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Examination of Multiplexing VDSL2 over ADSL2+ Line

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***Abstract*—Today, the second generation of Very High Speed Digital Subscriber Lines (VDSL2) is widely used to replace previous Asymmetric Digital Subscriber Lines (ADSL2+) in access networks in practice. However, the VDSL2 lines can be usually applied only for short distances and also some of the subscribers will probably keep using their old ADSL2+ lines. Due to that, the frequency band of symmetrical pairs with ADSL2+ lines will stay unoccupied above 2.2 MHz and could be possibly used for VDSL2 lines. That is why a new idea about multiplexing VDSL2 line over ADSL2+ is examined and described in this article. Both of these lines using one single symmetrical pair in a cable must be separated by frequency multiplexing method, when ADSL2+ line occupies frequency band up to 2.2 MHz, while the VDSL2 line would operate from 2.2 MHz to higher frequencies. The method could possibly increase the number of xDSL lines in one cable and could connect more subscribers using existing metallic lines. This article describes the initial idea together with the process of designing possible VDSL2 over ADSL2+ splitter, which was subsequently used for performing real measurements. Thanks to these measurements, simulations of several possible scenarios were performed and are presented in this article as well.**

***Index Terms*—DSL, filters, frequency division multiplexing, transmission line.**

I. INTRODUCTION

Today, the access networks in Europe still consist mostly of metallic cables and lines, which are effectively used for high speed xDSL digital subscriber systems [1]. The previous generation of Asymmetric Digital Subscriber Lines (ADSL2+) is now being widely replaced especially by modern Very High Speed Digital Subscriber Lines (VDSL2), which can potentially offer higher transmission capacity in both directions [2]. However, the real transmission rate of VDSL2 lines is highly dependent on real transmission conditions and is negatively influenced mainly by the attenuation, crosstalk (especially far-end crosstalk) and other problems in metallic lines [3]. Moreover, the VDSL2 lines can achieve high transmission rates only for short distances [4]. There is also a group of present ADSL2+ providers and subscribers, which are not interested in upgrading their existing ADSL2+ lines and investing money in new VDSL2 technology. Due to that, many existing subscribers will probably still keep using their old ADSL2+ systems. Because of that, the frequency band of symmetrical pairs with ADSL2+ lines will be occupied only up to 2.208 MHz, while the higher frequencies will remain available and unused. That is why an idea of multiplexing VDSL2 over ADSL2+ line should be examined.

The present ADSL2+ and VDSL2 systems are based on Discrete Multitone Modulation (DMT) or Vectored DMT (VDMT) techniques in future [5]. These modulation methods divide the entire frequency band into many separate narrow frequency sub-channels, which are independently used for data transmissions. Moreover, the xDSL full-duplexing transmission technique uses Frequency Division Duplex method (FDD) that creates two or more separate frequency bands for upstream and downstream directions. These frequency bands and sub-channels are specified in ITU-T recommendations G.992 [6] and G.993 [7]. The following Fig. 1 explains the upstream (US) and downstream (DS) frequency bands for standard ADSL2+ line and VDSL2 line with 998ADE17 spectrum profile over ISDN.

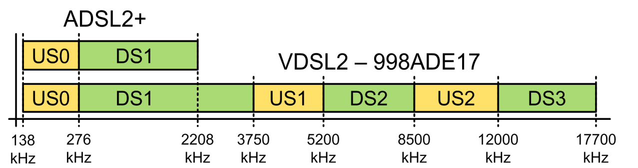

Fig. 1. The distribution of upstream (US) and downstream (DS) frequency bands for ADSL2+ and VDSL2 lines.

The previous Fig. 1 illustrates that ADSL2+ technology uses only 1 upstream and 1 downstream band, while the VDSL2 spectrum profile 998ADE17 is based on 3 separate downstream and 3 upstream regions.

The main idea presented in this paper is based on multiplexing the VDSL2 line over ADSL2+. It is evident, that the ADSL2+ line occupies frequency band only up to 2.208 MHz, therefore the higher frequencies could be possibly used for VDSL2 technology. Both xDSL lines can be easily separated by using simple frequency splitter with low-pass filter for ADSL2+ line and high-pass filter for VDSL2. Due to that, the VDSL2 line over ADSL2+ would be able to use only a part of its DS1 frequency band from

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2.208 MHz and the rest of US1, DS2, US2 and DS3 channels. Therefore its transmission capacity would be limited compared to a standard VDSL2 line with all upstream and downstream frequency bands. However, the application of ADSL2+ line together with VDSL2 over ADSL2+ line enables connecting 2 subscribers via one single symmetric pair. This technique can also improve the effectiveness of symmetrical pairs' utilization, because the unused frequency bands above the ADSL2+ lines can be used for another potential subscriber.

The first step presented in this article consists of obtaining necessary information about the ADSL2+ and VDSL2 communication scheme and handshaking procedures. Based on that, a splitter was designed and created for the purpose of performing real measurements of multiplexing VDSL2 over ADSL2+ line to verify previous assumptions. The last section of this article contains theoretical simulations for several scenarios of using VDSL2 over ADSL2+ lines and conclusions to present its potential applications.

II. VDSL2 OVER ADSL2+ DESIGN

The previous Fig. 1 illustrates that a frequency splitter is necessary at both sides (operator side, subscriber side) to separate the VDSL2 and ADSL2+ lines. This situation is presented in Fig. 2.

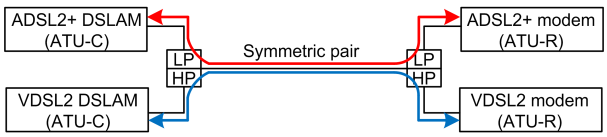

Fig. 2. The main idea of multiplexing VDSL2 over ADSL2+ line.

In order to keep the performance of ADSL2+ line unchanged, the cutoff frequency of low-pass (LP) filter must be set to 2.208 MHz, which denotes the end of ADSL2+ band. On the other hand, the cutoff frequency of an ideal high-pass (HP) filter for VDSL2 line should be also 2.208 MHz. However, there is also a transition band in case of a real filter. To avoid its influence on the performance of ADSL2+ line, the transition band should be located in VDSL2 frequency region and should be as much narrow as possible, so the VDSL2 line can use maximum DMT sub-channels. The Power Spectral Density (PSD) masks for both upstream and downstream directions are specified in ITU-T G.992 [6] and G.993 [7] rec. These PSD values must be taken into account during the process of designing VDSL2 over ADSL2+ splitter to decide optimum attenuations in stopband and passband regions of a splitter [8]. The character of PSD masks for ADSL2+ and VDSL2 for both directions is illustrated in the Fig. 3.

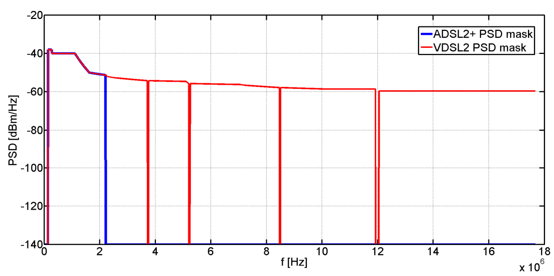

Fig. 3. The values of PSD for ADSL2+ and VDSL2 lines for both directions.

The handshaking procedure ensures exchanging important messages between xDSL ATU-C DSLAM side (Digital Subscriber Line Access Multiplexor) and ATU-R modem side during the process of establishing the connection. The ITU-T G.994.1 [9] recommendation specifies several sets of frequencies (sub-channels), which are reserved for handshaking procedure in both downstream and upstream directions. In order to establish the VDSL2 connection over ADSL2+ line successfully, the splitter must respect these frequencies sets or an acceptable VDSL2 handshaking profile with frequencies located in passband must be selected. That is why a VDSL2 handshaking profile V43 described in G.994.1 [9] rec. was selected and will be used for following real measurements. This profile uses frequencies between 3 and 4.3 MHz, which are located in the passband of designed splitter.

III. REAL VDSL2 OVER ADSL2+ MEASUREMENTS

First, it was necessary to design optimum VDSL2 over ADSL2+ splitter with parameters described in the previous chapter. The previous Fig. 3 clearly illustrates that the PSD mask of ADSL2+ line ends at 2.208 MHz, therefore no LP filter in a simple splitter is needed. Thanks to that, the VDSL2 over ADSL2+ splitter can consist only of HP filter for filtering the VDSL2 line up to 2.208 MHz. To achieve narrow transition band, elliptic (Cauer) type of filter was selected. The resulting HP filter is 11th order elliptic type with stopband up to 2.208 MHz, transition band from 2.208 to 2.3 MHz and passband above 2.3 MHz. The minimum attenuation of its stopband is 50 dB with several ripples, the maximum attenuation of passband is below 0.7 dB. The input and output impedances were optimized for 100 Ω to match the characteristic impedance of a metallic line used for real measurements. The magnitude frequency characteristic and modulus of input and output impedances of designed HP filter are presented in following Fig. 4 and 5.

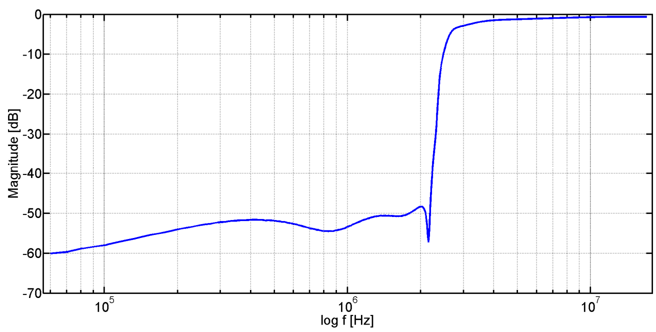

Fig. 4. The magnitude frequency characteristic of designed HP filter.

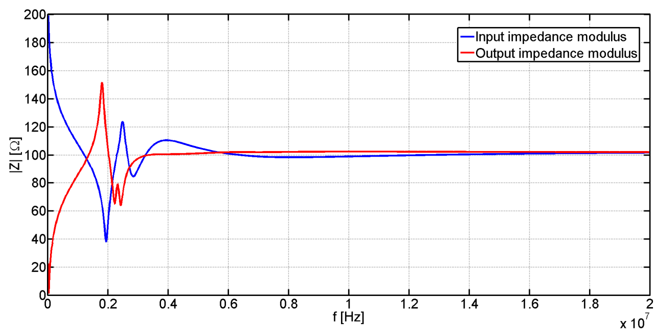

Fig. 5. The input and output impedances of designed HP filter.

The HP filter described above and with characteristics according to Fig. 4 and Fig. 5 was applied on real VDSL2 line for creating two separate xDSL lines – standard ADSL2+ line and VDSL2 over ADSL2+ line according to the schematic presented in Fig. 2. First, the PSD masks of both xDSL lines were simulated and are presented in Fig. 6.

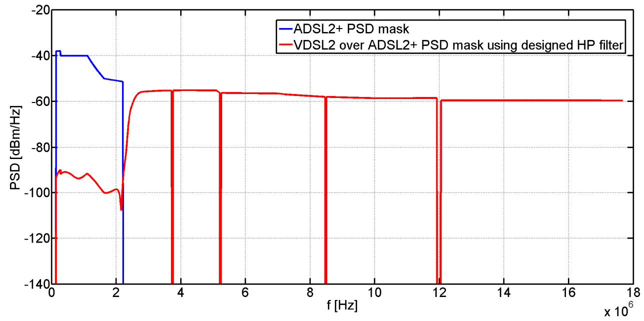

Fig. 6. The PSD masks of ADSL2+ line and VDSL2 over ADSL2+ line.

It is evident that due to the transition region of real HP filter from approx. 2.2 to 2.3 MHz, the transmission performance of DS1 band of VDSL2 line over ADSL2+ will be probably slightly decreased. However, in order to achieve more sharp and narrow transition band, higher order of resulting filter would be necessary, which would also negatively increase its complexity, pulse response or group delay characteristic. Next, real measurements with ADSL2+ and VDSL2 modems and DSLAMs were performed. The ADSL2+ line was realized using ZyXEL ADSL2+ DSLAM together with ZyXEL P-660R-T3 modem, while the VDSL2 connection consisted of Huawei VDSL2 DSLAM and ZyXEL P-870HN VDSL2 modem. One symmetrical pair of a local metallic cable with specification TCEPKPFLE 75x4x0.4 and with the length of 800 meters was used together with designed HP filter to create both ADSL2+ line and VDSL2 over ADSL2+ line via this single symmetric pair. The performances of ADSL2+ line as well as VDSL2 line over ADSL2+ were also theoretically estimated using models presented in [5], [8] together with transmission line parameters provided by British Telecomm. model [4] and typical ADSL2+ and VDSL2 parameters specified in ITU-T recomm. [6], [7]. The theoretical estimation was also based on the transmission function of a HP filter used for separating both lines presented in previous Fig. 4 and 5. Thanks to that, the following Fig. 7 contains the comparison of resulting bit allocation of ADSL2+ line and its theoretical estimation as well as VDSL2 over ADSL2+ line with its theoretical model.

The previous Fig. 7 shows that the idea of multiplexing ADSL2+ line together with VDSL2 line over ADSL2+ was correct and both lines can work via single symmetric pair using different frequency bands. It is also evident that the real HP filter used for separating the VDSL2 line negatively influenced resulting transmission performance especially in frequency band close to the transition region of a filter, so the real amount of allocated bit is lower compared to the theoretical model. However, the difference is not significant, as presented in the following Table I, which contains the resulting transmission rates achieved by real ADSL2+ line and VDSL2 over ADSL2+ line together with theoretically estimated performances in both directions.

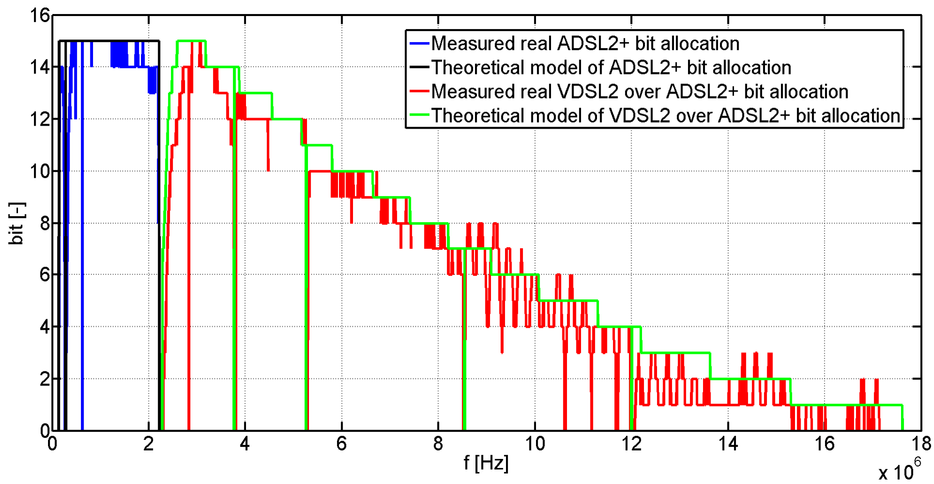

Fig. 7. Measured bit allocation of ADSL2+ and VDSL2 over ADSL2+ lines with theoretical estimations.

TABLE I. TRANSMISSION RATES OF ADSL2+ LINE AND VDSL2 OVER ADSL2+ LINE TOGETHER WITH THEIR THEORETICAL ESTIMATIONS.

xDSL line	**Transmission rate [Mbps]**			
	Measured values		Estimated values	
	Upstream direction	Downstream direction	Upstream direction	Downstream direction
ADSL2+	1.220	25.216	1.350	26.940
VDSL2 over ADSL2+	31.508	47.420	34.572	56.848

The next chapter contains the theoretical simulations of VDSL2 over ADSL2+ lines performance to illustrate several potential scenarios.

IV. SIMULATIONS OF VDSL2 OVER ADSL2+ LINES

One of the possible applications of VDSL2 over ADSL2+ lines is increasing the amount of subscribers, which can be connected via existing metallic lines and cables. This idea is useful mainly in situations, in which only limited number of symmetric lines and cables is installed or all available lines were already occupied. However, the transmission performance of xDSL is heavily influenced by various disturbances and noises in multi-pair and multi-quad metallic cables and especially by far-end crosstalk (FEXT) [3]. Due to that, the appropriate model of FEXT crosstalk [10] must be included in simulations of VDSL2 over ADSL2+.

The following simulations were performed for a situation with 4 symmetrical pairs of a local TCEPKPFLE 75x4x0.4 cable with the length of 800 meters. The simulations also use the HP filters used for separating the VDSL2 line over ADSL2+ with parameters presented in the previous section. The simulations of upstream and downstream transmission rates were performed for several different typical scenarios [11] and combinations of ADSL2+, VDSL2 and VDSL2 over ADSL2+ lines using 4 symmetrical pairs from the cable, which are presented in Table II.

The simulations were performed for both downstream and upstream transmission directions and the results are illustrated in the following graphs in Fig. 8.

TABLE II. THE COMBINATIONS OF ADSL2+, VDSL2 AND VDSL2 OVER ADSL2+ LINES USED FOR SIMULATIONS.

Scenario no.	**Number of xDSL lines used for simulation**			**Total number of lines**
	ADSL2+	VDSL2	VDSL2 over ADSL2+	
1	4	0	0	4
2	0	4	0	4
3	4	0	4	8
4	3	1	3	7
5	2	2	2	6
6	1	3	1	5
7	1+3	0	3	7
8	1+2	1	2	6
9	1+1	2	1	5

It is evident, that standard 4 VDSL2 lines provide the highest transmission rates (scenario no. 2), while on the other hand, 4 standard ADSL2+ lines represent the slowest solution (scenario no. 1) especially in upstream direction. The solution no. 3 based on 4 standard ADSL2+ lines together with 4 VDSL2 over ADSL2+ lines offers summary transmission rate close to the scenario no. 2, however, for 8 subscribers this time. This solution can be potentially used in practice, when more subscribers in a given area need to be connected via existing metallic lines. The scenarios no. 4, 5 and 6 with specific combinations of standard ADSL2+ lines, standard VDSL2 lines and presented VDSL2 over ADSL2+ lines offer probably the best combinations of achievable transmission rates and number of potential subscribers. On the other hand, scenarios no. 7 and no. 8 are not very effective. It can be also concluded, that in case of multiple lines, the transmission rates of VDSL2 over ADSL2+ lines in downstream direction are close to the performance of standard ADSL2+ lines (by comparing scenarios no. 1 and 3). This is caused mainly by the fact that the DS1 frequency band of these lines is partially limited by HP filter. Therefore, the VDSL2 over ADSL2+ lines can be potentially used as another ADSL2+ line in downstream direction with higher upstream transmission performance using the same symmetrical pair.

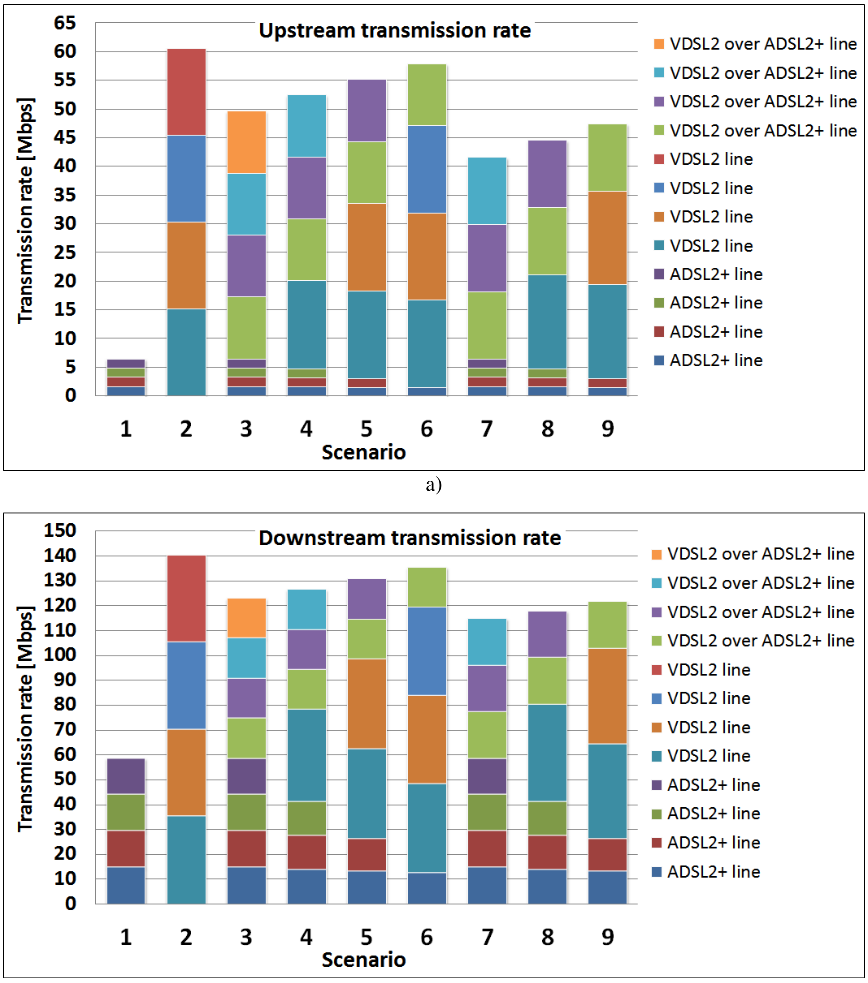

Fig. 8. The estimated upstream and downstream transmission rates for various scenarios of ADSL2+, VDSL2 and VDSL2 over ADSL2+ lines using 4 symmetrical pairs.

The resulting transmission rates in both directions presented in Fig. 8 were calculated for VDSL2 spectrum profile 998ADE17 and can be therefore different for other VDSL2 profiles.

The previous simulations also illustrate that the idea of multiplexing VDSL2 over ADSL2+ lines can potentially offer interesting advantages, such as increasing the number of subscribers in specific area as well as more effective utilisation of existing metallic lines. The summary transmission rates of VDSL2 over ADSL2+ lines with ADSL2+ lines are lower compared to standard VDSL2 lines due to the attenuation and imperfections of filters used in VDSL2 over ADSL2+ splitters. However, the simulations presented in this paper were performed with only simple filter, so more complex and accurate filters could possibly bring better results.

V. CONCLUSIONS

This paper presented an innovative idea of multiplexing VDSL2 and ADSL2+ line together and thanks to the usage of simple passive splitters, both lines can be transmitted via single symmetric line. The process of designing and creating possible HP filter for separating VDSL2 line over ADSL2+ was presented as well as its measured characteristics. More complex filters with better transmission parameters can further improve the performance of VDSL2 over ADSL2+ lines. The idea of transmitting VDSL2 lines over ADSL2+ can effectively exploit unoccupied frequency bands above the standard ADSL2+ frequencies and can potentially connect more subscribers using existing metallic cables in access networks. For that reason, several useful scenarios and combinations of standard ADSL2+ and VDSL2 lines together with presented VDSL2 over ADSL2+ lines were calculated and illustrated in the last section of this article. The VDSL2 over ADSL2+ lines can be also possibly used for future Fibre to the X (FTTx) applications together with VDSL2 outdoor cabinet conception.

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