A FTTdp White Paper

Accelerating Gigabit Broadband

Overview

With the advent of Google Fiber, AT&T LightGig, and CenturyLink's drive for FTTP as well as other similar offerings for residential subscribers, there is a growing trend of delivering Gigabit services to subscribers, or perhaps more correctly, delivering services over Gigabit links to subscribers.

The thought of a fiber to every subscriber is compelling, and indeed may be the long-term goal, but how does that play out "in the trenches" where we have to trench fiber through gardens and fences and deal with easements, building owners and local governments? The reality is that there are many circumstances where it is economically impractical to run fiber all the way to the subscriber, and we would instead prefer to use, to the extent possible, the existing copper assets.

The key to being able to provide services that approach the 1 Gbps mark using existing home, apartment building and other infrastructure wiring is short distances and advanced technologies. One approach to shortening the distance between the service provider equipment and the subscriber is known as Fiber To The distribution point (FTTdp). The basic idea behind FTTdp is to deploy fiber as deep into a neighborhood as is economically feasible, then use existing copper assets the last few hundred meters to and though out the house or apartment. FTTdp has been called a "hybrid FTTH" architecture [1] in that it provides a user experience similar to FTTH, but with a "copper extension cord" between the Optical Network Unit (ONU) and the subscriber.

In this white paper we will discuss methods for delivering services, with rates approaching 1 Gbps, over the existing copper infrastructure. In particular, we will look at two deployment scenarios: Multi-Dwelling Unit (MDU) and Single Family Unit (SFU). We will look at several copper transmission technologies: VDSL2 17a and 30a, G.hn and G.fast.

Deployment Scenarios

There are two deployment scenarios currently being considered to shorten the distance between service provider equipment and the subscriber, as shown in Figure 1.

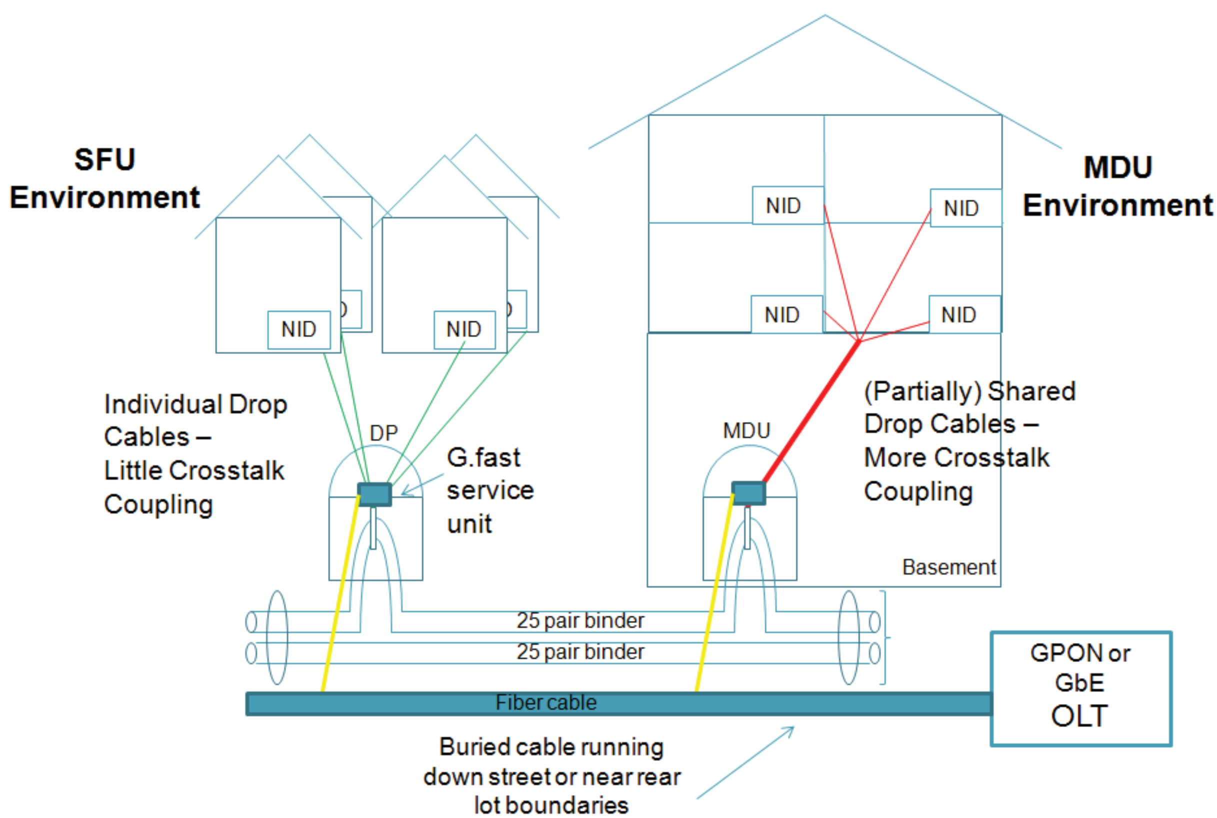


Figure 1: FTTdp Deployment Scenarios

In brownfield deployments, existing copper twisted pairs run down a street or down rear lot boundaries (in cables which are either direct buried or strung from poles) and then connect to a "distribution point" (DP) [2] (otherwise known as a terminal block in a pedestal or splice case) near the homes or in the basement of the building. From the DP, the twisted pairs are then distributed via the drop wires to the individual homes (in the SFU case) or to the individual dwelling units (in the MDU case). A service unit is mounted near the DP and connected to the drop wires. A fiber is also run to the DP, and provides the uplink from the DP service unit to the service provider. In this way, the existing twisted pair is used as the last drop to the subscriber. The fiber uplink could operate using either PON or point-to-point Ethernet. The general term FTTdp covers both the SFU and MDU cases described here.

FTTdp Attributes

Some attributes of the FTTdp architecture are 1) high service rate, 2) reverse powering, 3) cable crosstalk, 4) self-install and 5) emphasis on power conservation [3].

Because of the proximity of subscribers to the service unit, very-high service rates (approaching 1 Gbps) over the drop wires are possible, providing "fiber-like" service rates to the end subscriber. Utilizing fiber all the way to the DP will also approach "fiber-like" reliability even though the last link is copper.

One of the issues with this architecture is the cost of installing power for the service unit deep in the network. An approach to overcome this is to provide reverse powering from the subscriber to the service unit, which avoids the expense of running power lines to the service unit. There is a precedent for using subscriber power for network equipment with FTTH ONUs, the difference here is that with FTTdp, multiple subscribers could be providing power for a single service unit. Standards are being developed for reverse powering technical requirements. The main technical challenges are 1) getting the power consumption of the service unit low enough to be powered by the first subscriber and 2) managing a service unit which loses power when all of the subscribers turn off the power.

Another architectural issue is with shared cables. Particularly in the MDU case, the copper pairs can run some non-trivial distance bundled together before being split out to the individual units, thus introducing crosstalk between pairs. A solution is to use vectoring (crosstalk canceling) between all the pairs in the service unit, or to ensure that no two devices are transmitting simultaneously (crosstalk avoidance). There are cases where crosstalk is not a problem, for example where the drop wires from the DP are in a star configuration.

The copper can be terminated at the subscriber premises either on the side of the house or in the wiring closet, thus separating the service unit drop from the in-home wiring. This provides the highest performance by avoiding the noise and reflections caused by the in-home wiring. However, this requires a technician to be dispatched to install the Customer Premises Equipment (CPE) and to possibly rewire the house. A lower cost approach is self-install. In this instance, the service runs over the existing in-home phone wires and the CPE is simply mailed to the subscriber where it can be plugged into the wall jack. Self-install has several issues: 1) because of the "bridged taps" introduced by in-house wiring and the introduction of noise from the house, self-install provides lower performance, 2) providing Plain Old Telephone Service (POTS) and reverse powering with self-install is very difficult, 3) even if VoIP is being used, because the service would be run over the existing phone wires in the house, then either the house will have to be converted to wireless phones, or the second pair (if any) in the house must be used, or a more complex POTS distribution will have to be used.

Power conservation is an important aspect of FTTdp and not just to be "green". These deployments often require a hermetically sealed housing and the use of fans is often prohibitive. The cost of the housing needed to dissipate a large amount of power is higher than the housing needed to dissipate a small amount of power. The implication is that power must be conserved not only when there is data or no data to send, but also when there is much data to send since the power dissipation must be kept below the amount that the housing can dissipate [4].

Copper Technologies for FTTdp

There are several twisted pair copper technologies that may be considered for the FTTdp “copper extension cord”: 1) VDSL2, 2) G.hn and 3) G.fast.

VDSL2 is a technology that has been widely deployed in all regions of the world. It is designed to operate over longer distances than FTTdp, but can be used on short distances like the FTTdp environment. VDSL2 comes in different “flavors” known as profiles, where each profile has a specific associated bandwidth and power, which roughly translates into speed and distance. Table 1 shows two VDSL2 profiles and associated bandwidth and rates.

Table 1: VDSL2 Profiles and Associated Bandwidth and Rates

VDSL2 Profile	Maximum Bandwidth (MHz)	Maximum Downstream Rate (Mbps)	Maximum Upstream Rate (Mbps)
17	17.7	120	40
30	30	200	120

Most VDSL2 deployments in service today do not have any means to cancel crosstalk from adjacent pairs, which means they are generally limited to substantially lower rates than those given in Table 1. A technology known as vectoring is being introduced into the network which cancels crosstalk and allows actual speeds approaching those in Table 1. Vectoring is commercially available in VDSL2 profile 17 today, but not in profile 30.

Finally, another possible contender for the FTTdp application is G.hn. This is actually a home networking technology designed to work over coax, power line, and twisted-pair phone lines. It uses a bandwidth of 100 MHz, but because of certain inefficiencies tops out at around 800 Mbps. Most of the focus on G.hn deployments today is on powerlines.

G.fast is a technology still under development in the standards bodies. It is specifically designed to operate on short-distance loops like FTTdp. The standard has the target rates shown in Table 2.

Table 2: Target Rates for G.fast

Distance (m)	Target Downstream + Upstream Rate (Mbps)
250	150
100	500
<100	500-1,000

Some basic characteristics of G.fast are given in Table 3.

Table 3: G.fast Characteristics

Modulation	DMT
Bandwidth	106 MHz
Duplexing	TDD
Distance	<250m Typ
Bit Rate	<1.2 Gbps
Latency	<1 msec
Vectored	Yes
Up/Down Ratio	Variable
Retransmission	Yes
Low Power Modes	Yes

These characteristics of G.fast (as specified by agreements and draft standard in the ITU-T SG15/Q4 committee, which is producing the G.fast standard) are described briefly below.

- G.fast uses Discrete Multi-Tone (DMT) modulation, the same as VDSL2.
- The bandwidth of initial deployments is 106 MHz (similar to G.hn), but future versions of G.fast are planned that will increase this bandwidth to 212 MHz. VDSL2 has a maximum bandwidth of 30 MHz.
- G.fast uses Time Division Duplexing (TDD), as opposed to VDSL2 which uses Frequency Division Duplexing (FDD). (See paragraph below for more details.)
- G.fast is designed for much shorter loop lengths than VDSL2, around 250m or less.
- G.fast has a theoretical peak bit rate exceeding 1 Gbps, but this rate can only be achieved on very short loops.
- The one-way latency for G.fast is less than 1msec, to improve Web page load times.
- The G.fast standard will require that all transceivers support vectoring. Because crosstalk is stronger at G.fast frequencies than VDSL2 frequencies, vectoring in G.fast is more difficult than in VDSL2.
- The G.fast ratio of downstream rate to upstream rate is provisionable, but this ratio must be the same for all transceivers in the DP.
- G.fast has defined various low-power modes for different operating conditions, including battery operation. It also utilizes Dynamic Resources Allocation (DRA), which allows power minimization during “normal” operating conditions.

Previous xDSL standards such as ADSL and VDSL2 use FDD to transfer upstream and downstream data simultaneously. FDD means that downstream data is transferred in one set of frequency bands and upstream data is sent in a different set of frequency bands, as shown in Figure 2a. G.fast uses TDD, meaning that upstream and downstream data are not transferred simultaneously, and that the data transfer alternates between upstream and downstream, as shown in Figure 2b. The downstream/upstream period is around 750 usec. The advantage of TDD is that its performance is less affected by impedance mismatches of in-home wiring when compared to FDD—although the performance in the presence of these impedance mismatches is less than the performance on properly terminated loops.

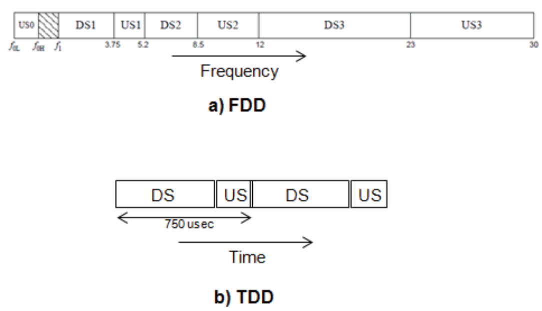


Figure 2: TDD/FDD Comparison

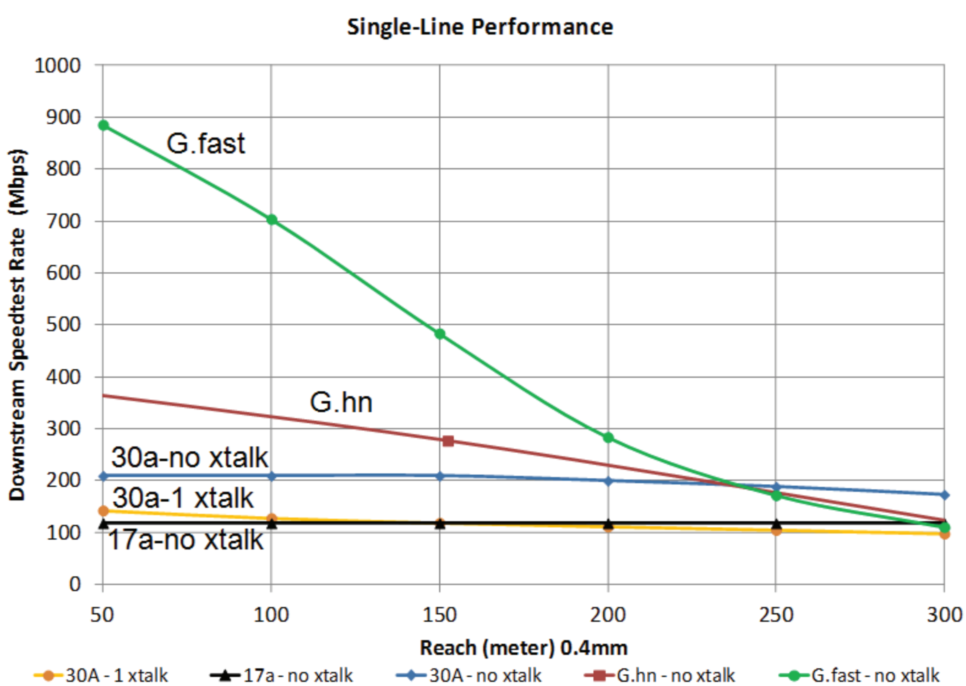
Performance Comparison of FTTdp Copper Technologies

A first comparison of these various copper technologies is with "single-line performance", where there is zero or very little crosstalk involved, as shown in Figure 3. This performance is for a downstream TCP-based speed test, so there is data flowing in both directions (data segments downstream, Acknowledgements (ACKs) upstream). This is an important point for comparing FDD-based technology like VDSL2 with TDD-based technologies like G.hn and G.fast.

As can be seen in Table 1, with no crosstalk VDSL2 profiles 17 and 30 attain close to the maximum performance. These no-crosstalk performance values are approximately what can be achieved with vectoring. Note that profile 30 without vectoring and with only a small amount of crosstalk (1-xtalk) has a performance comparable to profile 17 with vectoring.

G.hn with no crosstalk has better performance than VDSL 30 with no crosstalk. G.hn does not have crosstalk canceling available, but it does have the ability to coordinate between G.hn transceivers so that no two G.hn transceivers are transmitting simultaneously. This allows high peak rates when one transceiver has substantially more data to send than the others.

G.fast, which is designed to operate on short loops in the presence of crosstalk, has substantially better performance than all the other technologies.



A second comparison is in the presence of crosstalk, specifically crosstalk from VDSL2 profile 17 out of the cabinet. This scenario is shown in Figure 4. This represents a common scenario where VDSL2 has already been deployed out of the cabinet (FTTN), and FTTdp has started being deployed very close to the customer (at the DP or in the basement). The cabinet is distance “D” from the subscriber, and the DP or basement is distance “X” from the customer. Over distance “X”, the FTTN VDSL2 technologies are present in the same bundle of wires as the FTTdp copper technologies, thus causing crosstalk between the two technologies.

We assume in this scenario that FTTdp copper technologies will completely vacate any bandwidth occupied by the FTTN VDSL2 technology, and any bandwidth not occupied by the FTTN VDSL2 technology will be occupied by the FTTdp copper technology. More specifically, as the “D” increases, the amount of bandwidth occupied by the FTTN VDSL2 technology decreases, and the FTTdp copper technology increases to occupy the available bandwidth. Figure 5 shows the bandwidth occupied by the FTTN VDSL2 technology as a function of the distance “D”.

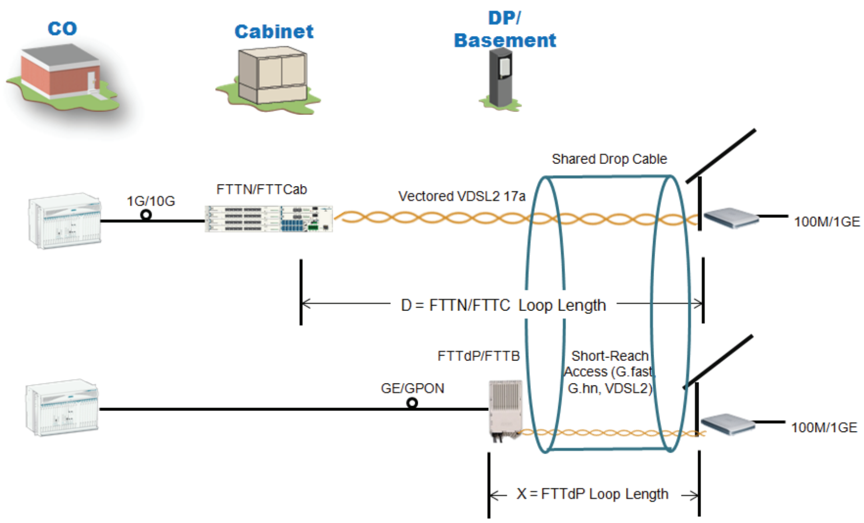


Figure 4: Deployment Scenario of FTTN Mixed With FTTdp in the Same Wire Bundle

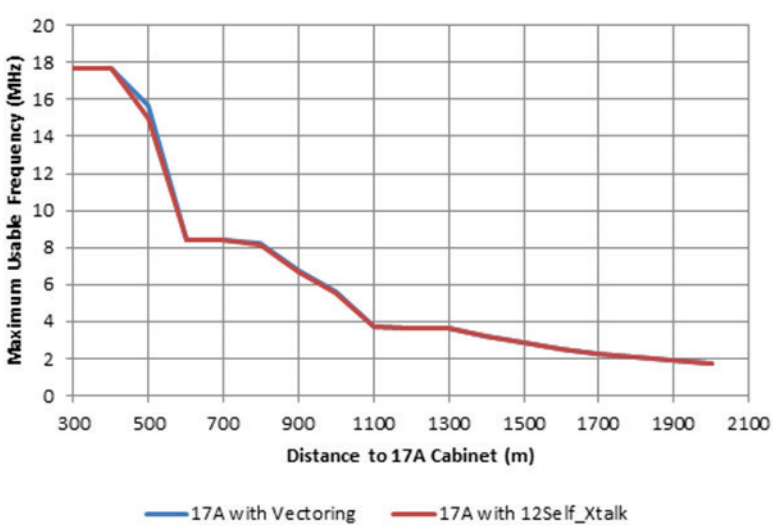


Figure 5: Bandwidth Used by FTTN VDSL2 as a Function of Distance “D”

The resulting performance of the FTTdp copper technologies is shown in Figure 6. The curve labeled "17A Vec From Cabinet" represents the performance of the FTTN VDSL2 as a function of distance "D". All the other curves are the performance of the FTTdp copper technologies, each representing a difference distance "X". As the distance "D" decreases, the amount of bandwidth occupied by the FTTN VDSL2 technology increases, which means the corresponding FTTdp bandwidth must decrease, causing the FTTdp performance to decrease.

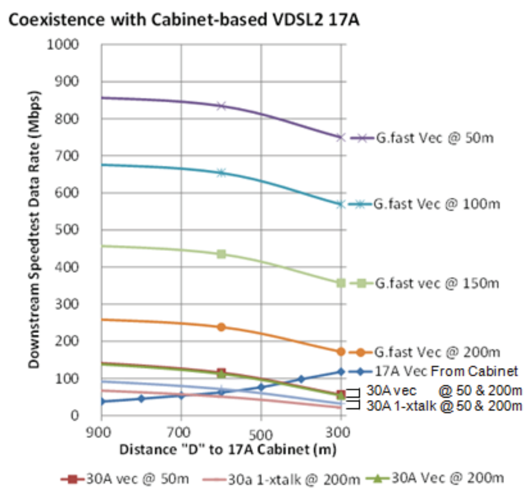


Figure 6: Comparison of FTTdp Copper Technologies in Same Wire Bundle as FTTN VDSL2

For example, consider the four G.fast curves in Figure 6. The top G.fast curve, labeled "G.fast Vec @ 50m", is the performance of vectored G.fast at distance "X" equal to 50m. As the distance "D" decreases, the 50m vectored G.fast performance decreases from around 850 Mbps to around 750 Mbps. This same approximately 100 Mbps drop in performance is seen in all four G.fast curves, because the G.fast bandwidth is decreased by (17.7 – 8.5) = 9.2 MHz.

The "30A Vec" curves show that profile 30 VDSL2 can achieve better than 100 Mbps performance as long as the cabinet is at least 500m from the subscriber.

The "30A 1-xtalk" curves show the substantial impact of even a small amount of crosstalk on VDSL2 profile 30.

An alternative to the scenario in Figure 4 is to move all of the cabinet-deployed VDSL2 customers to the DP. There are several issues with this approach: 1) it may be difficult to get all customers to upgrade their CPE to G.fast, so the service provider may have to provide VDSL2 profile 17 out of the DP, 2) assuming case 1, G.fast or VDSL2 profile 30 and VDSL2 profile 17 cannot be vectored together because of different tone spacing, so the G.fast or VDSL2 profile 30 out of the DP must vacate the lower 17 MHz of bandwidth. As a result, performance in this scenario is essentially the same as the D=300m case from Figure 6.

Conclusions

- The basic idea behind FTTdp is to deploy fiber as deep into a neighborhood as is economically feasible, then use existing copper assets the last few hundred meters to the house or apartment.
- There are two fundamental deployment scenarios for FTTdp, Multi-Dwelling Unit (MDU) and Single Family Unit (SFU)
- The attributes of the FTTdp architecture are 1) high service rate, 2) reverse powering, 3) cable crosstalk, 4) self-install and 5) emphasis on power conservation
- Several twisted pair copper technologies may be considered for the FTTdp "copper extension cord": 1) VDSL2, 2) G.hn, and 3) G.fast
- G.fast is specifically designed to operate in the FTTdp environment, whereas VDSL2 and G.hn have lower performance than G.fast

References

[1] Rob F.M. van den Brink, "Enabling 4GBB via the last copper drop of a hybrid FttH deployment," Broadband, Journal of the SCTE, Vol. 33 No. 2, April 2011, page 40-46.

[2] Per Ödling, Thomas Magesacher, Stefan Höst, and Per Ola Börjesson, Miguel Berg, Enrique Areizaga, Tony Bradley, "The Fourth Generation Broadband Concept," IEEE Communications Magazine, January 2009, page 63-69.

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[4] Richard Goodson and Martin Kuipers, "G.fast: Power Optimized G.fast Transmission", Contribution C-2197, October 2012, SG15/Q4a, Geneva, Switzerland.

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