

# How Enhanced DSL Technologies Optimize the Last Copper Mile

As broadband speeds increase to support the connected home, a debate continues over which type of network architecture is best suited for wireline services providers. FTTH may be the best media for the long term in greenfield installations. However, in brownfield environments, digging up the ground and laying new fiber is prohibitively expensive for most providers. Copper is the dominant link into most homes.

With recent DSL technology, such as VDSL2 bonded, downstream speeds of 100 Mbps on shorter loop lengths can be achieved. In addition, advancements in DSL technology such as vectoring, phantom-mode DSL, and G.fast are expected to boost performance well past 100 Mbps.

This white paper discusses the following:

- The Opportunity
- Requirements
- Future Technologies
- Conclusions

## The Opportunity

Existing copper plant has been considered a bottleneck to the delivery of broadband triple-play services. Figure 1, below, shows an example of a rate versus reach performance chart indicating downstream bit rate performance. The graph lines show performance for single line VDSL2, bonded VDSL2, single-line vectored VDSL, and bonded vectored VDSL. Single-line VDSL2, shown in pink, provides very good performance at roughly 75 Mbps on a 1000 foot (305 meter) loops. Bonded VDSL almost doubles the bit rate. A newer technology, called DSL vectoring, further increases performance by cancelling far-end crosstalk. Combining the two technologies offers even greater results.

### VDSL2 Downstream - Standard, Bonded and Vectored

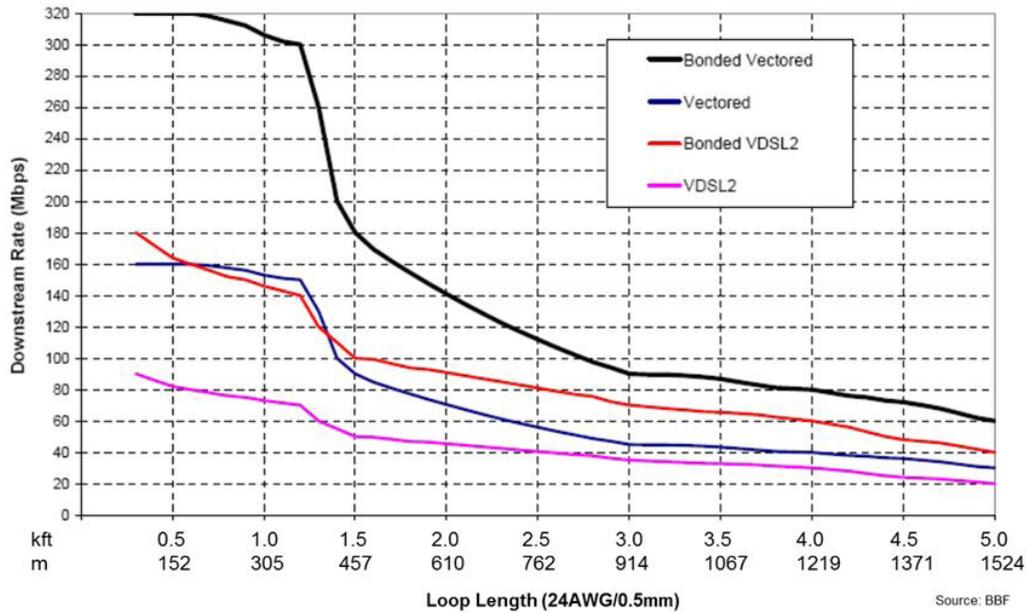


Figure 1. Enhanced VDSL2 rate/reach by technology

Copper attenuates DSL signals, so cable length constrains any transmission. However, bonded and vectored VDSL2 can deliver close to 300 Mbps in the 1000 to 1,200 foot (305 to 366 meter) range.

## Requirements

Taking maximum advantage of this opportunity involves five key factors/requirements:

- Higher VDSL Profile
- Bonding
- Vectoring
- Shorter Loops
- Smaller, Hardened DSLAMs

## Higher VDSL Profile

A higher VDSL profile such as 30a reflects the maximum in Megahertz level or range of the signal spectrum used, not to be confused with the data rate. Figure 2 shows various profile performances relative to loop length. Simply opening the profile up, especially on shorter loops, clearly increases the bit rate, but the benefit falls off quickly as length approaches 2000 feet (609.5 meters).

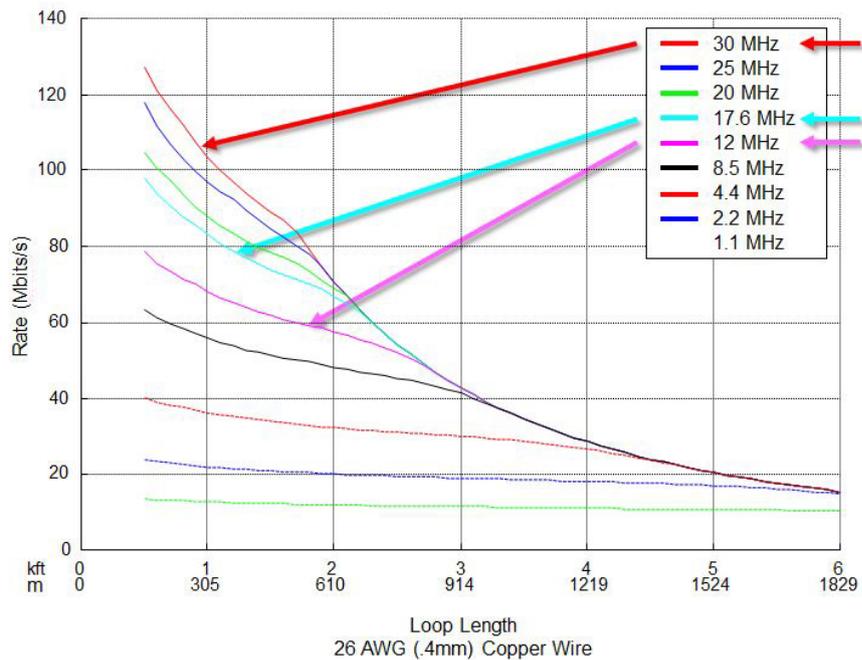


Figure 2. Comparative profile performance

## Bonding

Bonding uses two copper pairs from the DSLAM to the residence and joins them logically at the data layer as one pipe. Doing this almost doubles the bit rate, and is a standardized technique that applies to both ADSL and VDSL. The very flexible technology can deal with two quite different loops: up to a 4:1 bit rate delta on the pairs can be supported. This is not a typical deployment scenario, however, and would likely occur where something is unusual on the “second loop”—perhaps it is much longer, or perhaps it has some impairments.

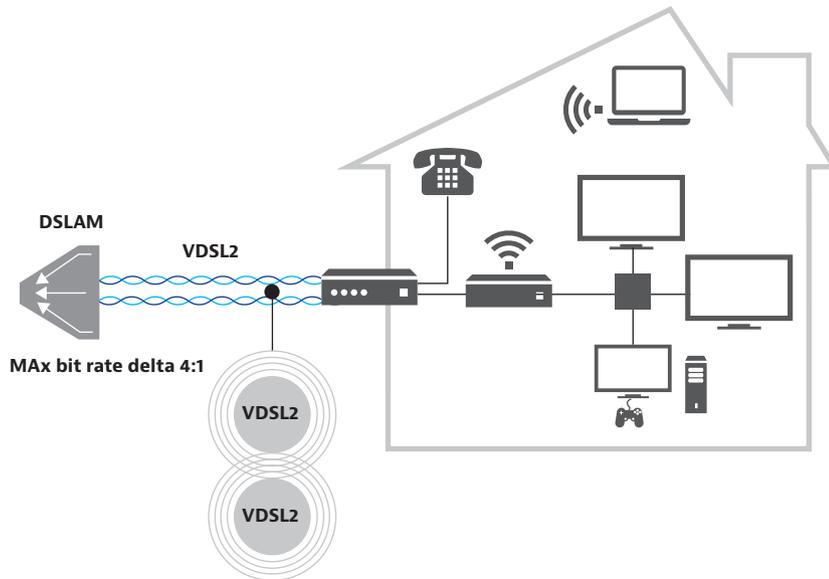


Figure 3. VDSL2 bonding

The ITU has standardized bonding in the G.998 (or G.bond) series. Standards include:

- G.998.1 — ATM-based multipair bonding
- G.998.2 — Ethernet-based multipair Bonding (ADSL2+, VDSL2)
- G.998.3 — Multipair bonding using time-division inverse multiplexing

## Vectoring

Vectoring is focused on eliminating the impact of far-end crosstalk (FEXT) within the binder group. The following section discusses the technology in detail.

DSL-based service involves multiple pairs in a binder group, all carrying DSL signaling. This signal energy radiates outside its pair and is picked up as noise by adjacent pairs. Far end crosstalk (FEXT) significantly reduces bit-rate performance compared to FEXT-free performance. A technique has recently been developed, called vectoring, which can significantly improve bit-rate performance by canceling the FEXT impact. This technique has been standardized by the ITU in the G.993.5 series and is widely available in the DSL vendor community.



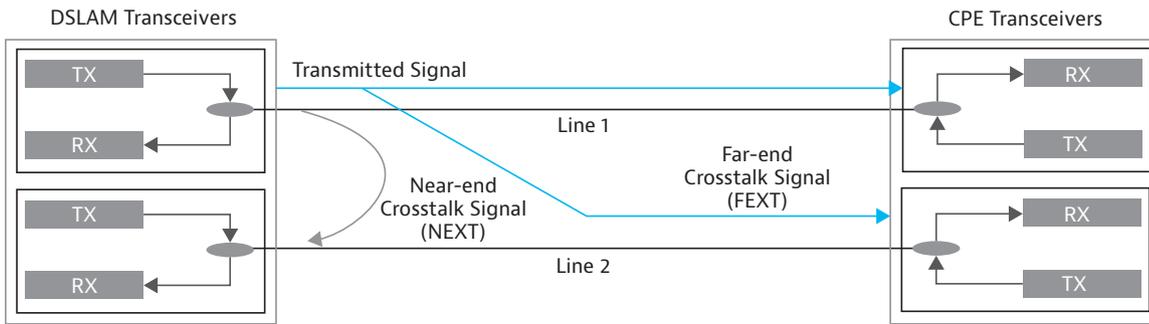


Figure 4. VDSL2 crosstalk

## Pre-Coding the Tx Downstream Signal

In the VDSL line cards, a VTU-O VDSL circuit receives the downstream data stream and processes it through a symbol encoder. This output is then processed by the output modulator and this signal is then coupled to the physical loop copper cable pair. In a vectoring design, a pre-coder function is added as shown below in Figure 5.

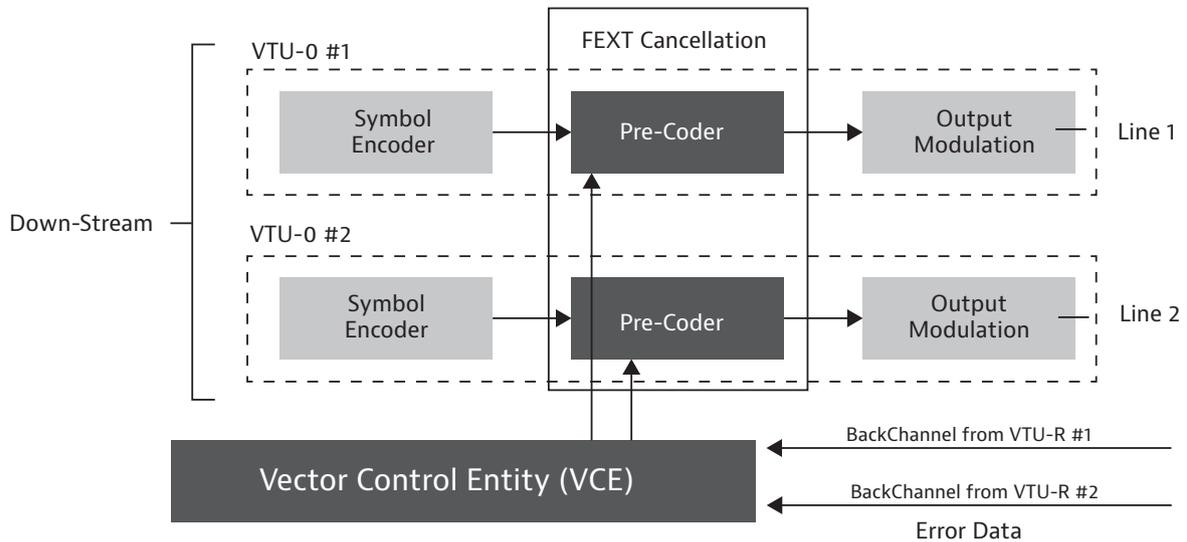


Figure 5. VDSL vectoring

The far-end VTU-R in the CPE receives a special pilot tone sequence of sync symbols and quiet symbols sent from the VTU-O for each discrete multitone (DMT) subcarrier. The VTU-R computes an error sample for each tone. This is, effectively, a vector data noting where the received QAM constellation was positioned when received versus where it should have been. The receiver says, "when you sent me the data, you said it should be here, but I didn't receive it here, I received it over there." There is a displacement.

The VTU-R uses a special, back-channel communication path to send this error sample data upstream to a vector control entity (VCE). The VCE is a new computing entity within the DSLAM that receives the error sample data from all of the lines in a vector control group. It calculates a channel matrix and associated FEXT coefficients from the received data. This data is used by a new pre-coder function to modify the output signal modulation. Through this process, the output signal is changed to anticipate how the receiver will be impacted by crosstalk. The modified signal "cancels" the crosstalk impact.

## Vectoring Scale

Vectoring control scale is very important. In Figure 6, below, the lower blue line shows a standard rate versus reach performance curve. The black line in the middle indicates a line-card level vector performance for lines related to one line card. However, a DSLAM has multiple line cards and lots of other activity: lots of other crosstalk in the shelf, or in the back plane, or in the larger binder group that may come out of the DSLAM. The vector control group cannot control all of the lines impacting the card. However, if a full, node level control group is made, all of the cabling, all of the line cards, all of the ports in the DSLAM can be managed. In this case, we can get a full doubling of bandwidth, as shown in the green line.

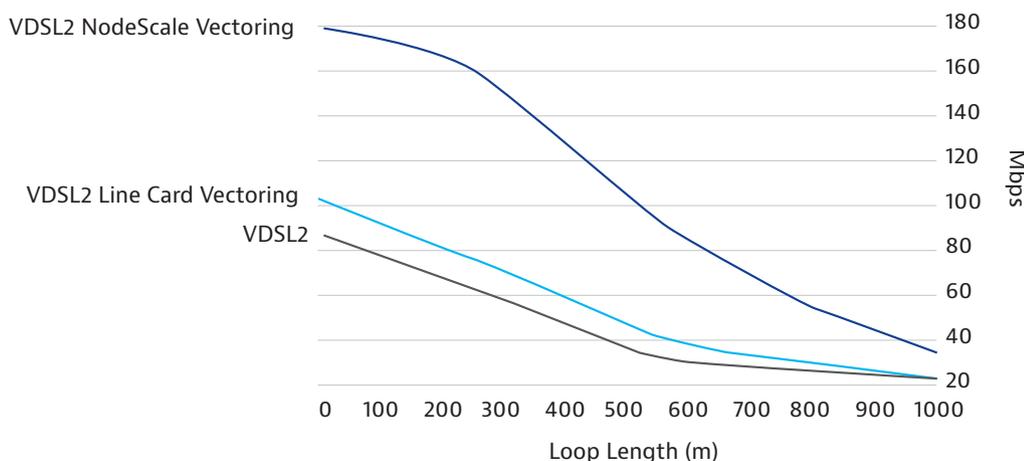


Figure 6. Node scale versus line card vectoring performance

## Vectoring Gain vs. Lines Managed

Any lines that may be in the binder groups used by the VDSL services, but are not controlled, are considered “alien crosstalkers.” Their crosstalk cannot be cancelled by the vectoring technique. Lines carrying T-1 or E1, HDSL, or even ISDN services may be mixed with the DSL lines. Figure 7 shows that to gain meaningful data-rate improvements, 90 percent or more of the lines in a group must be vectored; alien cross-talkers significantly reduce effectiveness.

In actual practice, removing a few bad noise lines will yield greater vectoring gains with less than 90 percent management. The green line shows that advances in digital signaling processing/post processing provide a larger gain with fewer lines being controlled.

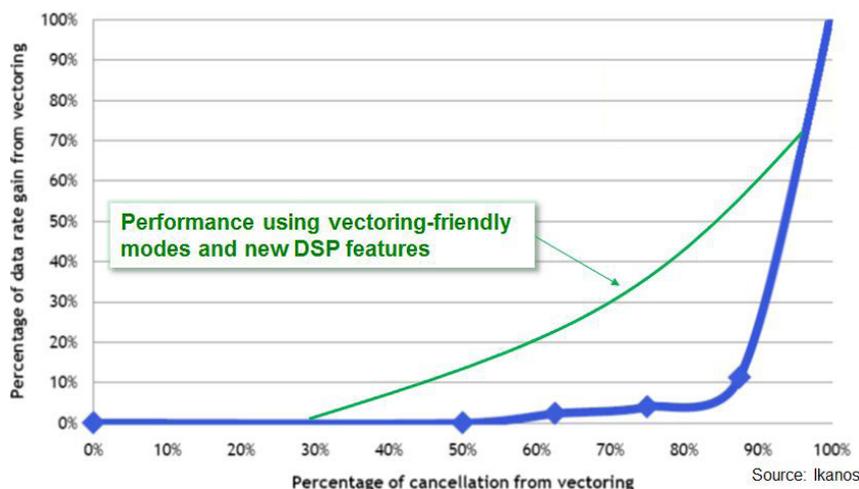


Figure 7. Data-rate gain as a function of the percentage of managed lines

## Shorter Loops

Implicit in any solution using enhanced DSL technologies is minimizing copper loop lengths by moving the DSLAM closer to the premises. The shorter the copper, the better all of these technologies will perform.

New DSLAMs that are smaller and hardened, enabling them to be placed much closer to residences, are now available. Some can be pole-mounted and remotely powered and located closer to the premise, enabling smaller line counts. This enables line control of all lines with a smaller node, thus improving vectoring performance. Using hardened DSLAMs provides a significant enhancement over what has been previously possible.

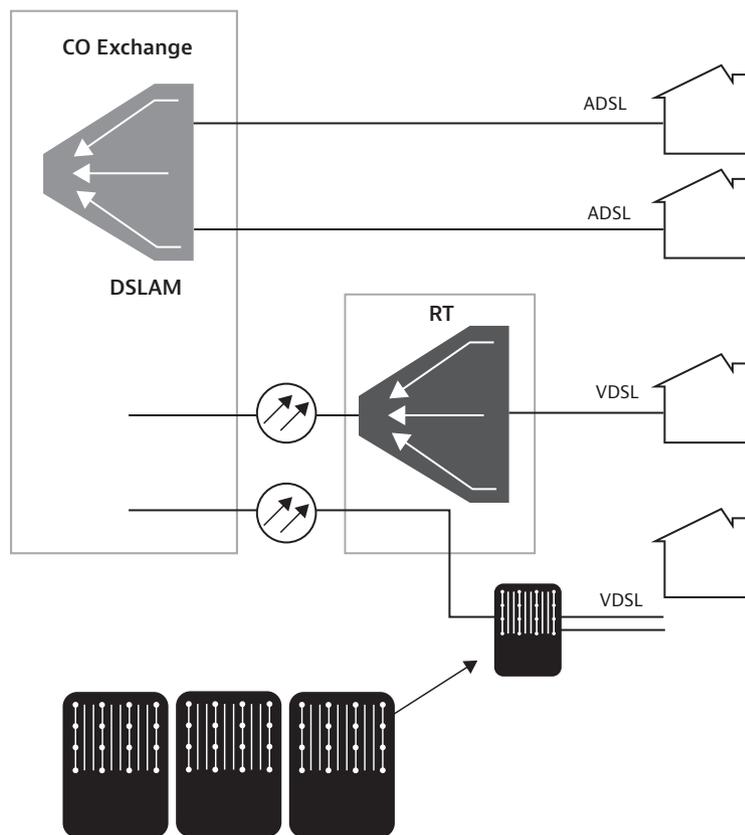
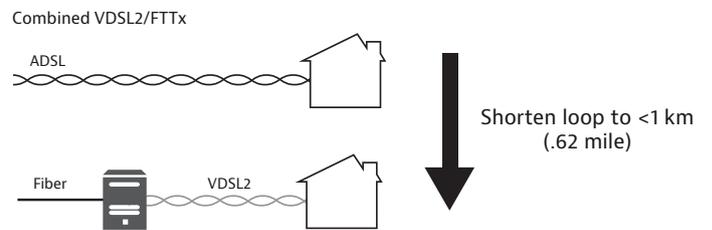


Figure 8. Environmentally-hardened DSLAMs enable shorter bonded loops

## Smaller, Hardened DSLAMs

The dotted green vertical line in Figure 9 shows how using a hardened DSLAM deployed closer to the premises can provide up to 300 megabits downstream over two copper pairs out to 1200 feet (366 meters). Comparatively, if we use a 2.5 GPON with a 32 split (32 homes served by one optical line terminal), the result provides about 78 MB per user—indicated by the horizontal red dotted line. Reducing the split to 16 doubles delivers bandwidth to 156 MB. The vectored and bonded DSL service far exceeds that. As a result, bottlenecks associated with providing good bandwidth to the home with DSL are truly starting to fade away.

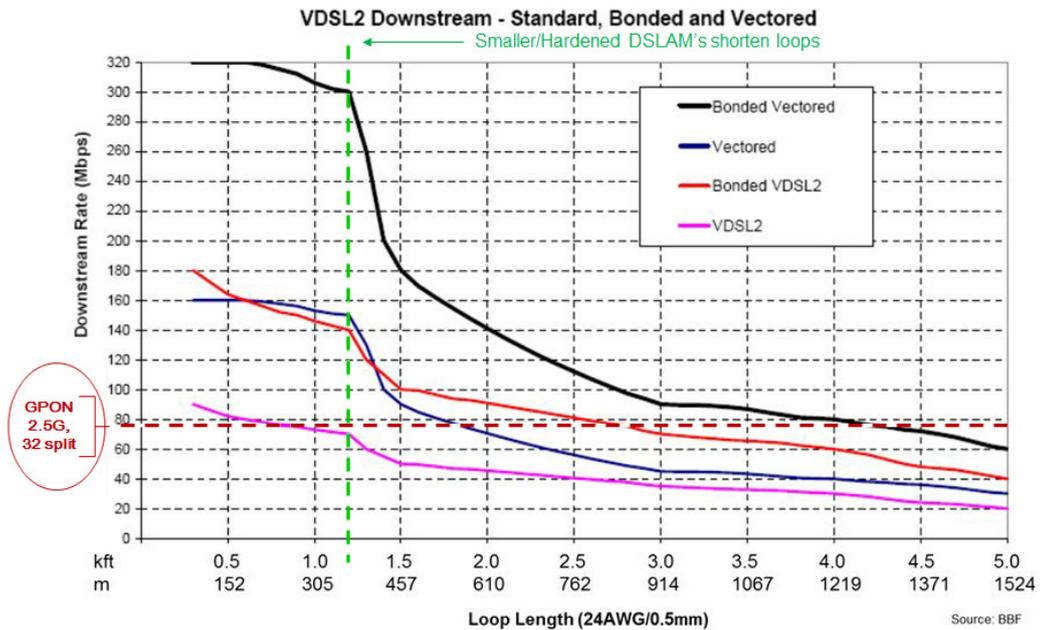


Figure 9. The impact of smaller, hardened DSLAMs on rate/reach

## Future Technologies

While bonded vectored lines over shorter loops deliver significant data rate improvements, two new technologies, Phantom-Mode DSL and G.fast, show promises of even more advances.

## Phantom Mode DSL

This technology adds a virtual, phantom pair to two copper pairs. The two typical DSL copper pairs operate in a differential mode, while the third signal is injected in common mode via a passive coupling device. Thus, phantom mode, indicated below, adds a “third pair” data path without having to add a third copper pair.

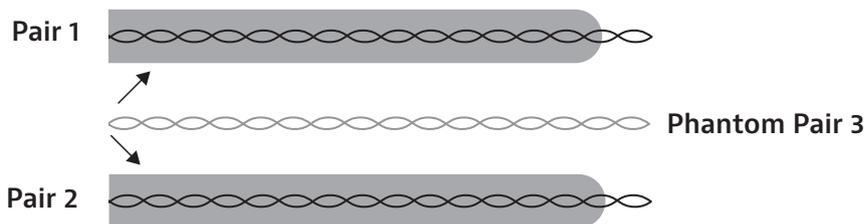


Figure 10. Using a common-mode signal injection to create a third, phantom pair

Figure 11 shows a standard line card with three ports. Ports one and two are wired up to the actual copper, while the third port is wired to a passive coupling device. This device, which is not powered, injects the common mode signal. It can be located away from the DSLAM line card, providing deployment flexibility. Data from port three rides across the copper in the phantom configuration. This means that the CPE must be changed to accommodate the new design, but this can increase data throughput significantly. Common mode is less sensitive to NEXT/FEXT, but it injects noise into the differential mode lines 1 and 2. Vectoring is thus required to reduce crosstalk in the bonded group.

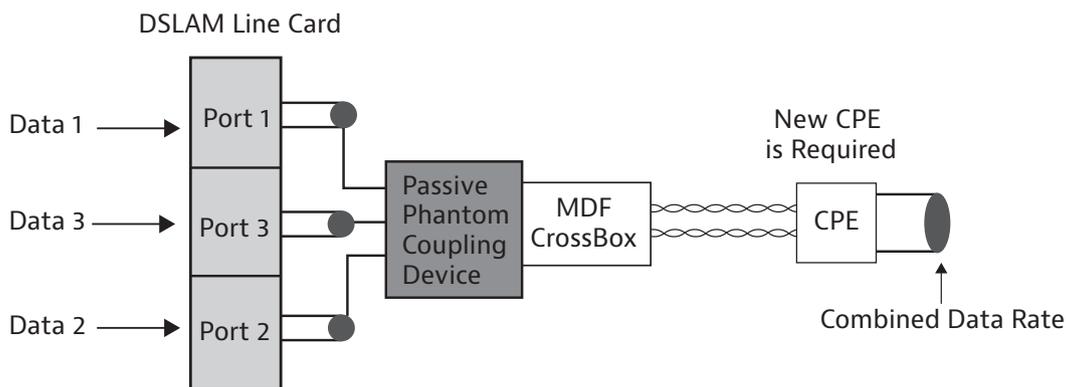


Figure 11. Phantom-mode DSL

As indicated in Figure 12, using bonding, vectoring, and phantom mode together can deliver close to 400 megabits out to 1300 feet, or 400 meters—decidedly attractive performance.

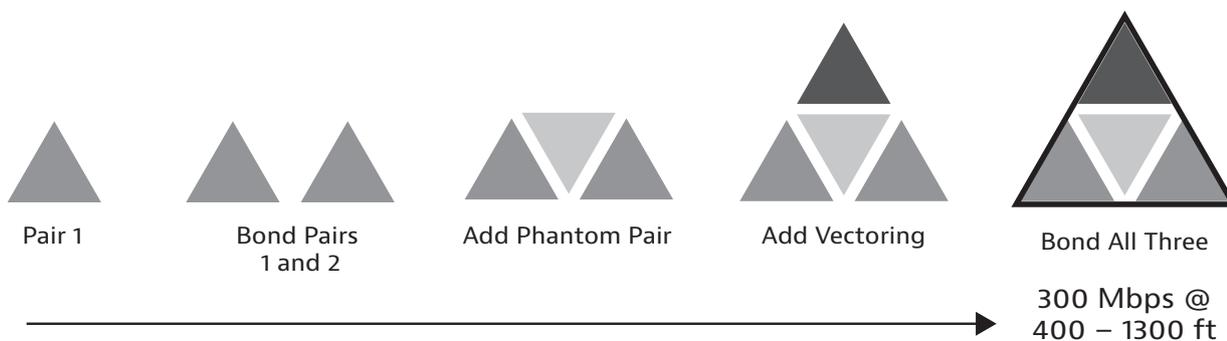


Figure 12. Combining technologies

## G.fast

G.fast is the short name given to work in the ITU to define a new copper transmission technology focused on providing much-higher bandwidth over copper loops out to 650 feet (200 meters). G.fast achieves this performance, in part, by increasing the signal spectrum to 200 MHz—although the exact spectrum has not yet been defined. The concept includes FTTCurb designs to achieve the very short loop lengths. The term FTTCdp (distribution point) describes a new type of ONU, shown in Figure 13.

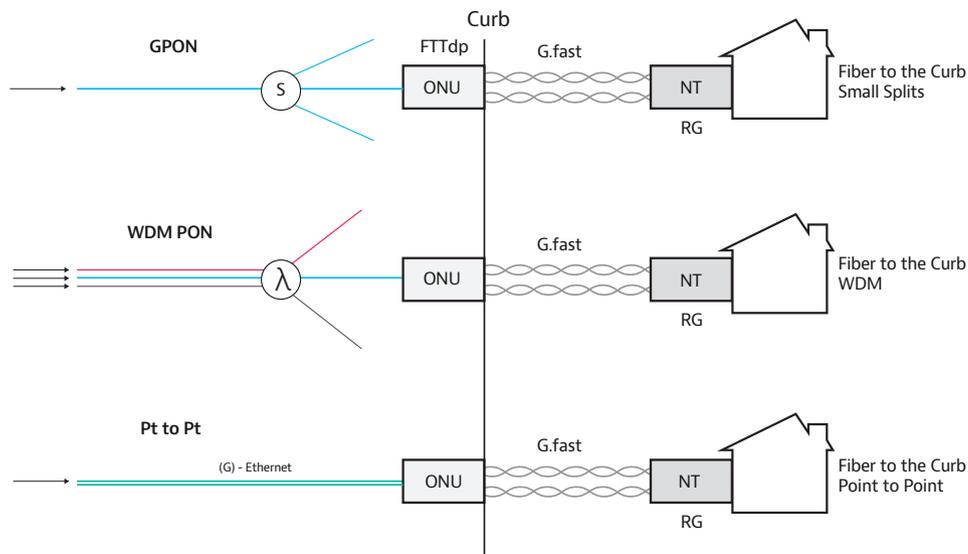


Figure 13. G.fast/optical network configurations

To be feasible, this approach requires new, inexpensive ONUs. Using power from the home over copper pairs significantly reduces costs. Speeds from 500 Mbps to 1 G are envisioned using this distribution point (dp) design, based on recent laboratory work.

The technology is extremely flexible, because it changes the basic technology use of the DMT structure. Current ADSL and VDSL use band plans, or tones, that are one way, or unidirectional. They are downstream, or they are upstream, but they can't be bidirectional. G.fast actually uses time division duplex (TDD) technology that allows each of the DMT tones, on a timed interval basis, to be either upstream or downstream, allowing them to shift back and forth as desired. This removes an arbitrary requirement of reserving up and down channels. If there is no reason to support an upstream bit rate, everything in the structure can be used for downstream data reception. Likewise, more can be used for upstream reception as well.

TDD enables carrying data in a much more efficient way by eliminating wasted spectrum in asymmetric applications. A single pair can support 1 G performance over 100 meters. This is only 300 feet (91 meters), but it only needs to reach from the curb to the NID. The technique will deliver 500 Mbps, bi-directionally, to about 650 feet, or 200 meters.

## G.fast with Fiber

Blending G.fast with a PON structure can yield the best of both worlds. The cost of digging to put fiber into the ground to get to the home is eliminated. This will require a special ONU and a new premise modem, of course, but for brownfield installations, the net can be a huge savings.

## Conclusions

Bonded and vectored VDSL are delivering significant data rate improvements, especially over shorter copper loops. However, vectoring places new demands on managing the outside copper plant. Hardened DSLAMS are making it possible to both improve vector control and shorten loop lengths. New technologies such as Phantom Mode and G.fast promise even more improvement in data rates. The chart below outlines a projection for what may be possible in bit-rate performance and estimated early availability of the associated technology.

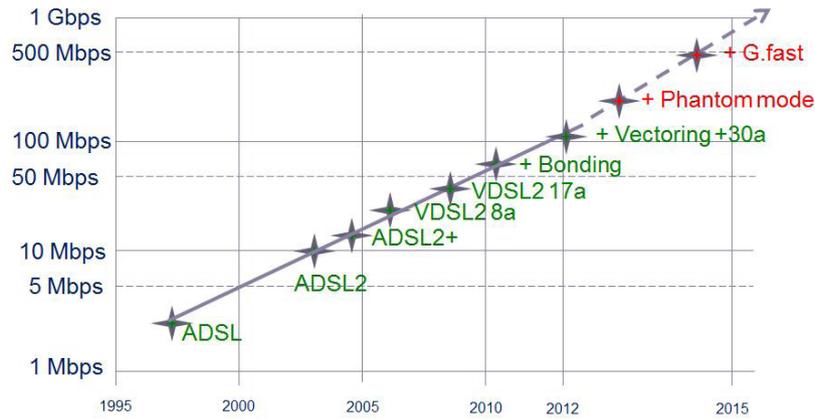


Figure 14. Evolution of copper plant performance

G.fast coupled with a PON network promises significant improvements in both cost and performance in the access network.