Proposed Number of Services to Coexist in The Cable Bundle with VDSL2 Service

Salem Yaakoub Iseed

Abstract — **We propose a suitable number of different services to coexist in the same cable bundle with VDSL2 service (Very high bit-rate Digital Subscriber Line 2). The situation for quad cables and twisted pairs is considered for real-case and bad-case assumptions. NEXT (Near-End Crosstalk), FEXT (Far-End Crosstalk), and background AWGN (Additive White Gaussian Noise) were taken into consideration. The real-case assumption was proven to be a good choice for limiting the noise that may affect VDSL2 service, by determining the services and their numbers to be used in the same cable bundle.**

Keywords — **Twisted pairs, AWGN, NEXT, FEXT.**

I. Introduction

NOWADAYS, the connection of optical fibers from the CO (Central Office) directly to the customers is difficult, due to the cost of civil engineering works (is restricted only for large businesses). xDSL (x Digital Subscriber Line) technologies were designed to exploit the already installed infrastructures of copper wires.

For the different requirements of users at recent years, many different xDSL technologies were developed and others are under studying, such as HDSL (High bit-rate DSL) [1], SHDSL (Single-pair High bit-rate DSL) [2], IDSL (ISDN DSL) [3], ADSL (Asymmetric DSL) [4], ADSL2 (Asymmetric DSL2) [5], ADSL2+ (Asymmetric DSL2+) [6], ADSL2++ (Asymmetric DSL2++), VDSL (Very high bit-rate DSL), VDSL2 (Very high bit-rate DSL2) …etc. Some of these services are asymmetric and the others are symmetric. Generally, the home users require asymmetric services, while the business users may require symmetric one. Approximately 33 % of the loops serve businesses [4], so 33% of the users may require high bit rates symmetrically or asymmetrically. For this reason each cable bundle has to be considered to include symmetric and asymmetric services.

VDSL2 allows the transmission of data over copper wires using a bandwidth up to 30 MHz, instead of 12 MHz in case of VDSL. VDSL2 can achieve total bit rates of 200 Mb/s for the sum of the downstream and upstream rates. VDSL2 can operate symmetrically or asymmetrically. Symmetrically, bit rates of 100 Mb/s can be achieved for both directions (upstream and downstream) over distances less than 300 m. VDSL2 has adopted DMT modulation, as to be compatible with ADSL, ADSL2, ADSL2+ and VDSL services.

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Researching the characteristics of the copper wires at high frequency bands, helps us to prevent some kinds of noises that affect these services when installing them.

The performance of a new service to be installed depends on the other services that already exist in the cable bundle. The disturbance caused by these services into the new and the one caused by the new into the already existing, have to be examined before installing it.

In the next subsections, we will describe briefly the background AWGN (Additive White Gaussian Noise), NEXT (Near-End Crosstalk), and FEXT (Far-End Crosstalk), that consist the dominant noises for VDSL2 technology. The effect of these noises together on VDSL2 service for the different disturbers, will be shown for the proposed number of services in the cable bundle.

II. TWISTED PAIR CHARACTERISTICS

Exploiting the existing copper wires, the relative low cost and fast process of installing VDSL2 services, in comparison with that of optical fibers, make them to be more preferable nowadays.

At the time of installing the telephone copper wires, their characteristics were studied for low frequencies (the frequencies at which the Plain Old Telephone Service (POTS) operates). Nowadays, the research for the characteristics of the copper wires is taken off to high frequencies, since the high frequencies can be used for very high bit-rates data transmission.

The primary constants RLCG that characterize the performance of the twisted pairs were chosen here for 0.5 mm underground distribution cables as described in DAVIC (Digital Audio-Visual Council) [7].

For a perfectly terminated loop with length d, the transfer function $H_{channel}(d, f)$ is given by [1]:

$$H_{channel}(d, f) = e^{-d \cdot \gamma(f)}$$

where $\gamma(f)$ is the propagation constant, and is given by:

$$\gamma(f) = \sqrt{(R + j\omega L)(G + j\omega C)}$$

and ω is the radian frequency $(\omega = 2\pi f)$.

III. THE EFFECT OF BACKGROUND AWGN IN THE LOOP PLANT

The effect of background AWGN in the loop plant does not cause a severe problem to VDSL2 signals. The sources of this kind of noise are the thermal and shot noises, while quantization and residual echo noises can be added also to its total amount. Thermal and shot noises are the arbitrary movements of electrons in a conductor and a discrete movement of electrical charges in a semiconductor, respectively. Quantization noise is caused due to the inaccuracy of digitalization the analogue signals. Residual echo noise is the remaining noise after the echo-cancellation process, and usually its level is 60 – 70 dB less than the transmit power level, so we did not take it into consideration here, as can be neglected. The level of background AWGN is usually taking values between -170 - and –140-dBm/Hz, without including the residual echo noise. Here, we considered the background AWGN to be –140 dBm/Hz.

IV. THE EFFECT OF CROSSTALK NOISE

Crosstalk noise is the coupling of signal energy between wire pairs of the same cable bundle. Crosstalk is considered to be the dominant noise that affects xDSL technologies. This kind of noise is caused in twisted pairs due to imbalances in the symmetry of twisting and due to twist pitches, since in the ideal conditions no crosstalk has to be caused. There are two kinds of crosstalk noises, each of them differently affects the signals of the other pairs. Modeling crosstalk requires taking these two kinds simultaneously over all the length of the line. These are Near-End Crosstalk (NEXT) and Far-End Crosstalk (FEXT). NEXT and FEXT are described as follows:

When user 1 is transmitting to the CO on one wire pair (pair 1), a coupling of energy is detected on pair 2 in the reverse direction (on the downstream of pair 2), as shown in Fig. 1. Also, other kind of coupling is detected on pair 2 in the same direction (on the upstream of pair 2), as shown in Fig. 2. The former coupling is the NEXT and the latter is the FEXT. The same is happening when data are transmitted from the CO towards one user. This coupling occurs, generally, between all the pairs of the bundle.

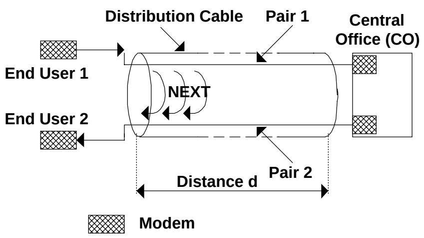

Fig. 1. NEXT coupling

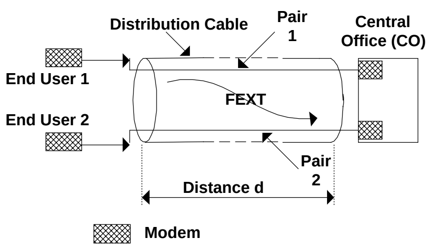

Fig. 2. FEXT coupling.

NEXT coupling is typically stronger than FEXT coupling. Since FEXT coupling has to travel along the line, will suffer a loss as the transmitted signal (as can be seen in Fig. 1 and Fig. 2). Thus, in the presence of NEXT, generally FEXT can be neglected for long loops.

We used the conservative crosstalk models in our calculations, since then no required knowledge about the transmission systems used, but only about their power spectral densities.

Another point to be mentioned here is that, we did not consider the activity factor [8], but instead of that, we left the gained difference (since not all the users use their lines at the same time) as a safety-margin required for such models.

V. THE EFFECT OF NEAR-END CROSSTALK

NEXT coupling of different services in the cable bundle has to be considered during the service design, since it cannot be avoided easily. NEXT coupling increases 15 dB/decade with frequency and is independent of the line length. The power spectral density of NEXT coupling is modeled by the following equation:

$$PSD_{NEXT}(f) = PSD_{disturber} \cdot (n)^{0.6} \cdot K_{NEXT\,1} \cdot f^{\frac{3}{2}}$$

where $PSD_{disturber}$ is the power spectral density of the disturbing signal, n is the number of disturbing pairs of the same disturbing service, f is the frequency in Hz, $K_{NEXT\,1}$ is the NEXT coupling coefficient for one disturbing pair, which is depending on the type of the cable used. For twisted pairs, $K_{NEXT\,1} = 8.54822 \cdot 10^{-15}\,(Hz^{-3/2})$ [4], while for quad cables there are three different coupling coefficients, depending on the physical location between the disturbed and the disturbing signals (pairs) [9]. The distance between disturbing and disturbed signals is more easy to be distinguished here than in the case of twisted pairs. There are three possible distances between the disturbed and the disturbing pairs in the cable bundle. The first is when they are located in the same quad (only 1 pair), the second when they are located in adjacent quads (8 pairs), and the third when they are located in other nearby quads (more far) in the bundle (40 pairs). So, in case of existing the disturbing signal (pair) in the same quad with the disturbed one, the coupling coefficient K_{NEXT1} is equal to $1.70608 \cdot 10^{-14}$-, while it is $7.17793 \cdot 10^{-16}$-, and $2.57632 \cdot 10^{-16}$-($Hz^{-3/2}$) for adjacent-, and other nearby-quads, respectively.

VI. THE EFFECT OF FAR-END CROSSTALK

FEXT coupling is weaker than NEXT coupling. The power spectral density of FEXT coupling is modeled by the following equation:

$$PSD_{FEXT}(f) = PSD_{disturber} \cdot (n)^{0.6} \cdot K_{FEXT1} \cdot d \cdot f^{2} \cdot \left|H_{channel}(d, f)\right|^{2}$$

where, $H_{channel}(d, f)$ is the transfer function of the loop, d is the loop length, n is the number of disturbing pairs of the same disturbing service, $K_{FEXT\,1}$ is the FEXT coupling coefficient for one disturbing pair, which is empirically derived from the FEXT measurements. For twisted pairs, $K_{FEXT\,1} = 2.6248 \cdot 10^{-20}\,(Hz^{-2} \cdot m^{-1})$, while for quad cables the coupling coefficients $K_{FEXT\,1}$ are $3.357 \cdot 10^{-20}$-, $9.120 \cdot 10^{-21}$-, and $3.548 \cdot 10^{-21}$-$(Hz^{-2} \cdot m^{-1})$ for same-, adjacent-, and other nearby-quads, respectively. The power spectral density of FEXT coupling here is for general loops and is not considering the different coupling lengths, since then knowledge about the exact loop configurations is required.

For the suitable number of services that may coexist in the same cable bundle with VDSL2 service (the real-case assumption), we considered that the twisted pairs consist of 1 ISDN basic access service existing alone, 14 ADSL with simultaneous existing POTS services (with overlay of POTS services), 3 ADSL with simultaneous existing 3 ISDN basic access (4B3T line code) services (with overlay of 3 ISDN basic access services), 3 VDSL services, 10 ADSL2 with existing POTS services, 5 ADSL2 with existing 5 ISDN basic access services, 3 ADSL2+ with existing POTS services, 7 SHDSL services and 3 VDSL2 services. While one bad-case assumption was proposed also. The bad-case assumption consists of 1 ISDN basic access service existing alone, 10 ADSL with existing POTS services, 3 ADSL with existing 3 ISDN basic access services, 3 VDSL services, 5 ADSL2 with existing POTS services, 5 ADSL2 with existing 5 ISDN basic access services, 3 ADSL2+ with existing POTS services, 7 SHDSL services and 12 VDSL2 services. The real- and bad-case assumptions were considered for two types of cables that are mostly used in Europe, the quad cables and the twisted pairs. Quad cables are more common in Europe, while twisted pairs are used also in U.S.A.

In the case of using quad cables, the real-case assumption assumes 1 ADSL with existing POTS service to be located in the same quad with VDSL2 service. The adjacent quads consist of 4 ADSL with existing POTS services, 3 ADSL2 with existing POTS services and 1 ADSL2 with existing ISDN basic access service. The other quads consist of 1 ISDN basic access existing alone, 9 ADSL with existing POTS services, 3 ADSL with existing 3 ISDN basic access services, 3 VDSL services, 7 ADSL2 with existing POTS services, 4 ADSL2 with existing 4 ISDN basic access services, 3 ADSL2+ with existing POTS services, 7 SHDSL services and 3 VDSL2 services.

In the bad-case assumption, the quad cables were assumed to have 1 VDSL2 service in the same quad, 3 VDSL services, 1 ADSL2 with existing ISDN basic access service and 4 VDSL2 in the adjacent quads. The other quads consist of 1 ISDN basic access service existing alone, 10 ADSL with existing POTS services, 3 ADSL with existing 3 ISDN basic access services, 5 ADSL2 with existing POTS services, 4 ADSL2 with existing 4 ISDN basic access services, 3 ADSL2+ with existing POTS services, 7 SHDSL services and 7 VDSL2 services.

The transmit power, power spectral densities and frequency bandwidth of the services used in the same bundle are shown in the Table 1.

VII. THE EFFECT OF TOTAL NOISE

The effect of NEXT, FEXT, and background AWGN were considered in the total noise that affects these two types of cables.

The power spectral densities of the total noise for the real-case assumption for twisted pairs and quad cables are shown in Fig. 3. The dadotted line represents the power spectral density at the subscriber's side for the total noise in case of using 300 m of 0.5 mm underground twisted pair, while the solid line represents the power spectral density at the subscriber's side for the total noise in case of using 300 m of 0.5 mm underground quad cable.

The power spectral density of VDSL2 signal after passing 300 m of 0.5 mm underground cable is presented with dotted line. Since the subscribers are far from each others, we considered that the difference made in practice can be left as a safety-margin. Fig. 4 shows the same comparison as in Fig. 3, but for the bad-case assumption.

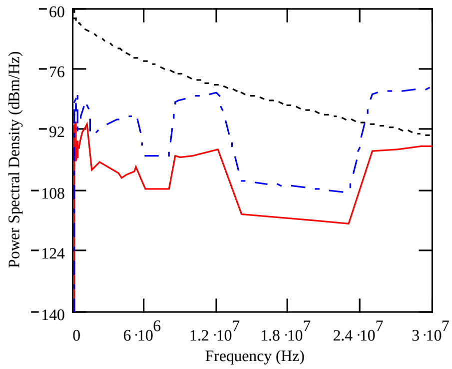

Fig. 3. Power spect. dens. of total noise for the real-case assumption

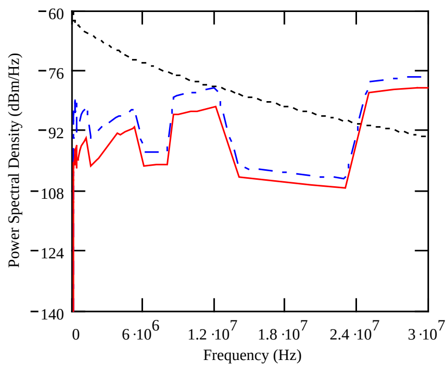

Fig. 4. Power spect. dens. of total noise for the bad-case assumption.

As can be seen in Fig. 3 and Fig. 4, the power spectral density of the total noise for quad cables is lower than that for twisted pairs. It is obvious in Fig. 3 that the level of the total noise for the real-case assumption when using 300 m of underground quad cables is lower than the level of VDSL2 signal after passing 300 m, while for this length of cable the total noise may affect the twisted pairs.

In the bad-case assumption, the level of the total noise may affect VDSL2 signal at frequencies above 24.89 MHz for both types of cables.

TABLE 1: THE SERVICES USED IN THE CABLE BUNDLE.

Services	Frequency (kHz)		Transmit Power (dBm)	PSD (dBm/Hz)	
	upstream	downstream		upstream	downstream
ISDN basic access	0-120	0-120	13.6	-37.19	-37.19
ADSL (POTS)	25-138	138-1104	19.2	-31.33	-40.65
ADSL (ISDN basic access (4B3T))	138-276	276-1104	19.2	-32.2	-39.98
VDSL	3750-5200 & 8500-12000	138-3750 & 5200-8500	14.5	-52.45	-53.896
ADSL2 (POTS)	25-138	138-1104	19.2	-31.33	-40.65
ADSL2 (ISDN basic access (4B3T))	138-276	276-1104	19.2	-32.2	-39.98
ADSL2+ (POTS)	25-276	276-2208	19.2	-34.797	-43.66
SHDSL	0-256	0-400	14.5	-39.58	-41.52
VDSL2	3750-5200, 8500-12000 & 24890-30000	138-3750, 5200-8500 & 12000-24890	14.5	-55.53	-58.47

The power spectral densities of the total noise, according to the real-case assumption, for quad cables and twisted pairs of 50 m, 100 m, 200 m and 300 m, are shown in Fig.5 and Fig.6, respectively.

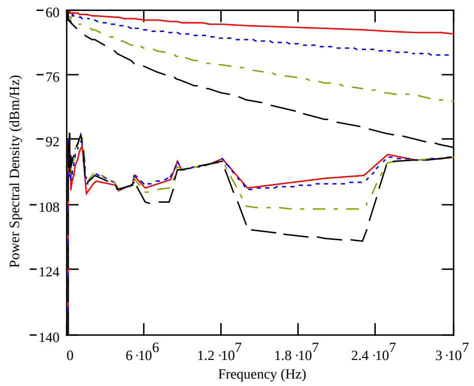

Fig.5. Power spect. dens. of total noise for diff. lengths-quad cables.

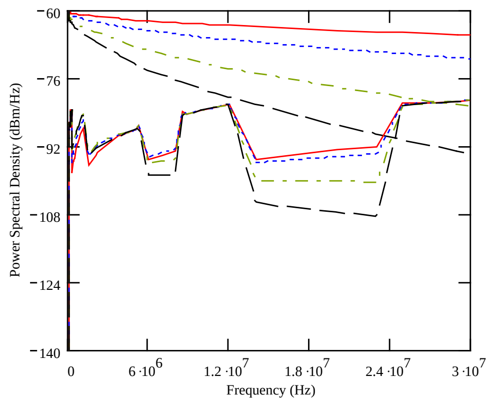

Fig.6. Power spect. dens. of total noise for diff. lengths-twisted pairs.

In Fig. 5, the lower four curves which have solid, dotted, dadotted and dashed lines, represent the power spectral densities of the total noise for quad cables at the subscriber's side for 50 m, 100 m, 200 m, and 300 m, respectively. The upper four curves which have solid, dotted, dadotted and dashed lines, represent the power spectral densities of VDSL2 signal after passing 50 m, 100 m, 200 m, and 300 m, respectively. In Fig.6, the same curves are presented but for the twisted pairs. It is obvious from these figures that the level of total noise caused on the 300m twisted pair may affect the level of VDSL2 signal, but for smaller lengths, the level of the total noise is lower than that for VDSL2 signal.

One point to be mentioned here is that, the primary parameters of the loops are important in limiting the FEXT noise caused on VDSL2 service. For this reason, it is desirable to use the best loops we have, in order to avoid the FEXT noise as much as possible.

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