Alcatel·Lucent

STRATEGIC WHITE PAPER

Leveraging VDSL2 for mobile backhaul: meeting the long-term challenges in the mobile broadband era

Operators know that legacy TDM mobile backhaul networks cannot cost-effectively scale to meet the growing bandwidth demands associated with 3G networks and mobile broadband. These demands will only keep increasing as radio networks transition to LTE. The industry consensus is that an end-to-end packet backhaul network is required. In the last mile portion of this network, optical fiber and packet microwave options are usually considered. Copper-based DSL solutions are seen as good stop-gap measures, but considered unable to cope with forecasted bandwidth demands. This paper evaluates this and other concerns with copper backhaul, and explains how continued investments in VDSL2 technologies will enable a successful long-term mobile backhaul strategy wherever copper-fed cell sites exist near VDSL2 residential build-outs.

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1. Positioning broadband access for mobile backhaul

As mobile operators deploy 3G networks, subscribers are increasingly accessing bandwidth-hungry data services such as Internet access and streaming video on their smartphones and via laptop dongles. Delivering these services has placed an immense strain on traditional TDM mobile backhaul networks, a problem that must be addressed before migration to Long Term Evolution (LTE) technology can be contemplated.

In response to this growing problem, vendors have developed an array of converged, packet-based mobile backhaul solutions. These solutions include fiber, microwave and copper technologies for the last mile connection to the cell site. The most cost-effective and fastest time-to-market option in the last mile will often be to leverage the broadband access network, which has already been engineered to hit the cost points for residential triple-play services.

More specifically, the incremental cost of backhauling cell site traffic on the existing residential network will usually be less than the cost of building out a separate overlay network. The savings mainly derive from:

- Re-use of outside plant copper pairs and Passive Optical Network (PON) splitters, feeder fibers, and optical line terminal (OLT) ports.
- Low-cost broadband aggregation available from existing access nodes, such as DSLAMs and PON OLTs, minimizing port consumption on relatively expensive switches and routers.
- Broadband access physical layers that are already cost-optimized for asymmetric bandwidth consumption, a usage pattern that is also expected for mobile broadband.

Triple play access networks already meet the bandwidth and quality of service (QoS) needs for video, voice and data. Unlike microwave backhaul, there are no requirements for line-of-sight or spectrum licensing. As a result, broadband access networks are uniquely positioned for relief of the mobile backhaul bandwidth crunch.

There are several fixed broadband access technologies for the operator to choose from, some leveraging all or part of the existing copper plant: ADSL/ADSL2+, SHDSL, and VDSL2. There are also some that run new optical fiber all the way to the home: PON and point-to-point (PTP) fiber. Each of these is capable of different bandwidths, and each is therefore positioned differently for backhaul applications. In the case of GPON (Gigabit-capable PON), even a PON serving residential users with heavy video demands will have a full Gb/s or more of bandwidth headroom. This is enough to backhaul one or more cell sites in the neighborhood being served. Of course PTP fiber, when implemented with Gigabit Ethernet (GigE), can also provide a Gb/s to a cell site. Both GPON and PTP fiber are strategic long term solutions for mobile backhaul.

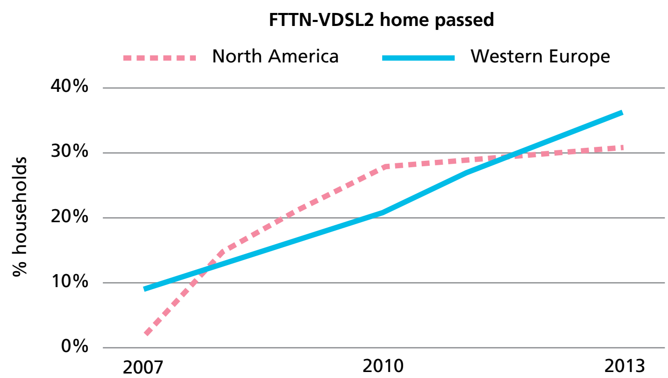
For copper solutions, it is a little more complicated. The bandwidth of residential DSL technologies is asymmetric, and is directly and inversely related to distance. Furthermore, the capability of copper solutions is augmented by pair-bonding, in which two (or more) pairs are combined via inverse multiplexing to multiply the bandwidth capacity.

Keeping these points in mind, ADSL2+ (with available 2-pair bonding) is able to support tens of Mb/s downstream. ADSL2+ (and its predecessor ADSL) is the most widely deployed fixed broadband access technology. G.SHDSL.bis, optimized for business access, supports 22 Mb/s symmetric bandwidth with a typical 4-pair bonding. With such bandwidth capabilities, ADSL2+ and SHDSL are well positioned to be short-to–medium term tactical solutions for low cost, fast time-to-market relief of the backhaul bottleneck.

Most interesting is the capability of VDSL2 for mobile backhaul. Deeper fiber and wider DSL spectrum allow much more bandwidth to be mined from existing copper pairs. VDSL2 is being aggressively deployed in support of triple play in North America and Western Europe. It is already passing approximately 25 percent of homes and that number is growing rapidly. See Figure 1.

Looking from the other side, about one-third of all cell sites worldwide are currently served by copper pairs (typically using legacy TDM E1/T1 leased lines). In North America, the number is two-thirds (source: Heavy Reading). This is a large addressable market for the increasingly ubiquitous VDSL2 networks. Consequently, this paper focuses on how to leverage the VDSL2 triple play network for mobile backhaul, and specifically highlights how well VDSL2 is positioned to meet the evolving requirements of mobile backhaul.

Figure 1. VDSL2 deployments in North America and Western Europe



Adapted from: Pyramid Research

2. VDSL2: a solution to the challenges of mobile backhaul in the mobile broadband era

The value proposition of a shared infrastructure — leveraging the VDSL2 residential broadband network for mobile backhaul — is clear. The geographic overlap between the growing footprint of VDSL2 and copper-fed cell sites is providing many opportunities. What remains to be established is how well VDSL2 technology can meet the current and future requirements for mobile backhaul, and whether it is a short-, medium- or long-term solution. There are many valid concerns:

- Bandwidth
- Synchronization
- Mixed RAN deployments
- Service availability
- Latency
- Quality of copper loops

Each of these concerns is considered in the following sections.

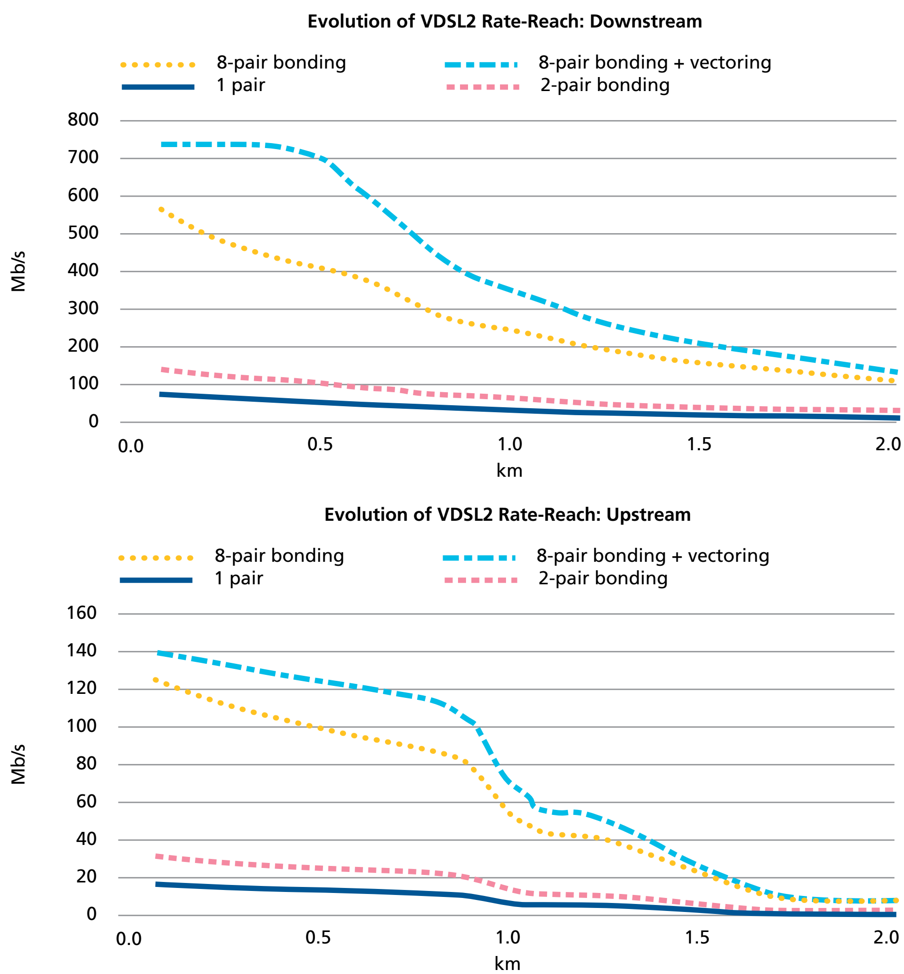
2.1 Bandwidth

As already discussed, the bandwidth of residential DSL technologies, including VDSL2, is inversely related to distance, as typically indicated in rate-reach curves. Optimized for residential services, DSL uses asymmetric technology, providing more downstream bandwidth than upstream. Therefore, the VDSL2 rate reach curves for downstream and upstream must be examined separately.

Referring to the curves in Figure 2[1], the dark blue curves show the bandwidth versus distance for downstream and upstream, representing what is currently deployed. The magenta curves indicate the near doubling of bandwidth resulting from 2-pair bonding, which has been available in commercial product since 2009.

[1] Actual rate-reach in the field is dependent on many variables. These are simulated results.

Figure 2. The evolution of VDSL2 rate-reach curves for downstream and upstream traffic

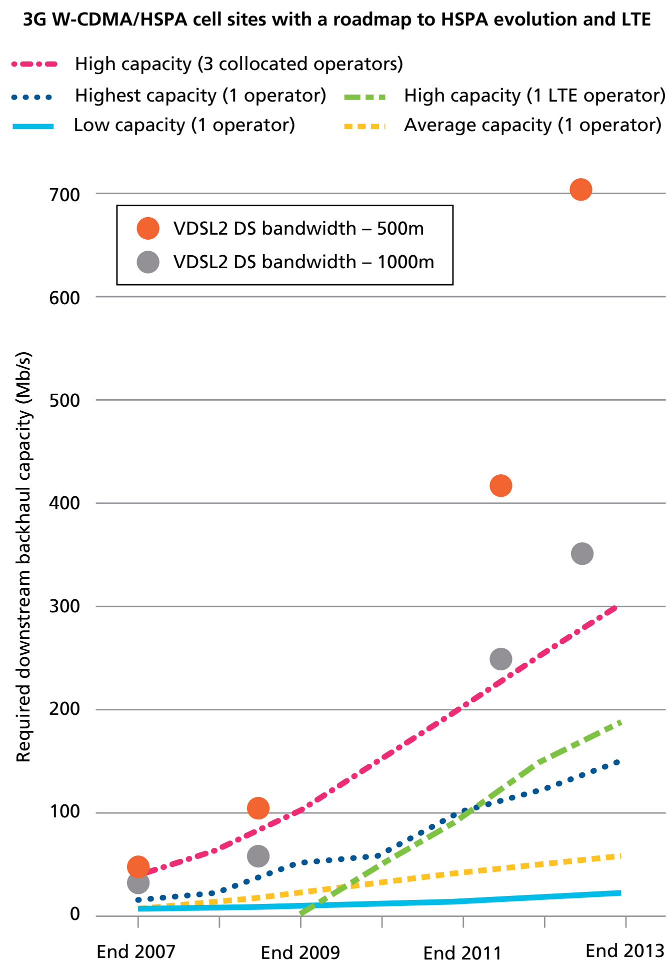


Multi-pair bonding is where it gets very interesting for mobile backhaul. Shown by the yellow curves, 8-pair VDSL2 bonding increases bandwidth by another factor of 4. This is likely to be commercially available by the end of 2011 or early 2012. Finally, when vectoring is available, probably by the end of 2012 or early 2013, there is an additional boost of approximately 50 percent, represented by the light blue curves.

Clearly, large and continuing investments being made in VDSL2 technology will enable a whopping 400 Mb/s downstream and 100 Mb/s upstream at a distance of about 1000 m (3.28 kft). Even more bandwidth will be available at shorter distances.

How does this evolution of VDSL2 match up with the bandwidth requirements for mobile backhaul? Figure 3 shows downstream bandwidth forecasts for various 3G cell site traffic loads (low, medium and high) as they evolve to LTE. There is also a curve for a pure LTE site. Finally, there is a curve representing the scenario where a wholesale provider is backhauling traffic from three col-located mobile operators, which represents the worst case.

Figure 3. Downstream backhaul bandwidth forecasts for cell sites, and available VDSL2 bandwidth



Cell site bandwidth curves adapted from: Heavy Reading

These forecasts are overlaid with downstream VDSL2 rate-reach data points from Figure 2 as the new technologies are rolled out over time, for both 500 m (1.64 kft) and 1000 m (3.28 kft). It can be seen that VDSL2 bandwidth at the longer distance is able to meet the requirements for the worst case bandwidth forecast. For the shorter distance, VDSL2 easily exceeds the requirements. Further improvements, not quantified here, like “phantom mode”[2], will continue to drive VDSL2 bandwidth capacity. From this analysis, it is clear that the VDSL2 technology curve can keep pace with 3G and LTE backhaul bandwidth needs.

2.2 Synchronization

There are two types of base station synchronization relevant to radio access networks: frequency synchronization and time-of-day (ToD) synchronization.

[2] Alcatel-Lucent Bell Labs achieves industry first: 300 Megabits per second over just two traditional DSL lines http://www.alcatel-lucent.com/wps/portal/!ut/p/kcxml/04_Sj9SPykssy0xPLMnMz0vM0Y_QjzKLd4x3tXDUL8h2VAQAURh_Yw!!?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=News_Releases_2010/News_Article_002043.xml

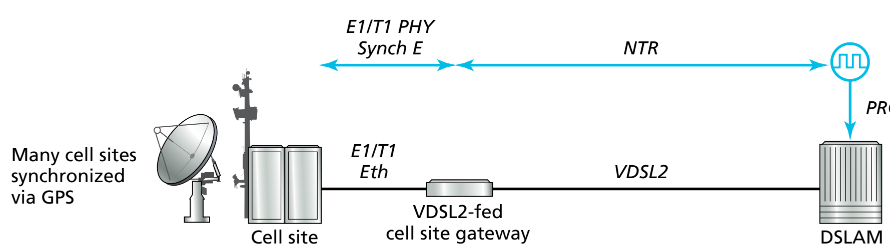
2.2.1 Frequency synchronization

Cell site equipment requires an accurate clock to set its radio frequencies in support of call handoffs. All cellular radio systems require frequency synchronization of ±50 ppb[3]. The questions are: must the VDSL2 backhaul network provide this frequency synchronization, and if so, how is it achieved? There are two instances when base station synchronization is provided by a source other than the VDSL2 network. This occurs when the base station is synchronized by a Global Positioning System (GPS), or, in a data off-load scenario. In the latter case, the VDSL2 network is only backhauling data traffic, complementing a legacy TDM leased line that already backhauls voice traffic and provides frequency synchronization. (This is an interim step in the evolution to a single converged packet-based mobile backhaul network.) The VDSL2 network must provide frequency synchronization when there is no GPS and when the legacy leased line network providing the synchronization has been decommissioned (which is, at any rate, the end goal).

Unlike TDM networks, traditional packet networks do not transparently transport frequency synchronization. However, in the VDSL2 standard, ITU-T G.993.2 Section 8.3, a Network Timing Reference (NTR) is defined. NTR supplies a reliable, deterministic physical layer frequency synchronization like TDM. This is in contrast to packet-layer synchronization techniques, such as the IEEE 1588v2 Precision Timing Protocol. Packet layer synchronization techniques are sensitive to the impairments of packet transmission (for example, traffic congestion), and are therefore not preferred wherever an adequate physical layer clock, like NTR, is available.

The VDSL2 CPE at the cell site, called the VDSL2-fed cell site gateway (CSG), can slave an E1/T1 or Ethernet cell site interface to the NTR clock, to provide the required synchronization to the base station. See Figure 4.

Figure 4. The VDSL2 CPE as CSG



2.2.2 Phase synchronization

With few exceptions, frequency-division duplex (FDD) radio systems require only the frequency synchronization discussed above. However, time-division duplex (TDD) radio systems also require phase synchronization for accurate framing of timeslots. Typical requirements are 1 to 2.5 µs. So far it is not clear if TDD systems will be widely deployed outside of China. Currently the best solution for phase synchronization is via GPS.

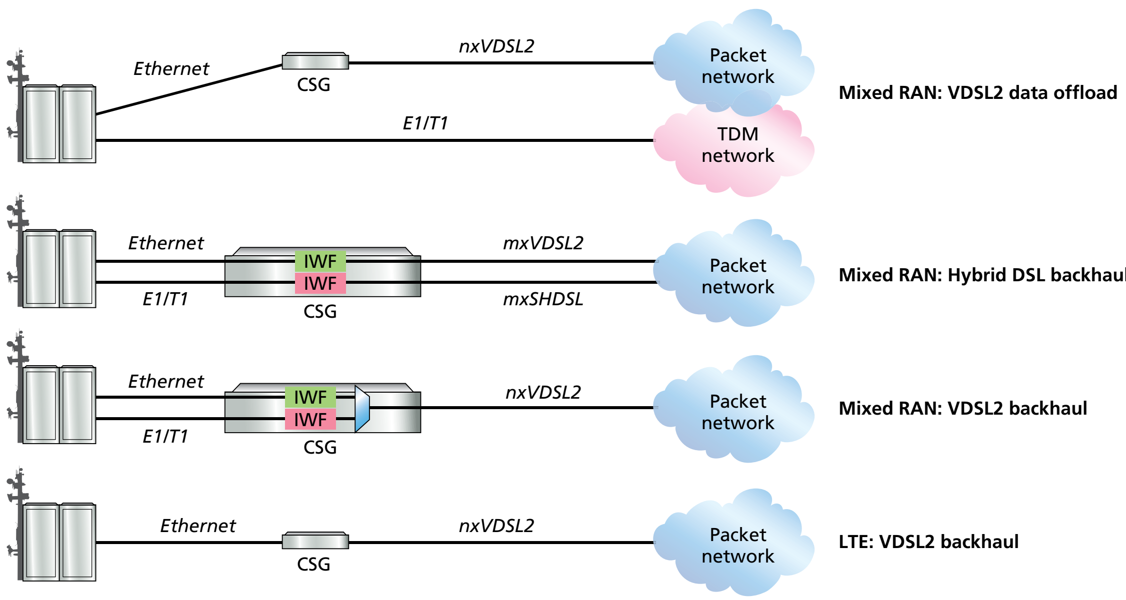
2.3 Mixed RAN deployments

As implied in the bandwidth discussion above, it will usually be the case that cell sites will not flash-cut from 2G to 3G to LTE. Instead, there will usually be a mix of radio technologies at a given cell site, especially when there are multiple collocated mobile operators.

[3] This is the requirement for the air interface. It translates to delivery of a local clock reference meeting at least the “traffic interface” jitter/wander requirements of ITU-T G.823 (for E1) or G.824 (for T1), or (in the absence of a sufficiently stable local clock) the more stringent “synchronization interface” requirements of G.823/G.824. A synchronization reference meeting this condition will enable most base stations, via filtering, to meet the ±50 ppb frequency stability requirement of the base station local clock.

VDSL2 transport is packet-based, but in these mixed RAN deployments the VDSL2 network must not only backhaul traffic from Ethernet cell site interfaces but also from E1/T1 (carrying TDM or ATM IMA traffic). This is the job of the CSG, which employs pseudowire technology to reliably transport the E1/T1-based traffic. Figure 5 illustrates several VDSL2-based mobile backhaul scenarios that can support various evolutions of the mixed RAN to pure LTE.

Figure 5. VDSL2-based mobile backhaul scenarios



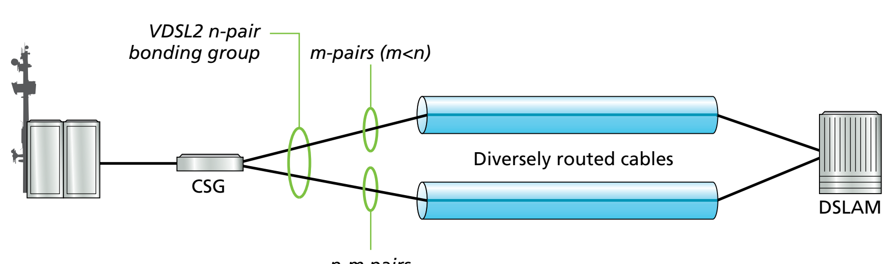
2.4 Service availability

Mobile backhaul service is often governed by a service level agreement (SLA) between the backhaul provider and the mobile operator, even when they are different business divisions in the same company. The SLA may have a provision for service availability, specifying limits to the amount of service downtime.

Strategies for meeting strict availability requirements in the access network include equipment redundancy in the DSLAM and maybe even the CSG. Interestingly, there is also resiliency built into the VDSL2 bonding protocol, which works like an Ethernet Link Aggregation Group. Normally, all pairs are usable to full capacity. If a pair fails, the bonding protocol automatically moves all traffic to the surviving pairs, thus providing pair protection.

Another strategy for attaining the highest levels of availability is for routing traffic over diverse routes so the service can survive a cable cut. Such a strategy is not usually considered for copper transport, but if the pairs in the bonding group are divided and routed via two different cables, VDSL2-based route diversity can be attained. See Figure 6.

Figure 6. Achieving route diversity with bonded VDSL2



2.5 Latency

Mobile backhaul latency requirements are driven by the application: voice requirements start at 200 ms, gaming at 50 ms. These are end-to-end one-way application delays, which are allocated to various pieces of the network, for example, 10 to 15 ms to the access network.

VDSL2 lines typically use impulse noise protection (INP) to protect against bit error bursts. INP employs forward error correction (FEC) and interleaving, and interleaving adds delay. A typical INP setting supports protection over two DMT symbols (INP=2), with 8 ms of interleaving delay (DEL=8). It should be possible in many cases for the backhaul operator to budget for this.

In the event that less delay is required in the access network, the VDSL2 line can be provisioned for, say, DEL=4 ms, in one of two ways:

- *Option 1*: Maintain INP=2 and accept a bandwidth penalty of approximately 15 percent due to additional FEC overhead.
- *Option 2*: Reduce to INP=1, with no bandwidth penalty.

Each line, and each direction of each line, can be individually provisioned. For example, residential and mobile backhaul lines can each be optimized to their separate requirements.

Again, investments in VDSL2 are always improving the technology, and future DSL PHY retransmission (G.INP) will give an effective INP=16 with only about 2.5 ms of one-way delay. So it can be concluded that VDSL2 INP latency can be managed successfully for mobile backhaul.

2.6 Quality of copper loops

Unlike optical fibers, copper pairs are susceptible to the transmission impairments of crosstalk and noise. A small fraction of copper pairs cause most of the troubles. To ensure that a “bad” pair is not used for an SLA-governed mobile backhaul service, operators can test the available pairs and select the best ones. Also, pre-conditioning of cell site backhaul pairs, by assigning outside plant craft to fix or improve the transmission characteristics of a selected copper pair, can mitigate problems. Pair selection and pre-conditioning would be especially recommended if the line is to be provisioned for low INP, as discussed above. While these measures are not usually cost-effective relative to the average revenue per user (ARPU) for residential deployments, they can be justified relative to mobile backhaul revenues.

3. VDSL2: a strategic solution for mobile backhaul

For cell sites already served by copper and within reach of a VDSL2 network, VDSL2 will likely be the lowest cost solution for backhaul relief. The operator will realize an improved return on investment on the existing VDSL2 network without having to build out a potentially expensive overlay network.

As wireless service providers migrate from 2G to 3G to LTE:

- VDSL2 technology will keep pace with cell site backhaul bandwidth requirements
- VDSL2 NTR will provide reliable physical layer frequency synchronization
- VDSL2-fed cell site gateways will support the transition from mixed-RAN to LTE-only
- VDSL2 pair-bonding will help support high service availability
- Provisionable VDSL2 INP parameters can neutralize latency issues
- Pair selection and pre-conditioning can ensure the quality of the copper loops.

VDSL2 technology has been improving for many years. Continued investment in the technology will allow it to keep pace with, and meet the demands of mobile backhaul now and into the future. Therefore, VDSL2 can be considered a strategic long-term solution for mobile backhaul.