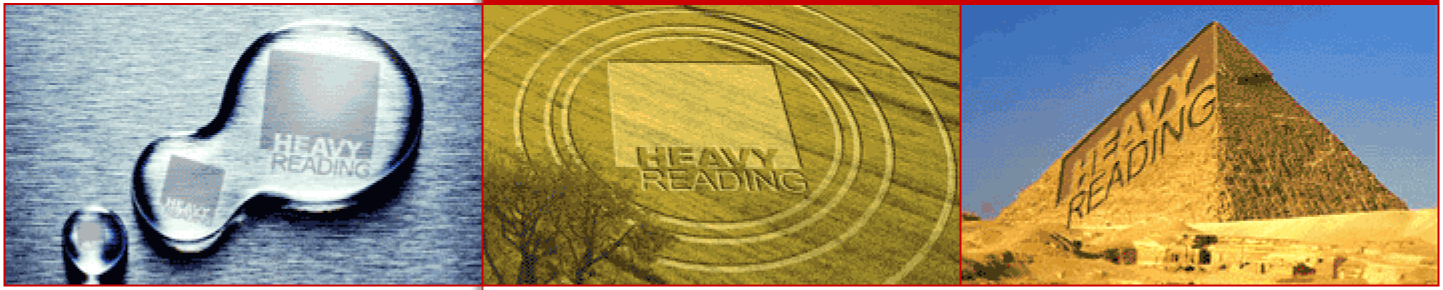
White Paper

DSL Acceleration: Making It Work



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Executive Summary

The deployment of wireline broadband networks in all developed markets (as well as some emerging markets) has been a spectacular success for both network operators and regulators. In the space of about 15 years, over 1 billion homes have been connected worldwide to always-on services, and the average speed of broadband connections has increased more than tenfold in that time.

But wireline broadband is now at an important crossroads in many countries around the world. The transition to higher speeds (more than 30Mbit/s downstream) presents a uniquely difficult set of challenges to both network operators and regulators. Resolving those challenges successfully will be vital to ensuring continuing evolution in broadband services.

The dilemmas are especially acute for incumbent wireline operators that serve the market primarily via DSL. First, there is stronger competition from cable MSOs deploying Docsis 3.0. Second, there is the parallel migration of mobile services to broadband, including Long Term Evolution (LTE). And finally, there is the complex and expensive transition to a fiber-rich access network.

For regulators, meanwhile, the challenge is to develop a plan for next-generation access that preserves or enhances the competitive environment without stifling infrastructure investment or resulting in services that are unaffordable. At the same time, universal service goals continue to evolve. Many political agencies have set public objectives for next-generation access, typically calling both for ubiquitous service at a minimum speed and for the broadest possible deployment of 100Mbit/s services.

The Role of DSL Acceleration

Fortunately, technology continues to evolve new solutions to these dilemmas. In the case of DSL, the emergence of a set of related techniques often bracketed as "DSL Acceleration" has created particular interest as a means to bridge the gap between current-generation DSL and full-fledged fiber to the home (FTTH). Though the latter is clearly the end-game for wireline networks, many operators will struggle to deploy it fast enough to meet the targets set by policymakers. Techniques such as DSL vectoring may help to resolve the dilemma.

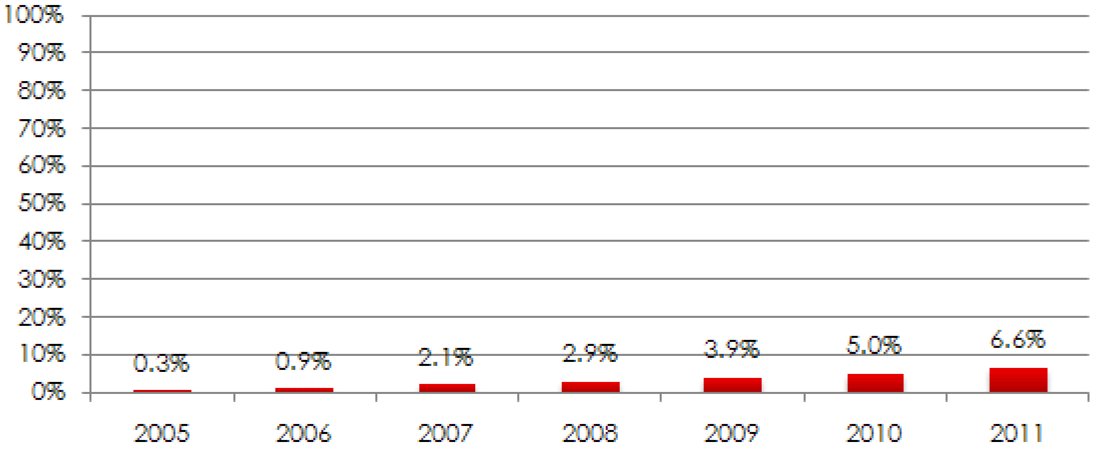
In this paper, we consider the role of DSL Acceleration from a technical, commercial and regulatory point of view. We conclude that DSL vectoring, in particular, shows great promise as an important interim technology on the road to FTTH. However, it does raise some challenges, and we discuss how these can be best overcome to meet the continuing desire for services that continue to increase access speeds while remaining affordable, competitive and widely deployed.

The Fiber Conundrum

The transition to FTTH presents a strategic conundrum to both operators and regulators. On the one hand, FTTH is clearly the end-game for wireline networks, providing near-infinite bandwidth in a network that will also be simpler to manage with lower opex. On the other, FTTH is expensive and time-consuming to deploy – a once-in-a-century replacement of a copper-based network that has been in place in some cases for many decades. But the world – and demand – won't stop while operators deploy it.

As **Figure 1** shows, although deployment of FTTH began at scale about seven years ago, only 6 percent of all copper-based fixed access lines have been converted during this period. In fact, this graphic exaggerates progress in most countries, because a small number of countries – including South Korea, Japan, China and the U.S. – account for most of the lines actually deployed. In most of Europe, the proportion of FTTH or even FTTB is much less than 5 percent of all broadband; all the rest is DSL or cable modem.

Figure 1: FTTH as a Proportion of all Global Wireline Access Lines



Source: Heavy Reading

Realistically, the deployment of FTTH throughout a network operator's wireline footprint is a project with a timescale of more than ten years in most cases. Taking Japan as a real-world example, NTT and a few other Japanese companies began deploying FTTH in 2002, and (in a relatively favorable environment with low deployment costs and supportive regulation) have converted about 44 percent of all lines. A determined smaller country could of course move faster, and some are; but most will see 10 years as a realistic timeline to achieve widespread availability.

But as noted above, demand won't wait for operators to catch up. Using Nielsen's Law* as a proxy for likely future requirements, by around 2016, higher-end customers will expect services of 100Mbit/s downstream and 10-20Mbit/s upstream.

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* Nielsen’s Law states that access bandwidth speed grows 50 percent per year. Based on the historic trend, this would mean that VDSL2 would no longer be adequate for high-end customers after 2015.

Figure 2: Next-Gen Broadband Access, Selected National Targets in Europe

COUNTRY	DOWNSTREAM SPEED	COVERAGE	DATE
Austria	100 Mbit/s	100%	2020
Denmark	100 Mbit/s	100%	2020
Finland	100 Mbit/s symmetric	100%	2015
France	100 Mbit/s (min. 50 Mbit/s)	100%	2025
Germany	50 Mbit/s	75%	2014
Sweden	100 Mbit/s	90%	2020
U.K.	25 Mbit/s	90%	2015

Source: European Commission

Many regulatory and political agencies have recognized the critical economic importance of continual improvement in broadband access speeds. One consequence has been the widespread establishment of clear targets for access speeds. For example, the EU announced in 2011 that by 2020 it wanted 100 percent household coverage of 30Mbit/s services, and 50 percent of households subscribed to 100Mbit/s services.

This target is unlikely to be achieved by FTTH alone. In separate work – see our December 2011 European FTTH Forecast – we have estimated that most countries will have achieved only 20 percent household penetration of FTTH or FTTB by 2018-2020, with 50 percent penetration not likely before the next decade. The main issue is cost: For instance, the European Commission's Broadband Communication notes that total investment required will be "between €181 billion and €268 billion to provide sufficient coverage so that 50 percent of households are on 100 Mbps services." This figure is based on deployment of FTTH.

In some countries, cable MSOs will play a role in achieving the 100Mbit/s target; in fact, many already advertise 100Mbit/s services. However, these services have serious shortcomings since bandwidth may be heavily contended, especially upstream, and cable is not ubiquitously available. In any case, most regulators want to see competition at the facilities as well as the services level.

In summary, accelerating demand for bandwidth, the need to meet regulatory rules and intensifying competition all make for some difficult strategic challenges for incumbent telcos shifting from DSL to fiber. Solutions to this dilemma vary: One is to accelerate FTTH rollout through public subsidy and direct investment by the state; but while this is a possibility, it seems unlikely to be at a sufficiently high level to make a real difference, given the very high cost and the difficulties created by high sovereign indebtedness.

In our view, although FTTH is clearly the preferred solution wherever it is feasible, a realistic plan for reaching the 100Mbit/s target is likely in most countries to include further enhancement to the copper plant. Recognizing this, operators and vendors have worked together to standardize a new solution that may achieve this aim – ITU G.993.5, also known as G.vector. Understanding the technical, commercial and regulatory implications of this transition is therefore critical. The rest of this paper considers these in turn.

DSL Acceleration: Vectoring & Beyond

"DSL Acceleration" has emerged as an umbrella term to describe a variety of technical innovations that can increase either the speed or the reach of high-speed broadband services. These include:

- **DSL Vectoring**, sometimes called G.vector, which applies noise cancellation techniques to increase bandwidth or reach
- **Bonding**, where two copper pairs are logically combined to double bandwidth per household
- "**Phantom mode**," which combines the benefits of vectoring and bonding on multiple pairs
- **G.fast, or Omega DSL**, which provides more than 100Mbit/s on very short loops (the standard targets 500Mbit/s at 100m, for example)

Figure 3 summarizes the benefits and drawbacks of these approaches.

Figure 3: DSL Acceleration Techniques

TECHNIQUE	ADVANTAGES	DRAWBACKS
DSL Vectoring	Enhancement to existing VDSL2; standardized by the ITU; product commercially available; should enable 100Mbit/s services on 400m loops; works on most existing copper plant; works with most recent VDSL2 modems	Immature (no significant commercial deployment yet); higher capex cost than VDSL2; creates some regulatory challenges; may require new CPE in some cases
Bonding	Existing technology already widely deployed in business market; no new standard required (covered in ITU-T G.998.x); two copper pairs per household fairly widely available	Requires two copper pairs per household (including installation) and new CPE, increasing cost; CPE for consumer market not widely available; potentially high cable management costs
Vectored Bonding ("Phantom Mode")	Can provide hundreds of Mbit/s in principle using two or more vectored pairs	Not fully standardized or productized; may be too expensive in consumer market, hence restricted to niche applications; may meet regulatory obstacles
G.fast, or Omega DSL	Enables speeds up to e.g. 500Mbit/s on loops up to 100m; obviates the problems of deploying fiber in the final drop and inside premises	Still in discussion, with no standard or product likely for several years; may fail to achieve sufficient momentum as operators shift to FTTH

Source: Heavy Reading

The Benefits of DSL Vectoring

As **Figure 3** suggests, DSL vectoring shows perhaps the greatest potential, because it is commercially ready, can be deployed almost everywhere in principle, and is an evolution of an existing DSL variant, VDSL2. The three other technologies listed can be seen as complementary to vectoring, since they can all be used to augment performance in certain circumstances.

Over the past five years, many operators have begun to shift from ADSL to VDSL2, which enables services to be provided (typically) at 30-50Mbit/s on shorter copper loops, usually provisioned from street cabinets where the fiber now terminates. An estimated 70 million homes are passed by VDSL2 worldwide, and deployment is accelerating as telcos respond to competition from cable MSOs using Docsis 3.0.

Vectoring enables some of that investment (e.g., in the fiber and the cabinets) to be preserved and VDSL2 line speeds to be substantially increased by cancelling almost all noise that is created by far-end crosstalk (FEXT), a phenomenon that occurs in the bundles of copper pairs typically deployed in telco access networks.

Vectoring enables investment in VDSL2 fiber and cabinets to be preserved and speeds to be substantially increased

Vectoring uses two techniques: It pre-codes the signal at the transmitter end for downstream traffic by measuring crosstalk from all the other lines in a given group and generating anti-phase signals that cancel that noise. Similarly, it post-codes the signal to cancel crosstalk at the receiver for upstream traffic. Initial simulations suggested that vectoring should be able to provide the critical 100Mbit/s downstream speed up to a 400m radius – i.e., well within the radius of typical VDSL2 deployments today.

The obvious benefits of vectoring encouraged the development of international standards and of chipsets and equipment from major vendors. ITU-T standard G.993.5, also known as G.vector, was ratified in May 2010, and systems conforming to this standard are now being marketed by at least six vendors. Good early test results in the lab are now being proven out in field trials.

One important feature of the improvement is that performance is more consistent across lines. Because crosstalk has widely varying impact, the spread between line performance is much greater without vectoring than with vectoring. So operators can consistently achieve an advertised speed – an important benefit given the widespread dissatisfaction with the current situation.

Performance reported by some operators in trials is shown in **Figure 4**.

Figure 4: Minimum Speed Achieved on VDSL2 Lines, With & Without Vectoring

OPERATOR	TRIAL LOOP LENGTH	DOWNSTREAM MINIMUM SPEED, NO VECTORING	DOWNSTREAM MINIMUM SPEED, WITH VECTORING
Swisscom	500m	24 Mbit/s	66 Mbit/s
P&T Luxembourg	Mix of 529m, 567m, 613m lines	30 Mbit/s	57 Mbit/s
Deutsche Telekom	Various lengths; results shown are for 450m	53 Mbit/s	92 Mbit/s
Slovak Telecom	505m	52 Mbit/s	90 Mbit/s
Belgacom	500m	20 Mbit/s	65 Mbit/s

Source: Operators, based on preliminary lab and field tests. Speeds shown are for the lowest-performing line in a bundle of copper pairs; number of pairs varied but was typically 24. Cable gauge also varied.

As a result of these encouraging findings, operators are either committing to the use of vectoring or expressing strong interest in doing so. Telekom Austria was first to announce a clear timeline, with deployment early in 2012 in part of Vienna, and, depending on trial results, wider rollout in the second half of the year. In an interview, the company said that vectoring would be a key technology to provide more bandwidth, as well as more stable bandwidth. The latter is just as important because there is zero tolerance among consumers to (for example) loss of an IPTV signal – so you need a highly stable link.

KPN has said it will deploy vectoring in the second half of 2012 (as well as pair bonding from 2011). TDC anticipated pair bonding this year and vectoring in 2013, with both together in 2014. Belgacom was one of the earliest VDSL2 entrants with an extensive network already in place, and describes vectoring as "a cornerstone in Belgacom's access network strategy," though full commercial nationwide deployment is not anticipated before 2014. Other operators known to have run trials or otherwise express interest include Orange and Turk Telecom.

Summarizing, we expect DSL vectoring to play an important role in the transition to higher-speed broadband services over the next five years in countries that have deployed VDSL2. This role, as well as timing, will vary considerably by country, but most operators that are widely deploying VDSL2 will deploy vectoring as well.

However, there is still some way to go before success is assured. Operational challenges must be overcome, and DSL vectoring must also be acceptable to regulators seeking to create the optimal regulatory environment for all broadband stakeholders. In the next section, we consider these issues in more detail.

Challenges of Vectoring

Vectoring is not cost-free. The per-customer equipment capex cost (not including fiber, aggregation, etc.) of vectored DSL is likely to be about twice that of non-vectored DSL lines. It requires new line cards, and may require new customer premises equipment (CPE) as well (although recently installed VDSL CPE may already support it or be compatible with it).

Significant opex will also be incurred, especially in initial stages. Until vectoring has actually been deployed commercially in real customer settings, some doubts will remain about opex, and about actual field improvement in speed in the presence of other noise sources, such as impulse noise, which must either be tolerated or removed using other techniques such as the ITU's G.inp standard.

However, the main issue raised by vectoring is that it can only deliver the full improvement where all the VDSL lines in a given cable are vectored and managed by a single operator or entity. Where there are non-vectored VDSL lines, or some vectored lines that are controlled by a third party, performance will be seriously reduced unless further measures can be proven out to deal with the problem. (Note that ADSL lines have only a minor impact on vectoring performance).

> The main issue raised by vectoring is that it can only deliver the full improvement where all the lines in a given group are managed by a single operator or entity

These so-called "alien disturbers" can have a major impact on performance. In lab tests at Swisscom, the minimum speed in a 24-line bundle fell from 68Mbit/s to 38Mbit/s, with only five alien disturbers, and even one alien disturber can have a major impact on the minimum achieved speed; in effect, the much more consistent performance that is a key benefit of vectoring no longer obtains.

In fact, actual impact is quite variable, since it depends on the impact of each individual alien disturber on each individual "victim line." This lack of predictability is a major obstacle to advertising vectored VDSL2 at higher bit rates in any situation where all lines are not under control of one operator.

A number of techniques and approaches have been suggested to ameliorate this problem. In the first place, operators can increase the size of the group that is being vectored so as to be able to include more alien lines into the vectored group (thereby effectively reducing the number of alien lines). This is only possible if those alien lines are also under the control of the same operator. Doing so can minimize the *average* impact of alien disturbers, though this will not improve performance on the worst-affected victim lines. Average performance improves because the number of these alien disturbers is reduced.

The initial objective is "board-level vectoring," which applies vectoring to all the lines in a single line card. The next step is "system-level vectoring," which applies vectoring across a whole system that includes multiple line cards. Both of these options are now commercially available from several vendors, giving operators more ways to resolve at least some of the issues here. System-level vectoring will likely be preferred by many operators; Swisscom, for instance, says it will need system-level vectoring in vector group sizes of 288 lines, while Telekom Austria told us they would like to be able to vector across groups as large as 1,000 or more, at the CO level. "Having vectoring at this level would be the best way to [reduce] the impact of [non-vectored] lines."

A further possible step is "cross-DSLAM vectoring," which aims to cancel crosstalk between adjacent DSLAMs that are controlled by different operators, or where vectoring is only being used in one DSLAM. This is only just becoming available, and there are still some significant challenges to be overcome. In the absence of a standard, operators must agree to use the same equipment, and there are multiple operational challenges.

Some have also suggested applying additional dynamic spectrum management (DSM) techniques to resolve the problem. DSM could reduce the impact if all operators apply similar DSM techniques, or if operators agree to apply vectoring via a single spectrum management center. DSM techniques vary, but one suggested approach is to limit the transmit power of non-vectored lines to 25Mbit/s, in order to reduce the impact of crosstalk. A lab trial suggested that this would almost eliminate the impact of alien disturbers, though it does raise separate competitive issues.

In order to deal with the problem of non-conformant VDSL modems in the networks, a further remedy is to apply a software upgrade to these modems in line with two annexes recently added to the VDSL2 standard, so that the CPE becomes "vector-friendly." This upgrade enables crosstalk from these "friendly" lines into neighboring vectored lines to be canceled.

Regulatory Issues

For regulators, these developments raise important issues, many of which they are already grappling with as a result of the transition to VDSL2. As described earlier, regulators and policymakers have set a variety of goals for next-generation broadband – goals that can have the potential to conflict with each other. Resolving those conflicts will be critical to realizing the potential of next-generation access technologies.

Space precludes a complete discussion of all of the issues in different global jurisdictions, so we focus primarily in this section on the European Union by way of example, since it is currently the largest contiguous market for DSL (more than 102 million lines) regulated by a single agency (the European Commission, in conjunction with national regulatory agencies).

Dominant operators in the EU, primarily ex-incumbent telcos, are governed by a variety of rules on how they provide services. From the point of view of this white paper, the most important regulations are contained in the European Commission's Directives 2002/21/EC and 2002/19/EC. Both were amended in 2009 (in 2009/140/EC), and transposed into national law in 2011.

Among other things, these regulations mandate the ex-incumbent telcos to unbundle the local loop (ULL) at the central office, so that competitive operators that want to deploy their own DSLAMs at these sites can do so. This is consistent with the Commission's so-called "ladder of investment" thesis, which encourages alternative operators to invest in infrastructure, rather than simply buy wholesale incumbent products, and thereby allow maximum variety and differentiation in products offered to end users.

This policy has been highly successful. According to the European Commission, 64 percent of new-entrant broadband lines at January 2011 were based on full ULL, and the percentage has been rising steadily.

The transition to VDSL (and to GPON FTTH) has, however, put this policy under pressure, and required the EU and the national regulatory agencies to consider a new set of rules. VDSL usually pushes fiber further into the network, and VDSL line cards are generally deployed in street cabinets. This led the European Commission to tell operators to make available "sub-loop unbundling (SLU)," so that competitive operators could deploy and maintain their own equipment at cabinets, and most regulatory agencies have called on operators moving to VDSL2 to offer SLU.

In practice, however, the operational and economic difficulties of managing the requirements of multiple operators at this level means that very little sub-loop unbundling has in fact occurred. As a result, Ofcom in the U.K. has stated that, "It is unlikely that we will see the deployment of multiple NGA [next-generation access] networks based on SLU... in the same area in the next few years. [This remedy is] therefore unlikely to be the basis for competition in the next few years."

Similarly, Austrian regulator RTR has concluded that SLU, which has had little impact in Austria, will never be an effective remedy and may be withdrawn altogether, while BIPT in Belgium says that SLU has failed and it is being withdrawn from the market. In brief, SLU at present appears to be economically unviable except in a few limited instances.

Sub-loop unbundling appears to be economically unviable except in a few limited instances

What about vectored VDSL2? As described earlier, vectoring only works well where one entity controls all the lines in a given group. This gives rise to potential problems where some lines have been unbundled to other operators. "At the moment, ULL and vectoring won't work together: You have to vector all lines in one cable under your control," said Telekom Austria, "and right now we don't see another technical solution out there."

As a result of the deployment of VDSL2 and the prospect of vectored VDSL2, regulators are all looking to enhance bitstream-based access, sometimes calling this "virtual unbundling," as the main wholesale product offered by ex-incumbents to alternative operators. In simple terms, virtual unbundling extends the range of options available in bitstream products along a number of dimensions. Ultimately, the aim is to create a bitstream product that is as flexible as ULL; BIPT, for instance, believes that this should be feasible, and has gradually evolved and extended the regulated offer in an attempt to achieve this aim.

However, enhanced bitstream, or virtual unbundling, is a work in progress, since there is no settled definition of what it means. The U.K.'s Ofcom, for instance, will in principle call on BT to extend its existing product, called Generic Ethernet Access, which currently offers telcos services at 40/2Mbit/s, 40/10Mbit/s and 80/20Mbit/s. But the emerging definition remains unclear at this point. U.K. alternative operators, while generally welcoming the virtual unbundled local access (VULA) approach, have pointed to a number of unresolved issues. In particular, competitors are anxious to ensure that the maximum flexibility is preserved – a position that would require significant adaptations to conventional bitstream offers.

In Austria, RTR is currently in negotiation with Telekom Austria and its retail competitors for development of a virtual unbundling product based on Layer 2 Ethernet. Telekom Austria's initial virtual unbundling product, launched in 2011, was not accepted by the major Austrian service providers, which have asked for a range of amendments. The regulator says there are many issues to resolve, including the way in which different QoS is delivered, the range of speeds offered and the means by which the migration from existing products is handled. However, it hopes to conclude an agreement in the third quarter of 2012.

For its part, BIPT approved a new enhanced bitstream offer in 2011 as a replacement for SLU. This includes a wider range of QoS options, speeds, prioritization, better options for TV, and so on, and BIPT says it will add options on request from operators to ensure it is as close as possible to a true ULL product. It is also planning to revise tariffs to make it more attractive.

Both RTR and BIPT also pointed to issues that might arise around the upgrade that will be required to VDSL CPE that is owned by non-incumbent operators, but not vectoring-friendly.

For its part, the European Commission approved the virtual unbundling schemes unveiled by regulators in Austria and the U.K., but it also said that operators should impose full unbundling "as soon as technically and economically possible." The European Commission's strong preference for true unbundling means that it has not yet accepted bitstream, enhanced or not, as the primary long-term solution, though it did approve withdrawal of SLU in Belgium.

While the issues may vary in other jurisdictions outside the EU, the fundamentals remain the same everywhere: How can regulators ensure that major network builders continue to invest in infrastructure upgrades that improve services, while at the same time preserving a competitive market? It is clear from the discussion here that there is no perfect solution, and regulators must pick the best possible compromise if they are to move the market forward. This is discussed further in the following section.

Summary

Although FTTH is clearly the preferred end-game for access networks, the successful deployment of vectored VDSL is likely to be essential in some countries to the achievement of regulatory and political objectives for widespread access to higher-speed services before 2020. As discussed in the first section, FTTH probably will not be deployed quickly enough everywhere, and vectored VDSL provides a lower-cost alternative that can be deployed much more quickly. As Telekom Austria put it: "FTTH is definitely the long-term solution, but rollout is really slow compared to FTTC vectoring." But can competition be preserved while enabling VDSL2-based vectoring to take its place in the services portfolio?

Practically speaking, we believe the best near-term solution is likely to be virtual unbundling schema based on extensions of existing bitstream services. This is the solution that has already been adopted in principle by Ofcom in the U.K., RTR in Austria and BIPT in Belgium, whose plans have been accepted by the European Commission, albeit with the conditions described earlier. Regulators in other countries such as Denmark, Germany and the Netherlands are said to be considering similar approaches. This approach can be deployed quickly, overcomes the difficulties of unbundling at street cabinets and, if properly implemented, can meet most of the objectives of competitive providers.

Other approaches currently have significant shortcomings. Cross-DSLAM vectoring, which would allow alternative operators to deploy DSLAMs at street cabinets, shows some promise, but must overcome a range of technical and operational challenges before it is operationally viable. More fundamentally, it is open to the same objections as VDSL2 SLU, which has generally failed in the marketplace. A second alternative – use of spectrum management techniques that, for instance, called on all lines to be capped at 25Mbit/s – would potentially run into difficulties with operators that didn't want their customer lines to be capped, or were already offering higher-speed services. In general, regimes that require detailed ongoing cooperation among operators are open to the objection that it would not be practical and could lead to higher opex and protracted deployment delays.

Though alternatives to enhanced bitstream or virtual unbundling are therefore at best "works in progress," we still believe the European Commission was correct to tell regulators in the U.K. and Austria (and by implication elsewhere) that they must add a fully unbundled option in the future, if it becomes technically and economically feasible, thus encouraging continued technical and regulatory innovation to achieve this aim. If enhanced bitstream proves to be the only commercially viable approach in the near and medium term, this will enable higher-speed services to be deployed while retaining a reasonably competitive environment – a compromise, certainly, but clearly better than any solution that either reduces competition or increases costs. But if this approach does not succeed (and it remains to be proven out in volume deployment), other avenues will need to be explored.

DSL Acceleration & the Role of Vectoring

It would be a mistake to overstate the role of vectoring in next-generation broadband access, but so long as remaining regulatory and operational challenges can be overcome, it will play an important role in enabling higher-speed broadband services over the next five years in many countries. While no panacea, it has important benefits, including much lower capex than FTTH, commercial availability, standardization and widespread applicability in existing networks. On balance, we expect it to play a key role in the long transition to all-fiber wireline networks.