Paper

Performance and Limitations of VDSL2-based Next Generation Access Networks

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Abstract—In this paper, we first briefly review the main operational aspects of FTTC (xPON)/VDSL2 access networks. Then, we present performance measurements with respect to network sub loop operating length and VDSL2 operational profiles (8b, 12a, 17a), studying the rates that can be achieved at different scenarios. We then provide results of the effect of stationary crosstalk and non-stationary impulse noise on the provisioned service in an operating VDSL2 access network.

Keywords*—*DSL networks, impulse noise, VDSL2 next generation access networks, crosstalk.

1. Introduction

VDSL2-based Next Generation Access Networks based on Fiber-To-The-Cabinet (FFTC) architectures are currently deployed on worldwide scale, and offer a favourable intermediate step towards Fiber-To-The-Home access implementations [1]. FTTC/VDSL2 networks offer the prospect of delivering very high bandwidth (up to 200 Mbit/s) to end-users which should be more than sufficient for the near future, combined with much lower deployment costs than fully optical access networks. Indeed, the combination of optical xPON (e.g. GPON, XGPON) FTTC networks with the legacy copper last mile boosted by VDSL2 technology offers a very attractive balance between cost/performance.

However, to hold the promise of delivering the high bandwidth the VDSL2 technology is capable for, noise-induced performance degradation issues must be studied and addressed. Indeed, the Quality of Service (QoS) in VDSL2 implementations may suffer from severe degradation, with the two principal sources of degradation being stationary (self-crosstalk) and non-stationary (impulsive) noise [2]. While there is a large number of papers in the literature that theoretically consider these two noise sources, experimental studies of the effects of noise on real VDSL2 networks are scarce. In this paper, we first present performance measurements with respect to network sub loop operating length and VDSL2 operational profiles (8b, 12a, 17a), studying the upper limit of the rates that can be achieved at different scenarios and without the effect of noise. We then provide results of the effect of stationary crosstalk and non-stationary impulse noise on the provisioned VDSL2 service.

2. VDSL2 Single-Line Performance

2.1. VDSL2 Operational Profiles

The realization of the first phase of an NGA network is achieved by combining further penetration of the optical technology into the access network with the VDSL2 access technology [3].

The FTTC topology enables the provisioning of extremely high data rates on longer loops, while extending the reach of the fiber network assisting the future transition towards a fully optical access network. Additionally, VDSL2 is an access technology capable of a total rate of up to 200 Mbit/s, while offering a wide range of alternative profiles providing Telcos a very flexible field of options to choose from, depending on their business plan.

The available profiles mainly differ in terms of total output power and available spectrum. Table 1 lists the main characteristics of all the available profiles of the 998 ADE VDSL2 band plan, according to the ITU G.993.2 standard [4]. The inherent spectral and power characteristics of each profile determine whether it should be deployed either from the Central Office (CO), or from a remote DSLAM located in the remote cabinet (or RDF – Remote Distribution Frame). Generally, higher frequencies are more susceptible to attenuation, degrading much faster than lower frequencies as the length increases. VDSL2 8b is characterized by roughly four times the spectrum of ADSL2+ and the same maximum aggregate downstream power. As a result, it provides a higher bit rate than ADSL2+, while maintaining the same effective reach. VDSL2 12a transmits at a lower power level and employs a wider upstream frequency range, thus offering higher data rates but on shorter loops. Similarly, the trade-off between maximum bit rate and effective reach is even more evident on VDSL2 17a and VDSL2 30a.

2.2. Rate Measurements

Rate measurements were performed to assess the performance of the most representative VDSL2 operational profiles for deployment in a FTTC topology (i.e., injection of VDSL2 signal at a remote cabinet with a relatively shot sub-loop distance). A VDSL2 DSLAM (DSL Access Multiplexer) was used that was connected to a CPE (Customer Premises Equipment) via a 0.4 mm diameter UTP copper

Table 1
VDSL2 ADE 998 profile characteristics

Profile	Maximum aggregate downstream transmit power [dBm]	Maximum aggregate upstream transmit power [dBm]	Highest supported data-bearing downstream frequency [MHz]	Highest supported data-bearing upstream frequency [MHz]	Minimum bidirectional net data rate capability [Mbit/s]
8a	17.5	14.5	8.5	5.2	50
8b	20.5	14.5	8.5	5.2	50
8c	11.5	14.5	8.5	5.2	50
8d	14.5	14.5	8.5	5.2	50
12a	14.5	14.5	8.5	12	68
12b	14.5	14.5	8.5	12	68
17a	14.5	14.5	17.660	12	100
30a	14.5	14.5	24.890	30	200

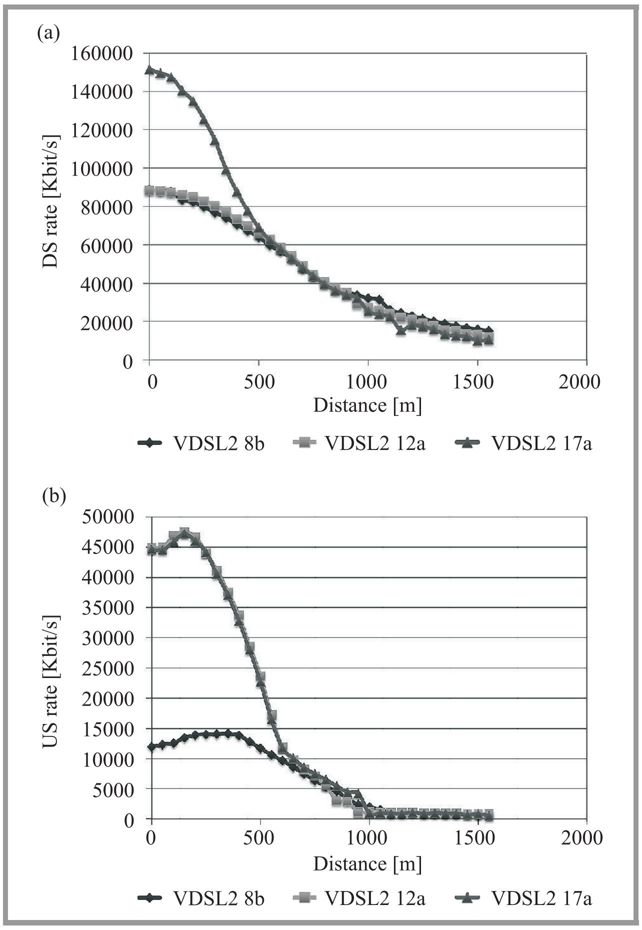

Fig. 1. Attainable downstream rate as a function of the distance between the remote cabinet and the CPE (a); Attainable upstream rate as a function of the distance between the remote cabinet and the CPE (b).

line simulator. The length of the simulated line was varied in a broad range in order to evaluate the performance under different Remote Cabinet CPE distances that may occur in the field. Figures 1(a) and 1(b) show the attainable downstream and upstream rates respectively as a function of the distance between the remote cabinet and the CPE for the VDSL2 profiles 8b, 12a and 17a, the most representative deployment profiles.

3. VDSL2 Performance with Crosstalk

The co-transmission of signals from two distinct points inside the same local loop presents the challenge of crosstalk (electromagnetic interference). The propagation of an electromagnetic signal inside a copper conductor results in the emission of electromagnetic fields, which in turn interfere with adjacent copper pairs and electromagnetic coupling phenomena emerge. As an outcome, the signal affected by crosstalk can sustain severe degradation, shortening its effective reach and/or limiting its data-bearing capability. As Figure 2 shows, the two eminent types of crosstalk caused by the downstream and upstream signals are FEXT (Far End Crosstalk) and NEXT (Near End Crosstalk). FEXT refers to the interference caused by signals on neighbouring lines propagating in the same direction, while NEXT refers to interference from counter propagating signals. Due to the fact that xDSL technologies employ FDMA, NEXT tends to be considered as having a minor effect as the downstream and upstream frequency bands are spectrally separated.

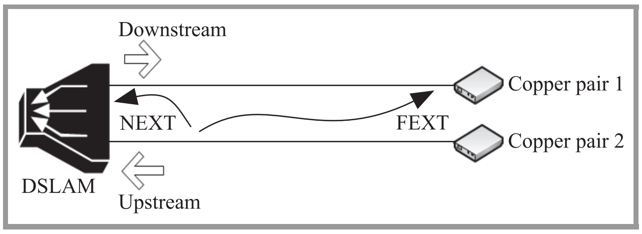

Fig. 2. Illustration of FEXT and NEXT. Downstream directions refers to signals from the DSLAM to the CPEs, while upstream from the CPEs to the DSLAM.

The severity of crosstalk is directly connected to the output power of the disturber line creating the interference, as well as to the power level of the victim line receiving it. Understandably, an attenuated signal is more sensitive to crosstalk than a robust signal. This is the case in access networks including active equipment both at the CO and at the RDF. A strong signal induced at the RDF meets an attenuated signal that has already lost a considerable amount of its power and therefore decreases the available SNR margin for bit loading. This impairment is followed by a considerable decrease of the CO line's effective reach. In that case some sort of downstream power back off (DPBO) protection needs to be applied. Here, we only consider signals that are injected at the remote cabinet, as applying to the case of VDSL2 provisioning in an FTTC topology. Hence, all signals are generated at the same point with equal power. The DPBO technique here cannot be applied, hence our measurements show the rate that can be realistically achieved in such cases.

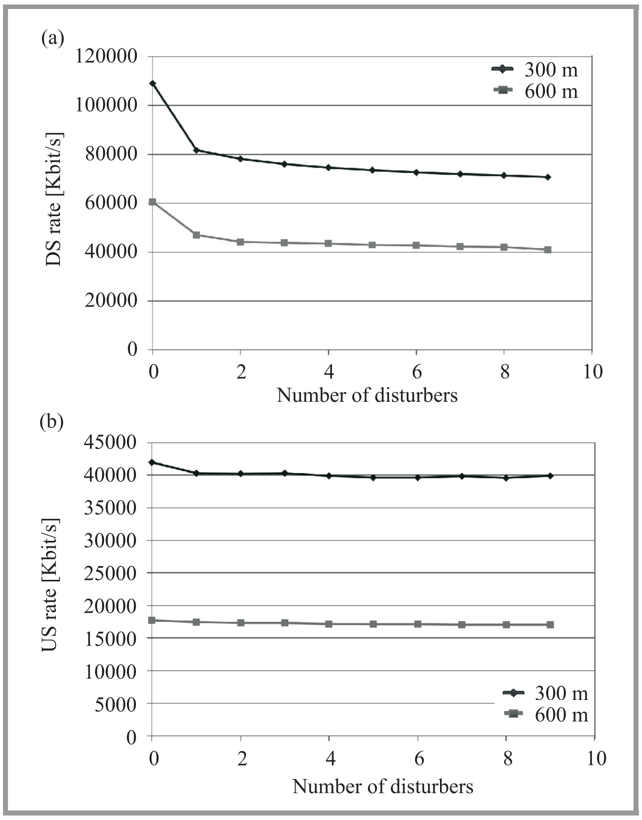

Fig. 3. Downstream (DS) and upstream (US) VDSL2 performance as a function of active disturbers within the same binder.

Figure 3 shows the individual laboratory performance (uplink and downlink rates of transmission) of a line with VDSL2 spectrum allocation plan Annex B: 998ADE17 and how it is affected due to stationary self-crosstalk noise from the gradual activation of identical adjacent lines. The profile used is the 17a, which is the most common for cabinet deployment as it ensures a high bandwidth for the short sub-loops expected in these cases. Ten total lines are used, and this case corresponds to a fully occupied 10-pair distribution cable binder. Data are shown for two representative sub-loop lengths: 300 m and 600 m.

As can be seen, the self-crosstalk phenomena, which are strengthened by activating neighbouring lines have significant adverse effect on the performance can be achieved. Specifically, a decrease in transmission rates as high as 30% can be observed with the increase of the neighboring active lines. The performance drop rate is somewhat saturated when the number of disturbers exceed 4–5, possibly as a result of the pairs geometry within the cable binder.

4. VDSL2 Performance with Impulse Noise

Impulse Noise together with Crosstalk constitute the major performance impairment factors of the VDSL2 copper access network which unlike attenuation their impact cannot be predicted. In contrast to crosstalk, whose nature can be considered as stationary, given that the disturbers' kind and number do not change, impulse noise (which is usually induced by nearby electrical apparatus) is regarded as stochastic. Under the scope of this study, a series of measurements were conducted in order to evaluate the effects of bursts of REIN (Repetitive Electrical Impulse Noise) to the performance of VDSL2 998ADE17 lines. The duration of the impulse noise applied on the lines was predefined to 250 ms, while its power was –110 dBm/Hz. Multiple operational profiles are used, in which the SNR margin is either 9 or 11 dB, either in fast mode or in interleave mode (depth = 10 ms) and with an impulse noise protection of 2 symbols. Figure 4 shows some initial results on the impact of REIN on the performance of VDSL2 lines as a function of sub-loop length and operational profile param-

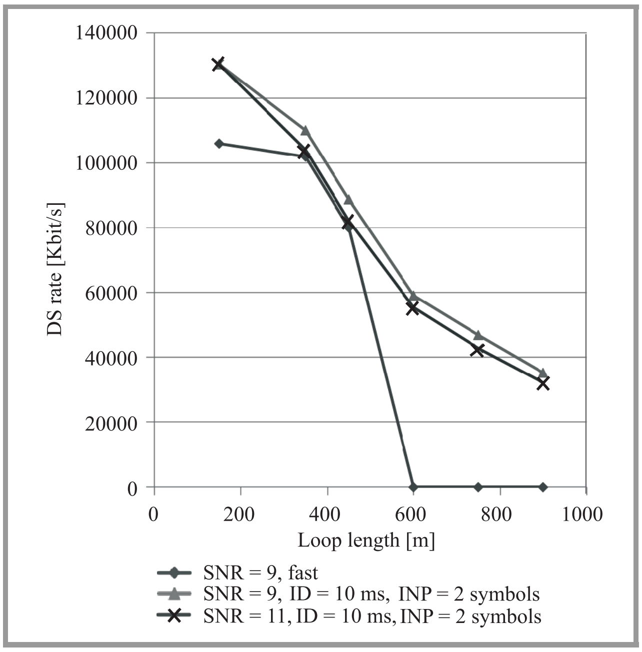

Fig. 4. Downstream rate in a VDSL2 line with REIN for three different service profiles.

eters. It can be seen that REIN can have a severe impact on the sync rates, and varies with length as well as the interleave settings of the service profile. We are currently performing a detailed study to resolve the interplay of these factors with VDSL2 performance and construct optimized service profiles.

5. Conclusions

As was evidenced in the previous paragraphs, crosstalk and impulse noise phenomena can have a very detrimental effect on the performance of VDSL2 NGA networks. Therefore, the further analysis and the addressing (e.g., with dynamic spectral management methods) of such adverse effects of is absolutely necessary in order to improve service quality in such access networks. Here, we presented initial results of our ongoing experimental study.

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