Whitepaper

# G.fast Technology and the FTTdp Network

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## Abstract

This white paper gives an overview of use cases and applications of G.fast transmission technology that is currently under development. The goal of G.fast is to deliver data at fiber speed to the customers using telephony copper wires.
This solution shall provide high speed services at reasonable deployment cost for many subscribers. Low power consumption and ease of use for the customers are the main goals of the technology.
Hardware-based simulations shall demonstrate the capabilities of G.fast for different applications. The channel models used to build different network topologies are based on a joint work of Deutsche Telekom and Lantiq.
Lantiq has provided solutions for specific core features of G.fast which are presented in this paper.

## Introduction

The demand for higher data rates is continuously increasing, which makes improvements of the network architecture necessary. There are governmental programs for Broadband coverage. Applications like Cloud Computing, Video Streaming, Big Data and the Internet of Things drive these demands.
Strong competition of cable network operators increases the pressure on traditional network operators to deliver high speed services. But a pure fiber network will cause very high costs to be built today at a large scale. During the transition from copper-based access networks to pure fiber networks, the fiber network is gradually extended to bring them closer to the subscribers.
The idea of a copper fiber hybrid network has been described already in [ OMH09]. A dense fiber network, where the fiber ends very close to the subscribers and the remaining gap is closed using copper wires, requires introducing a new network node, the distribution point (DP). At this point, the fiber is connected to a small number of copper pairs using an active device called the DP box.
Fiber to the distribution point (FTTdp) provides new solutions between the existing fiber to the home (FTTH), fiber to the building (FTTB) and fiber to the curb (FTTC) topologies. In many cases it is not favorable to connect the fiber directly to the customer premises. The copper wires between the DP and the customer may be low quality telephony cable bundles with wire pairs for multiple subscribers. The most critical feature of the DP box is its power consumption and a suitable method to supply the device with power.
With the idea of reverse power feeding (RPF), the problem of supplying the DP box with power can be solved. However, this creates new challenges as the energy budget for a reverse powered DP box is very limited.

The goal of G.fast standard [ITU06] [TGNM13] is to develop and describe methods to transmit data at fiber speed over short copper wires, probably to multiple subscribers sharing a cable binder, with low power consumption. This is an important building block to drive fiber deployment.
This white paper gives a short overview on the fiber to the distribution point (FTTdp) network, which is the generic term for all FTTx topologies where a distribution point is used. It is focusing on deployment cases and characteristics of short copper wires at high frequencies. Details of the G.fast physical layer technology with respect to specific applications are shown. Simulation results of data rates at specific deployment scenarios complete the paper.

## FTTdp Network Topologies

G.fast may be used in network topologies with different requirements for the physical layer coding and signal processing. To evaluate signal processing requirements and predict the system performance for deployment scenarios of interest, reliable channel models are required.
In a first step, a closer look at different deployment strategies helps to get an impression on the expected line lengths, cable binder sizes and cable types of the FTTdp network.

## Deployment Scenarios

Based on the three deployment scenarios, single-port-, multi-port-FTTdp and FTTC, the requirements on G.fast front-end electronics and the distribution point hardware are evaluated. A more detailed description of FTTdp deployment scenarios can be found in the Broadband Forum (BBF) document WT-301 [Bro10].
This section gives a short overview over network properties where G.fast is applicable. It also answers the question, why copper access technologies are still an integral part of the fiber access network.

## Fiber To The Home vs. Single Port FTTdp

Deployments with one fiber link per subscriber are the network topology for rural areas where the population is not too dense. G.fast can help to reduce deployment cost in such areas.
At a first glance, there is no copper access technology required to build a FTTH connection. But in practice, connecting the fiber directly to the customer premises causes some disadvantages that can be solved by the hybrid copper/fiber approach, where the fiber is extended with a single-port DP and a short copper wire.

- While fiber connections require a technician to install the customer premises equipment, the copper-based CPE may be installed by customer (customer self install), because the only action required installing the copper-based CPE is to connect the CPE to the phone plug with the delivered cable. This saves cost for new subscribers and makes the home installation much easier.

- In urban environments, deploying fibers to the subscriber homes may not be possible due to legal restrictions or because of difficulties to install fibers in existing buildings.
- Lead times can be unpredictable, particularly if permission for construction work is required from home owners and tenant associations

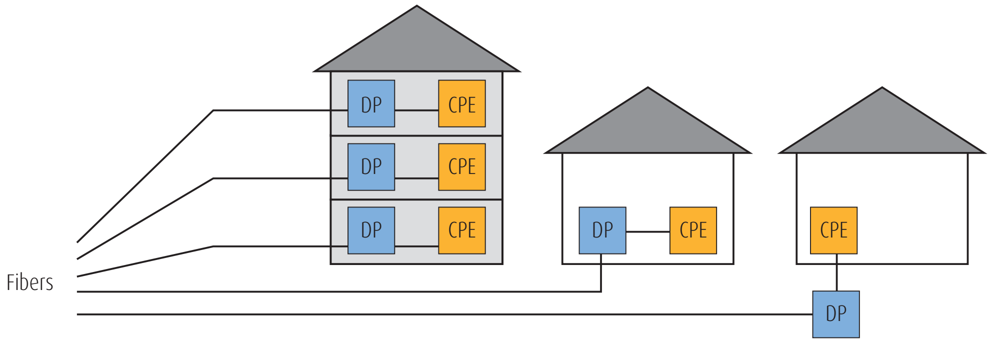



Figure 2.1:
Single Port FTTdp applications

Single Port FTTdp is the easiest to implement from a DP box hardware perspective, but also the most expensive one. There is one fiber per subscriber which is very costly for the network operators.

Fig. 2.1 shows some Single Port FTTdp deployment cases. The distribution point translates the signals from one fiber to one copper twisted pair. No crosstalk cancelation is required and the line length is short, in the range of 100m but in most cases much shorter. The distribution point is supplied from the customer side using reverse power feeding.

Devices of this type, which are based on VDSL Profile 30, exist already. Fig. 2.2 shows such type of distribution point. The fiber connection is provided by the Lantiq Falc™ON chip with up a 2.5 Gbit/s GPON link and the copper connection is based on the VINAX™DP single port VDSL device.

Figure 2.2:
Single port distribution point based on VDSL 2 Profile 30, serving up to 300 Mbit/s

This device provides aggregate data rates (upstream+downstream) around 300 MBit/s and may be replaced by a G.fast-based DP when higher data rates are required. The VINAX™DP-based distribution point already shows that the concept of a small reverse powered fiber extension can work for the single port application.

The G.fast-based DP will be capable of supporting up to 1 GBit/s for the 106 MHz profile and around 2 GBit/s with the future 212 MHz profile in this specific environment, as demonstrated in the last chapter.

### Multi-Port FTTdp and Fiber To The Building

FTTH deployments are very limited and cost is not the only reason for that. Multi-line distribution points are a smarter solution to provide fiber-speed services. Deployments with multi-line DPs are used in areas with a more dense population and multi-unit residential buildings.

- Most in-house telephone installations still rely on copper cables for most existing and newly constructed buildings because fibers are expensive and difficult to handle.
- The unbundled lines may not be accessible for the service provider to install individual DP boxes
- Especially in existing buildings, the copper wire bundles may be of a poor quality.

Besides in-building or in-home installations, there are different outdoor locations where the distribution point may be placed. Examples are manholes, pole-mounted distribution points or small street cabinets. The main advantage of FTTdp in comparison to existing FTTB solutions is reverse power feeding. It allows placing the DP box at any appropriate place, with out the requirement of a local power supply.

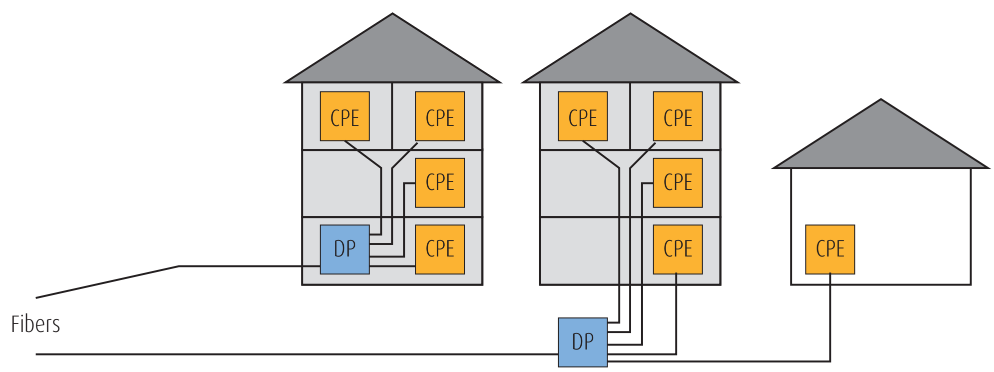



Figure 2.3:
Multi-port FTTdp deployment examples

Multi-line DPs with G.fast allow to deliver fiber-speed data rates under these conditions. While the line length of the copper wires is moderate, in most cases shorter than 100m and only in rare cases up to 250m and the cable binder are small, usually no more than 16 pairs. But cros-stalk between the pairs limits the achievable data rates for a G.fast service.

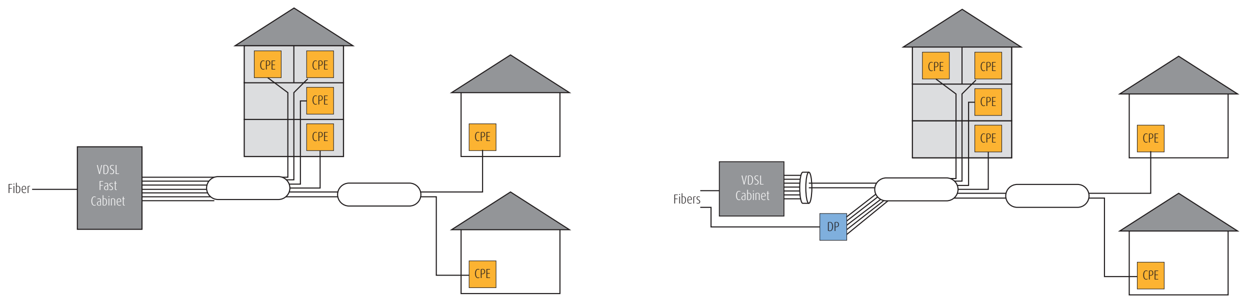
Fig. 2.3 shows Multi-line FTTdp scenarios. The DP may be placed inside the building or outside, with one or more buildings connected. The subscribers of one DP share the data rate of one or more GPON links. For today's Vinax™DP-based multi-port DP-boxes, the performance impact due to crosstalk is small. But for a G.fast-based DP box crosstalk cancelation becomes critical for performance. Crosstalk cancelation on twisted pair telephony wires at frequencies as high as 106 MHz or even 212 MHz opens a new field for innovation.

But for the development of improved crosstalk cancelation techniques, a good understanding of the cable behavior is very important as will be shown later. FTTB and multi-port FTTdp is not the most demanding environment for G.fast systems.

## Fiber To The Curb with G.fast

The transition from current VDSL technology to the new G.fast service is a very critical step, because in this time, VDSL and G.fast coexist in the network. Lantiq provides solutions to serve G.fast from the VDSL cabinet.

The next generation Vectoring chip supports crosstalk cancelation for up to 48 G.fast channels.




(a): G.fast/VDSL Cabinet

(b): Manhole/Pole Mount/Mini Cabinet

Figure 2.4:
G.fast topologies with VDSL coexistence

Up to 48 G.fast ports are expected for FTTC. Due to the fact that these binders may not only contain G.fast lines, but also legacy VDSL 2 lines, interoperability between G.fast and VDSL must be considered, here.

Street cabinets with G.fast support may serve G.fast and VDSL from one location, depending on the rate requirements and line length as shown in Fig. 2.4 (a). For manholes and pole-mounted distribution points, the VDSL signals may be provided from a street cabinet at some distance from the DP as shown in Fig. 2.4 (b).

For the G.fast FTTC, the G.fast reach is extended to 300m or even more. Subscriber lines with longer lines may exist in both FTTC scenarios, but they are served using VDSL and not G.fast. But for the scenario of Fig. 2.4 (a) with a multi-service cabinet, near-end crosstalk between G.fast and VDSL may become very strong. Therefore, near-end in addition to far-end crosstalk must be considered in the crosstalk scenario. A channel model is required to describe near-end and far-end crosstalk correctly.

## Channel Modeling

The parameters of the channel model are selected to match the properties of different network topologies. Tab. 2.1 summarizes the main properties of different network topologies as mentioned before. The naming in standardization documents such as [Bro10] or [Bro14] can be different.

| Topology | Line length | Binder Size | Power Supply | Crosstalk Environment |
|---|---|---|---|---|
| 1-port DP | 1m...100m | 1 pair | RPF | No crosstalk |
| Multiport-DP | 10m...250m | 1 to 16 pairs | RPF | Self-FEXT |
| FTTC | 50m...300m | up to 48 pairs | RPF or local supply | Self-FEXT and alien crosstalk |

Table 2.1:
Properties of different FTTdp network topologies

There are different types of channel models for twisted pair copper wires available, which have been used to develop xDSL technologies. There are single line models like the ETSI model [Sta03] and MIMO models for crosstalk modeling like the ATIS model [Jan08].

But they are not sufficient for FTTdp channel modeling, because they do not cover the G.fast frequencies up to 212MHz. Measurements at high frequencies show a demand for improved channel models because of several behavioral aspects of the cables which are not covered by present models.

## Crosstalk in G.fast

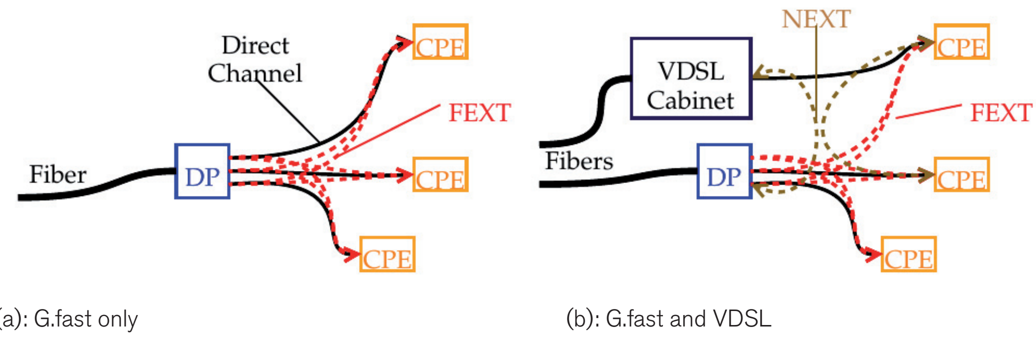



Figure 2.5:
G.fast crosstalk scenarios

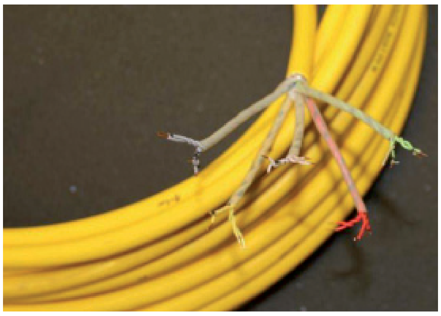
Crosstalk is present in most G.fast topologies. Whenever multiple subscribers are part of the same cable binder, some portion of the signal from one line disturbs the signals of other lines through the electromagnetic coupling between them. With increasing frequency, the crosstalk coupling between the lines becomes stronger until the crosstalk couplings and the direct connection have the same strength at very high frequencies, which is then very similar to a wireless channel.

We distinguish between two types of crosstalk near-end crosstalk (NEXT) and far-end crosstalk (FEXT). The situation of a binder with G.fast lines only is shown in Fig. 2.5 (a). In this case, only FEXT is present, where the G.fast receivers get signals from the corresponding far-end transmitter, but are disturbed by far-end signals from other lines. NEXT does not exist in pure FTTdp scenarios, because the DP synchronizes the transmit signals such that all lines send their downstream and upstream signals at the same time.

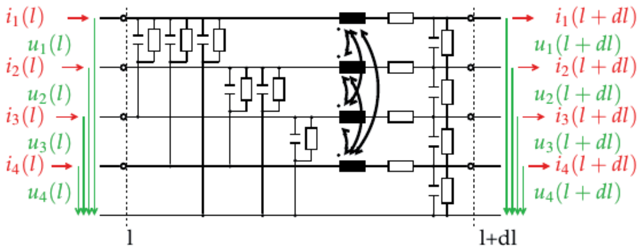
Near-end crosstalk, where the transmit signal of one line disturbs the receiver of another line at the near-end, e. g. transmitter and receiver are within the same mini-cabinet, exists for the FTTC scenarios with VDSL and G.fast in the same binder. This is shown in Fig. 2.5 (b). Due to the fact that G.fast uses time division duplexing (TDD) and VDSL uses frequency division duplexing (FDD), a street cabinet DP with both services experience near-end crosstalk in addition to FEXT at the overlapping frequency spectrum.

Good channel models are required to evaluate the effects of crosstalk on the data transmission and to develop appropriate signal processing methods to achieve the highest data rates.

## Wideband Crosstalk Modeling



(a): Measured cable




(b): Model

Figure 2.6:
Deutsche Telekom cable and abstract model for G.fast

Lantiq and Deutsche Telekom work on channel models for G.fast frequencies. Based on measurements of several access and in-house cables at Deutsche Telekom, a realistic channel model has been created and published. The fundamentals have been presented at the GLOBECOM conference [SSU13].

More details are presented in a BBF study document [Bro14], where the detailed description of the channel model can be found. Simulation results shown here are based on the described type of channel model.

Fig. 2.6 (a) shows one of the measured access cables with ten twisted pairs, organized in five star quads. Measurements are done for frequencies up to 300 MHz to cover the full G.fast frequency spectrum.

Measurement data of transfer functions of this type of cable show that the crosstalk behavior at high frequencies is very different than predicted by crosstalk models like the ATIS model [Jan08]. To reproduce the high frequency behavior in a simulation model, a cable binder is represented in terms of an equivalent circuit that describes direct channels and crosstalk transfer functions of the cable binder. Fig. 2.6 (b) shows the equivalent circuit as it is proposed in [SSU13].

A comparison between measurements and the model of one of the Deutsche Telekom cables demonstrates the advanced behavior of the new m-MIMO channel model. Fig. 2.7 shows the direct channel and FEXT transfer functions up to 300 MHz.

Important aspects of the crosstalk behavior at high frequencies can now be simulated. The direct channel attenuation (blue) in Fig. 2.7 increases at high frequencies and the transfer function may be even weaker than the crosstalk couplings to other pairs (green). These effects are not covered by other models.

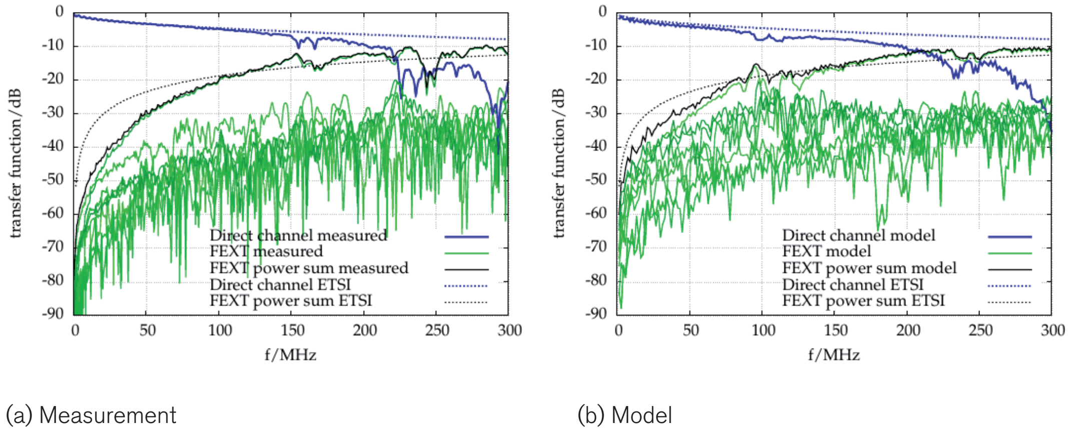



Figure 2.7:
Measurement and model of direct channel and FEXT transfer functions of twisted pair cables up to 300 MHz

Based on this model, complex topologies like Fig. 2.4 can be simulated. Based on the simulations, specific requirements for G.fast transceiver technology are derived.

## G.fast Technology

G.fast is based on the latest VDSL technology including crosstalk cancelation and retransmission.
Main changes are done for physical media dependent (PMD) layer of the system. The physical layer design is based on the idea of an energy efficient small access node, the distribution point. The medium access is done with time division duplexing (TDD) rather than frequency division duplexing (FDD) which reduce analog complexity and analog front-end power consumption. The power consumption can be further reduced by a method called discontinuous operation. Lantiq has provided important contributions to combine vectoring and discontinuous operation to a working solution.

To achieve high data rates on low quality cables, crosstalk cancelation, as it has been introduced in VDSL 2 Vectoring (G.993.5) is of increasing importance. Due to the increasing crosstalk strength at high frequencies used in G.fast, advanced crosstalk cancelation methods must be evaluated.

While for a spectrum up to 106 MHz, linear precoding in combination with a spectrum optimization method, which has been developed at Lantiq, is the best choice in terms of complexity, power consumption and performance, the 212 MHz G.fast service may require nonlinear coding techniques.

For a grace transition from vectored VDSL to G.fast, combined VDSL/G.fast cabinets may be introduced. Lantiq provides optimized spectrum management techniques to allow both services to share the same cable binder.

## Framing

The frame structure of G.fast is different to VDSL due to TDD. Fig. 3.1 illustrates the G.fast frame structure. The data is organized in superframes, where each superframe starts with a sync frame that is followed by multiple data frames. The default setting is a superframe that consists of 8 TDD frames.

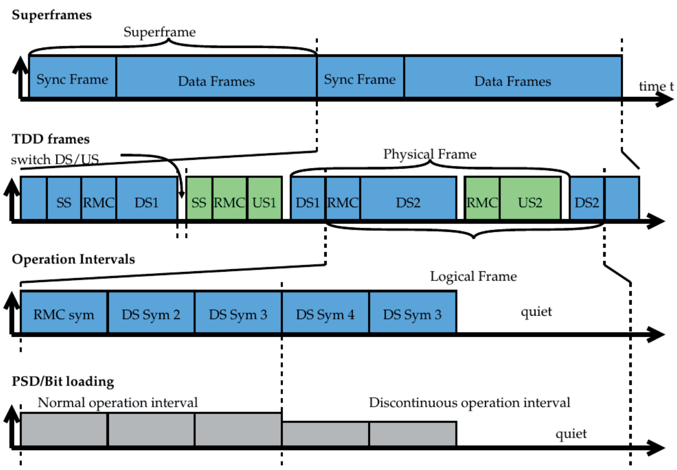



Figure 3.1:
G.fast frame structure with discontinuous operation

Each TDD frame has the length of an integer number of DMT symbols. It contains a group of downstream symbols and a group of upstream symbols as well as guard times between upstream and downstream data. Both guard times of a TDD frame sum up to the length of one DMT symbol in time.

Furthermore, each TDD frame contains an RMC (robust management channel) symbol for fast reconfiguration and physical layer management. The TDD sync frame contains a sync symbol for channel estimation and synchronization.

As shown in Fig. 3.1, there are two definitions of the TDD frame. The physical TDD frame consists of one downlink and one uplink symbol block and starts with the downlink data block. The logical TDD frame for sync frames starts with the sync symbols and for other TDD frames it starts with the RMC symbol which is somewhere in the middle of the downstream data.

The downstream data symbol block and the upstream data symbol block are further split into a normal operation interval (NOI) and a discontinuous operation interval (DOI) where discontinuous operation can be applied. In the normal operation interval, all lines of a DP are active and transmit or receive data. During the discontinuous operation interval, the lines may stop transmitting to save power.

In this time, the line drivers and analog front-ends may be switched off to save power. But in a multi-line distribution point with crosstalk cancelation, the signals cannot be treated independently which requires additional signal processing to facilitate discontinuous operation.

## Vectoring

Most G.fast applications require data transmission over cable bundles where crosstalk between the lines is present. Even in VDSL 2 systems, Vectoring [Sch10] gives significant performance improvements. In G.fast, crosstalk becomes even more dominant due to the high frequencies and crosstalk cancelation is a core feature of G.fast systems.

In downlink direction, from the DP to the CPE, this is called precoding, because the signal is pre-distorted such that the receive signals are free of crosstalk at the CPE side. The upstream signals from the CPE to the DP are processed by matrix equalization.

## Impact of Crosstalk in G.fast

Looking at the measurement data from Fig. 3.2, the crosstalk channel can be even stronger than the direct connection between the DP and a subscriber. When crosstalk is treated as a disturbing signal in this context, this is a serious issue.

However, the strong crosstalk couplings which are present in G.fast systems can be used to transport a portion of the useful signals to the subscribers. Fig. 3.2 shall demonstrate that.

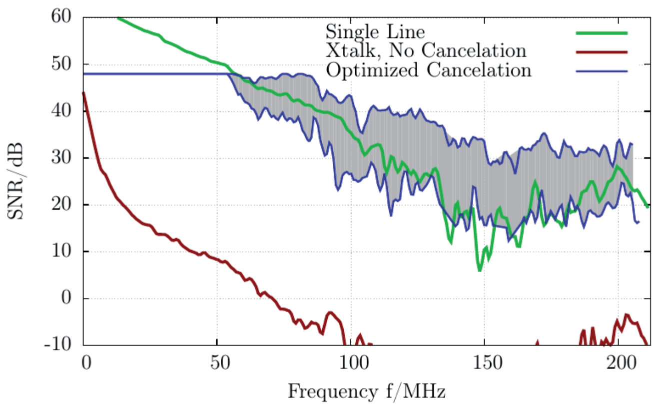



Figure 3.2:
SNR for on line with and without crosstalk cancelation

The plot shows several signal-to-noise (SNR) ratio curves of one G.fast line in a cable binder of 16 lines. When all other lines are switched off, no crosstalk is present and the SNR curve of the green line is achieved. But when all lines are active, crosstalk is present and the SNR reduces dramatically to the red line.

With crosstalk cancelation, the negative effect of crosstalk can be compensated while all lines are still active.

## Optimized Linear Precoding

Lantiq has developed optimization methods for crosstalk cancelation in G.fast which can be used to improve performance of specific lines in presence of crosstalk. Individual high priority lines can achieve even higher performance than it would be the case without crosstalk. This is shown with the blue curves in Fig. 3.2 and the shaded area between them. Optimized linear precoding can achieve any point in this area, outperforming even the crosstalk-free case.
This fact makes crosstalk cancelation in G.fast different to Vectoring for VDSL where the intention was just to remove the crosstalk. Crosstalk can be used to enhance the link quality of a specific line rather than reduce it. The individual user data rates can be optimized with respect to their specific rate requirements.

## Other Crosstalk Cancelation Methodsg

For the precoder, two methods are under investigation, linear precoding and nonlinear precoding. Linear precoding is widely used in VDSL vectoring systems and gives a good performance with limited complexity. The disadvantage of linear crosstalk cancelation is a power increase caused by the precoder in downlink direction. The nonlinear precoder has a small power increase, but it requires much higher hardware complexity and increases power consumption. Fig. 3.3 shows the SNR comparison between the precoding methods.

For 106 MHz G.fast systems, a spectrum optimization step at the precoder input, combined by a linear precoder (blue curves) gives the best performance in simulations provided by Lantiq. However, for some special channel conditions in the 212 MHz profile, the nonlinear techniques (red curves) give higher performance than optimized linear coding.

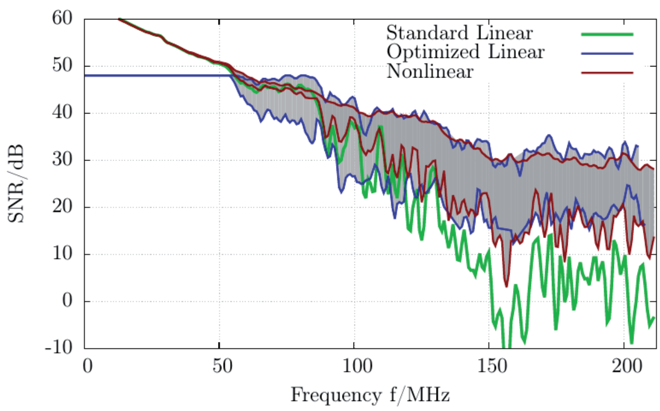



Figure 3.3:
SNR for linear, Lantiq optimized linear and nonlinear precoding

As indicated in Fig. 3.3, the nonlinear precoder also supports priorities, such that there is an achievable SNR range between the red curves rather than a single SNR curve. The precoder without spectrum optimization step (green curve), as it is used for VDSL vectoring, results in weak performance under the G.fast channel conditions.

Another interesting aspect of the G.fast physical layer is discontinuous operation and how it combines with crosstalk cancelation.

### Discontinuous Operation

Discontinuous operation basically means that no data symbols are transmitted when there is no data available. While a VDSL system sends idle data packets, the G.fast system can mute these data symbols and switch off the analog front-end components for this time.

The idea sounds straight-forward. However, this means that the analog components must shut down and boot up during a time period around one microsecond. Otherwise the delays caused by switching off the transceivers are too long and the user may notice reduced data rates.

At a first glance, there is no issue combining discontinuous operation with crosstalk cancelation. But in detail, there are some issues. Fig. 3.4 shows the signal flow for two lines in downstream direction with precoding.

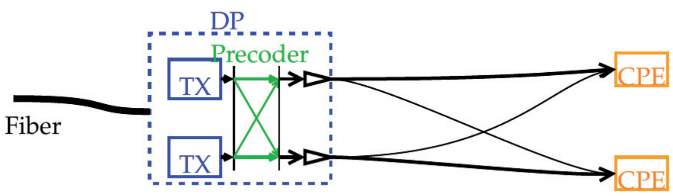



Figure 3.4:
Signal flow with precoding and all lines enabled

Due to the precoding operation, some of the signal of subscriber 1 is transmitted via the precoder over the front-end of subscriber 2. This part of the signal reaches subscriber 1 through the crosstalk channel from transmitter 2 to CPE 1. Fig. 3.5 shows what happens, when the front-end of subscriber 2 is switched off because of discontinuous operation.

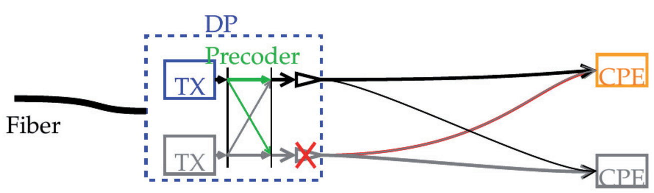



Figure 3.5:
Signal flow with one discontinued transmitter

Shutdown of transceiver 2 removes some of the signal of subscriber 1. Due to the strong crosstalk, this can be a significant portion of the signal and the link might drop.

Lantiq has developed a method how to “replace” the signal for active lines that is lost because of shutting down other lines. This is based on a very fast correction of the crosstalk canceler settings such that the receiver does not notice the changes.

However, that causes an increase of transmit power at the active lines which must be compensated. Therefore, the G.fast crosstalk canceler is capable of performing a fast correction of the transmit power to keep the signal strength in the allowed range.

## Coexistence with VDSL

So far, we were looking at methods how to treat crosstalk that disturbs G.fast lines and is caused by other G.fast lines, the so-called self-FEXT. In mixed scenarios of FTTC applications, there is also crosstalk between different services, G.fast and VDSL, present. This is called alien crosstalk, more specifically alien FEXT and alien NEXT.

The alien crosstalk cannot be canceled like self-FEXT because of the different transmission technologies used. The SNR curves of Fig. 3.2 indicate that the performance impact of crosstalk and G.fast without crosstalk cancelation is dramatic. Therefore, the standardization bodies propose to use only the spectrum above VDSL for G.fast in this case, as shown in the upper part of Fig. 3.6.

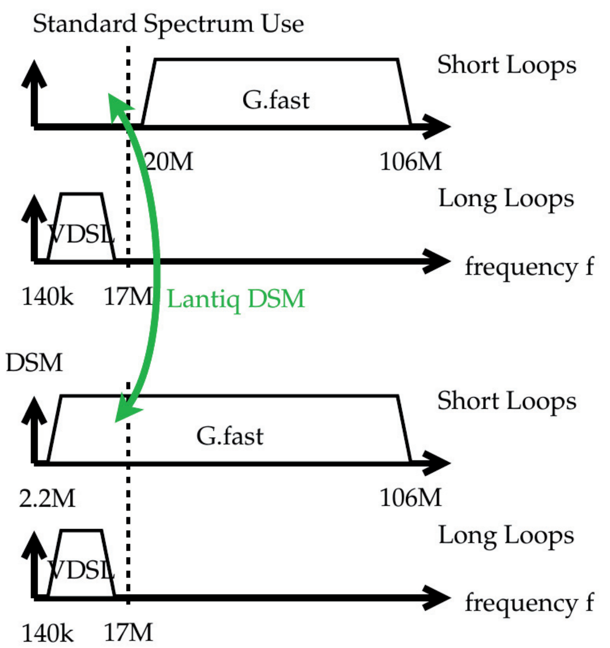



Figure 3.6:
Spectrum usage in mixed G.fast/VDSL scenarios, standard vs. Lantiq spectrum overlap

But for alien crosstalk between G.fast and VDSL, the picture is different than for self-FEXT. The lower part of Fig. 3.6 indicates the solution provided by Lantiq, which increases performance without additional hardware complexity. This is possible because power end spectrum used by the different services is very different.

- G.fast uses a 6 (or even 12) times wider frequency band than VDSL (106 MHz vs. 17 MHz).

- G.fast transmit power is more than 10 times lower than VDSL transmit power (4dBm vs. 14.5dBm).

Due to the low transmit power, the G.fast signal is too weak to disturb the VDSL transmission seriously. The crosstalk from VDSL lines into G.fast is much stronger in terms of power, but it affects only a small fraction of the frequency band.

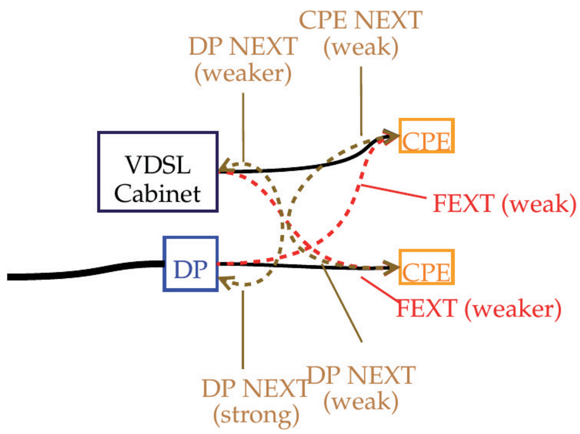



Figure 3.7:
Crosstalk couplings in a mixed G.fast/VDSL scenario

Furthermore, the crosstalk coupling paths have very different strength as indicated in Fig. 3.7. The near-end crosstalk from VDSL into G.fast at the DP side is usually very strong due to the short coupling path and the high power of the VDSL downstream signal. However, it disturbs only a small part of the upstream band and the upstream transmission is a smaller part of the transmission time.

NEXT from G.fast into VDSL at the DP side is weaker because of the lower transmit power. The near crosstalk couplings from one CPE into another CPE are usually not too strong because of the line length from one CPE to the binder and back to the other CPE. FEXT coupling from the VDSL lines into G.fast in downstream direction also cause a noticeable performance impact while FEXT from G.fast into VDSL is too weak to cause reduce the data rates significantly.

Overall, the overlapping transmit spectrum of G.fast and VDSL in the mixed scenarios can be used to increase the achievable data rates of the G.fast lines. It is not required to separate VDSL and G.fast spectrally. An advanced spectrum allocation algorithm is required to use the overlapped spectrum for both services. The algorithm runs on the G.fast lines. It detects parts of the spectrum that can be used for data transmission and selects the transmit power accordingly.

## Results and Outlook

This chapter presents performance results for G.fast lines for the different topologies from the first chapter. It is based on the channel models provided by Deutsche Telekom and Lantiq as described in the channel modeling section.

Due to the increasing variance of channel characteristics at higher frequencies, a special framework is used to evaluate the data rates.

## Evaluation of G.fast Data Rates

Modern chip development is based on intensive simulations of the system behavior. The simulation environment is used to design hardware components as well as software components of the system and allows parallel development of hardware and software components. All presented results are based on a simulation model of the G.fast physical layer. The achieved data rates are measured at the interface between PHY and MAC layer.

The average data rates as well as the rate distribution are evaluated as a function of line length. Therefore, many random realizations of each topology with different line number and line length are created. For each cable bundle, the system trains the links and optimizes the transceiver settings according to the methods provided by Lantiq. Hardware limitations of the G.fast analog and digital front-end electronics are incorporated into the model.

## Simulation Results

For each of the scenarios, single-port DP, multi-port DP and FTTC, rate vs. reach simulations are shown. The results represent crosstalk free performance, MIMO simulations with self-FEXT and crosstalk cancelation and simulations with large bundles and VDSL alien crosstalk for the FTTC case.

## Single -Port FTTdp

For this first scenario, single line rates of G.fast on German access cables are presented. The 106 and the 212 MHz are evaluated, both starting at 2 MHz. For both, the usual simulation assumptions of -140 dBm/Hz background noise ad 4 dBm transmit power are used.

Data transmission is simulated for 100% downstream time for simplicity of presentation. In the actual system, the aggregated data rates are split into an upstream and a downstream portion. The split can be configured according to the subscriber demands.

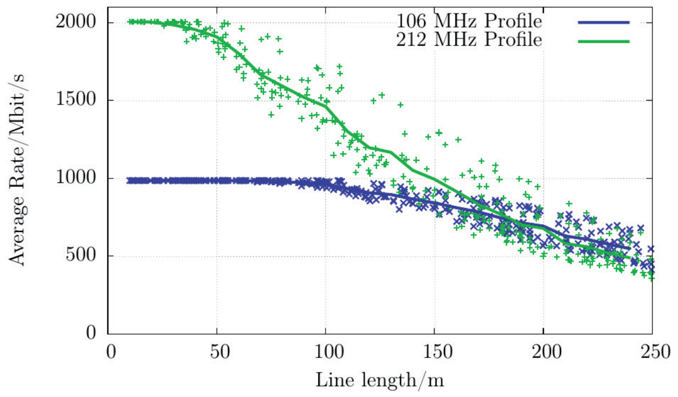



Figure 4.1:
Rate vs. reach of single line G.fast systems

Fig. 4.1 shows the rate vs. reach for 106 MHz and 212 MHz G.fast single port transmission. Each of the individual points in the plot marks one line with its specific line length and achieved data rate. Solid lines mark the average rate vs. reach of all simulations.

For the reach of interest below 100m, almost 1 GBit/s can be achieved with the 100 MHz profile. The 200 MHz profile delivers even higher data rates which may be required in future.

### Multiport FTTdp

In this section, multi-port G.fast systems with crosstalk cancelation are evaluated. Again, the 106 MHz and 212 MHz profile with 2 MHz start frequency are used. There is self-FEXT from the other G.fast lines present.

The cable bundles have up to 16 lines and a line length up to 250m.

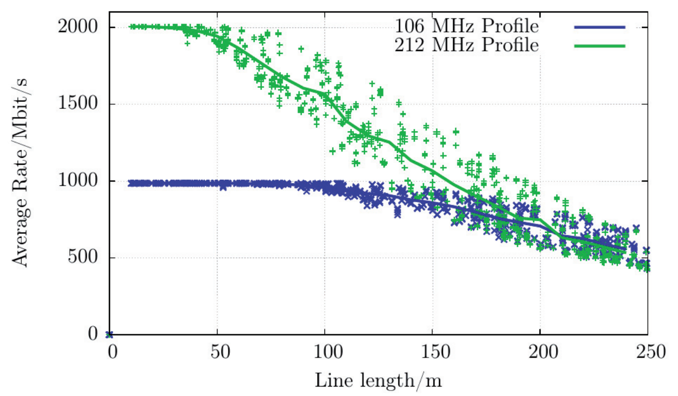



Figure 4.2:
Rate vs. reach curves for G.fast with crosstalk cancelation

Fig. 4.2 shows the rate vs. reach curve for the multi-port G.fast scenario with linear crosstalk cancelation for the 106 MHz and 212 MHz G.fast profiles. The system still reaches similar data rates as for the crosstalk-free case.

This is due to Lantiq's advanced spectrum management techniques which allow the G.fast system to manage the available transmit power and transmit spectrum such that the highest data rates are achieved for every subscriber.

## FTTC with G.fast

In this section, deployments with G.fast and VDSL lines within one binder are considered. The VDSL lines operate in a 17 MHz profile, while the G.fast lines use the 106 MHz Profile.

For G.fast, the upstream/downstream ratio is set to 20%/80%, while in VDSL, the upstream and downstream spectrum is fixed by the profile. The binders used are based on a German access cable with binders up to 30 pairs and a line length up to 600m.

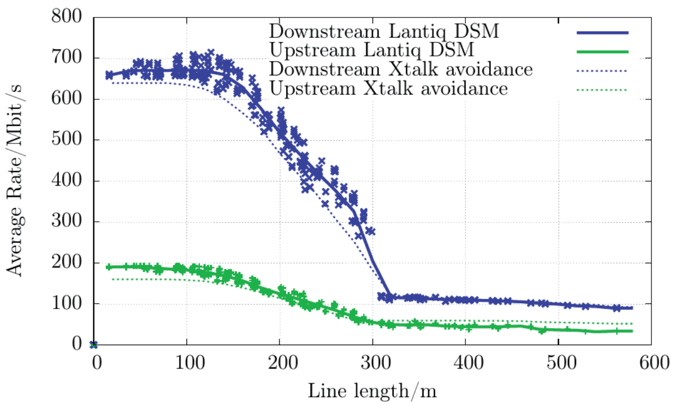



Figure 4.3:
Rate vs. reach curves for G.fast/VDSL FTTC

Fig. 4.3 shows the rate vs. reach plots for the FTTC scenario. All shorter lines use G.fast while the longer lines fall back to the legacy VDSL 2 service. The switch from G.fast to VDSL causes the kink in the rate vs. reach plot at 300m.

The dashed lines show data rates that were achieved with a usual crosstalk avoidance scheme where the VDSL frequency bands are excluded completely from G.fast data transmission. The results clearly show the performance advantage of a overlapped scheme when the Lantiq base DSM methods are used.

## The Road to Gigabit Broadband

FTTdp with G.fast is the solution for Gigabit-class broadband services over traditional telephone cables. In most deployment scenarios, it is a low invest alternative to FTTH. It's important to note that the introduction of the new FTTdp network topology and the transition from VDSL2 to G.fast can be performed sequentially in a two-step process. In a first step, service providers can start immediately with FTTdp node installations using commercially available FTTdp units based VDSL2. Once G.fast will be required from a performance perspective and ready for volume deployment, a smooth transition will be ensured. Taking both steps at once adds complexity and delays commercial trials to after the time the G.fast eco-system will be ready for mass market deployment. Therefore, the move to G.fast is recommended after FTTdp and reverse power feeding schemes have been established with VDSL2. Waiting for G.fast means losing time and missing opportunities.

We also want to emphasize that FTTdp with VDSL2 already provides impressive performance improvements far beyond the current VDSL2 services. It's today's solution for services up to 300 Mbps aggregate downstream plus upstream data rates. Commercial systems are available and ready for field deployments. The use of established GPON and VDSL technologies and standards ensures interoperability with the standard VDSL2 routers in the market. The performance of those systems already exceeds 2018/2020 targets of any government broadband initiative worldwide. It's more than enough for video and cloud services and the right answer to high-rate Cable broadband offerings. The Lantiq VINAX™dp is the most popular FTTdp chipset solution today. It was designed with G.fast in mind, so operators can prepare their networks for future G.fast upgrades, and benefit already today from the FTTdp topology. With the Lantiq VINAX™dp solution, network operators' investment into the fiber link (Lantiq FALC ON) and the CPE platform (Lantiq AnyWAN™) is fully protected, a later G. fast upgrade will be the only change in the network configuration.

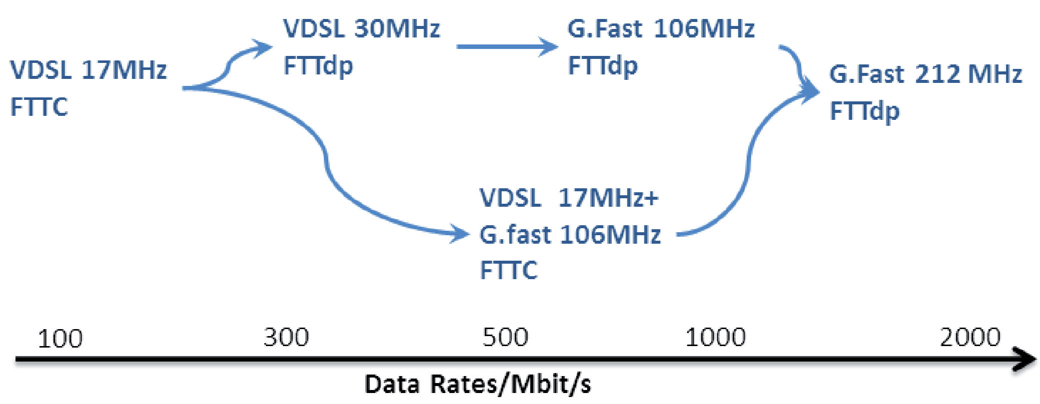



Figure 5.1:
The road to gigabit broadband access

## Outlook

This paper gives an overview on the current state of G.fast technology and sketches possible solutions for practical problems. Lantiq has contributed to the development of G.fast and is actively working on G.fast system solutions. For example in the FlexDP research project, Lantiq [Lan14], InnoRoute and Fraunhofer ESK [ESK14] work on solutions for the fiber to the distribution point network.

Internet service providers have different strategies for the transition to G.fast-based FTTdp networks. Many operators today have an immediate need to push DSL performance to the limits. In particular operators pushed by Cable competition or forced by government mandates need a solution as soon as possible. New market entrants benefit from the rapid time-2-market and short return-of-invest cycles of the FTTdp business model. VINAX™dp facilitates the transition to distribution point-based networks. Single port and multi-port configurations provide aggregated data rates of 300 Mbps per twisted pair. Trials and commercial deployments have started worldwide.

At some point in the future, rate requirements will exceed the capabilities of VDSL2. With DOCSIS 3.1 technology, Cable operators will challenge DSL service providers in the future with Gigabit data rates. Future generation cloud services rely on Gigabit-class broadband connections and will drive broadband demand. With FTTdp/G.fast on the horizon, DSL providers get a future proof technology and a clear upgrade path. Many operators are considering to use G.fast not only in the FTTdp configuration, but also as the future copper PHY technology for MDUs, and street cabinets.

Lantiq G.fast products reflect the leading role in G.fast standardization process. Active cooperation with universities, e. g. TU München and HS Augsburg and research institutes like Fraunhofer ESK helps to integrate the latest scientific results in our products. Lantiq combines a theory-based deep understanding of the FTTdp network and future technologies, with long expertise from broadband access products like VDSL-based FTTC and FTTdp, VDSL Vectoring as well as GPON-based fiber access.

The first first prototypes of the new technology have been demonstrated during the Broadband World Forum 2014. From standardization to first prototypes, Lantiq has always been at the forefront of G.fast development [RR14].

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## Terminology

| | |
|---|---|
| ATIS | Alliance for Telecommunications Industry Solutions |
| BBF | Broadband Forum |
| CPE | Customer Premises Equipment |
| DOI | Discontinuous Operation Interval |
| DP | Distribution Point |
| DSM | Dynamic Spectrum Management |
| ETSI | European Telecommunications Standards Institute |
| Falc™ON | Lantiq GPON solution |
| FDD | Frequency Division Duplexing |
| FEXT | Far End Crosstalk |
| FlexDP | Research Project on fiber to the distribution point |
| FTTH | Fiber To The Home |
| FTTB | Fiber To The Building |
| FTTC | Fiber To The Curb |
| FTTdp | Fiber To The distribution point |
| FTTx | Generic term for fiber topologies |
| G.fast | Fast Access to Subscriber Terminals technology |
| GPON | Gigabit Passive Optical Network |
| MAC | Medium Access Layer |
| MIMO | Multiple Input Multiple Output |
| NEXT | Near-End Crosstalk |
| NOI | Normal Operation Interval |
| PHY | Physical Layer |
| PMD | Physical Media Dependent sublayer |
| PSD | Power Spectral Density |
| RMC | Robust Management Channel |
| SS | Sync Symbol |
| TDD | Time Division Duplexing |
| VDSL | Very High Speed Digital Subscriber Line |
| VINAX™DP | Lantiq VDSL solution for distribution points |
| xDSL | Generic term for DSL technologies |

## List of Figures



## List of Tables

## References


[Bro10] Broadband Forum WT-301 Rev. 11. Fiber to the Distribution Point, 2010.

[Bro14] Broadband Forum SD-285 Rev. 06. Copper Transmission Models for Testing above 30 MHz, 2014.

[ESK14] Fraunhofer ESK. Gigabit-Datenraten auf Telefonleitungen, 2014.

[Jan08] Jan Verlinden. NIPP-NAI-2008-010R1 Crosstalk Cannnel Model, 2008.

[Lan14] Lantiq. Lantiq Joins Team Researching Ultra-Fast Copper Broadband, 2014.

[OMH 09] P. Odling, T. Magesacher, S. Host, P.O. Borjesson, M. Berg, and E. Areizaga. The fourth generation broadband concept. IEEE Communications Magazine, 47(1):62–69, 2009.

[Sch10] H. Schenk. Vector Engine: Signal Path and Coefficient Update, Internal Whitepaper, 2010.

[SSU13] Rainer Strobel, Reinhard Stolle, and Wolfgang Utschick. Wideband Modeling of Twisted-Pair Cables for MIMO Applications. In IEEE Globecom 2013 - Symposium on Selected Areas in Communications (GC13 SAC), 2013.

[Sta03] ETSI Standard. Ts 101 270-1. Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements, 2003.

[TGNM13] Michael Timmers, Mamoun Guenach, Carl Nuzman, and Jochen Maes. G.fast: evolving the copper access network. IEEE Communications Magazine, 51(8), 2013.

[ITU06] ITU-T G.9961. Unified high-speed wire-line based home networking transceivers - Data link layer specification, 2006.

[RR14] Rider Research. Lanitq Is First with Reference Design for G.fast Residential Gateway, The Online Reporter, Issue 899 October 10-16, 2014.