required to complete an end-user request, such as to start streaming a video or download a webpage. Beyond the speed of the connection, reduced latency improves response times and makes for a better end-user experience.

By providing extra protection and reducing latency on the DSL link, G.INP improves the entire communication chain.

The table below compares traditional INP and G.INP

| | Traditional INP | G.INP |
|---|---|---|
| Endpoint communication | Without feedback | INP using feedback |
| Forward error correction | Reed-Solomon FEC + interleaving | RSOH mainly for error detection thus limited FEC as side-effect |
| High Speed Internet | OK | OK |
| Video | Can be impacted by errors | OK |
| Latency Overhead | higher for a given level of INP, as overhead always present even when no INP occurs | Retransmission overhead only when needed |
| Noise type | Best suited for REIN | Suited for SHINE and REIN |
| | Good RFI robustness | RFI robustness using intra-DTU interleaver |

## What does G.INP mean for RSPs?

G.INP minimises the impact of impulse noise on xDSL lines providing a better end user experience. It can be applied to both VDSL2 and ADSL2+ but may require new CPE or CPE Firmware upgrades to work.

If the CPE is not G.INP compatible then VDSL2/ADSL2+ will fall back to standard INP.

While G.INP and vectoring cannot solve all of the problems that arise in the field which can have many root cases, such as bad wiring, modem incompatibilities, multiples, etc. they can significantly improve the performance of the majority of VDSL users.

## Next Steps

We are trialling VDSL2 vectoring and G.INP in our Innovation laboratory.

The next step is to undertake a field trial to quantify both the benefits and challenges of these technologies in the real world.

## Glossary of Terms

| Term | Description |
|---|---|
| 5530 NA-C | The 5530 NA-C (Network Analyser – Copper based technologies only) is a web-based software application that helps Service and Network Providers provision broadband and narrowband access services, troubleshoot customer and equipment problems, and manage their xDSL infrastructure. |
| ADSL2+ | **Asymmetric Digital Subscriber Line** is one form of the Digital Subscriber Line technology. |
| DSL | **Digital Subscriber Line** a data communications technology that enables faster data transmission over copper telephone lines |
| VDSL2 | **Very high speed digital subscriber line 2** is a form of the Digital Subscriber Line technology, significantly faster than ADSL2+, but with less range. |
| Sync rate | **Synchronisation rate** is the negotiated bitrate between the DSL modem at the customer end and the DSLAM within the Chorus Network. Measured in Mbps or Kbps |
| Noise margin | **Noise margin** is the relative strength of the ratio of DSL signal to noise. Measured in dB. |
| Impulse noise protection | **Impulse noise protection** works with error correction and interleaving delay to provide protection from impulse noise by adding a polynomial checksum to the transmitted data, errors are automatically corrected by the receiver. Measured in symbols. |
| Interleaving | **Interleaving Delay** is the delay in data transmission used to provide error correction. Measured in milliseconds. |
| Maximum PSD | **Maximum Power Spectral Density** specifies the signal voltage based on the PSD measured in dBm. |
| EUBA | **Enhanced Unbundled Bitstream Access** is the variant of the regulated UBA service that is provided with a CR component. |
| BUBA | **Basic Unbundled Bitstream Access** is the original variant of the regulated UBA service that is provided on ASLAMs with copper ATM backhaul. |

| | |
|---|---|
| DLM | **Dynamic Line Management** is xDSL service enhancement that optimises the performance of the service by changing the configuration. |
| G.INP | **Provides improved impulse noise protection** |