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PRACTICAL LIMITS OF TRANSMISSION CHANNELS USED BY THE PROPOSED VDSL TECHNOLOGY

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For successful expansion of new multimedia services through the VDSL technology in the access network in Slovakia, it is necessary to know basic features of the VDSL signal. This article introduces two parts of the analysis focused on the performance evaluation of proposed SCM and MCM modulation techniques for the VDSL technology. The first part of the analysis is dedicated to the bit allocation for particular subbands. The second part of the analysis is dedicated to the bit rate dependence on the line length. Also, total transmission rates dependent on line lengths and maximum reaches of the effective VDSL transmission according to various traffic types are presented.

K e y w o r d s: VDSL environment, SCM and MCM modulations, bit allocation, bit rate dependence on the length

1 INTRODUCTION

In [1], we introduced theoretical and practical limits of transmission channels used by the ADSL technology in the metallic lines environment in the access network in Slovakia. Conclusion of that analysis indicated that an effort for the proposal of new modulation techniques utilized by xDSL modems has to be more intensive. In this paper, we introduce practical limits of transmission channels used by the proposed VDSL technology [2], [3], [4] for the homogeneous lines with real parameters in the metallic access network. This analysis is divided into 2 parts - a bit allocation for particular subbands and a bit rate dependence on the line length in the SCM and MCM modulations. Also, we used results of the analysis focused on environmental impacts on power spectral densities of VDSL signals, concretely demands on VDSL spectrum allocations including FTTCab and FTTEx spectral masks and the determination of the SNR ratio for particular SCM subbands and MCM subchannels. Comparable and extended results can be also found in the work [5] that is dealing with the analysis of the signal transmission over metallic homogeneous lines with intention on modulation schemes proposed for the VDSL technology in latest standards.

2 THEORETICAL PART

The difference between new VDSL and older xDSL modems is mainly defined in providing extremely very high-speed transmission rates. In VDSL modems, various types of modulations and duplex methods are considered. VDSL modems can use a frequency bandwidth up to 30MHz and, therefore, the VDSL transmitter must solve problematic situations not emergent in older xDSL modems. To these problems belongs the spectral compatibility and cooperation with another xDSL signals in the same cable binder and a high level of crosstalks from different resources. At the analysis of the signal transmission through metallic homogeneous lines in the VDSL environment, we need to know 3 basic parameters - properties of the signal transmitted into the line, the transmission function of the transmission channel and features of the noise and crosstalk negative environmental influences.

In [6], general relationships and frequency characteristics of basic noise and crosstalk types occurring at the signal transmission in the environment of metallic homogeneous lines are introduced. With respect to possible VDSL deployments in the access network in Slovakia, we use spectral masks defined for the FTTCab and FTTEx variations and for the coexistence with narrowband services in the same pair. In both spectral mask variations, the ADSL presence is supposed. The analysis of negative influences of noises and crosstalks on qualitative parameters of homogeneous lines can be extended to the VDSL environment. Another part of the noise in the VDSL environment can be created by the radio frequency interference (RFI). This type of the noise is involved in our analysis by using of appropriate spectral masks. For more information, solving of the RFI issue is introduced in the work [7].

In our analysis, however, the NEXT crosstalk is not considered because this one can disable a communication in the VDSL frequency bandwidth. For avoiding the NEXT influence in the VDSL signal transmission, the FDD or TDD duplex methods can be used [8]. For calculating transmission functions of homogeneous lines and for describing characteristic features of the AWGN noise and the FEXT crosstalk, we use mentioned relationships adjusted for the VDSL environment.

For particular SCM subbands and MCM subchannels, the signal-to-noise ratio (SNR) can be determined on the basis of known parameters - power spectral densities (PSD) of the VDSL signal, a transmission function of the transmission channel and frequency characteristics of the AWGN noise and the FEXT crosstalk. In our analysis, we are also using a linear equalization (LE) process by a reason of eliminating influences of the intersymbol interference (ISI). The power level of the VDSL signal can

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be acquired by integrating of its PSD characteristic at the end of the transmission path, respectively of its PSD characteristic adjusted by the correction. For each established subband in the SCM, limits of the integral present values of highest and lowest frequencies (Tab. 1) [3]. For each subchannel n in the MCM, the interval of frequencies is allocated between $< n\Delta f, (n+1)\Delta f >$, where $\Delta f = 4.3125$ kHz is the DMT subchannel bandwidth. The power level of noises can be calculating by integrating of the AWGN noise and the FEXT crosstalk power spectral characteristics for the given frequency area. If the received VDSL signal is adjusted by the correction, also noise characteristics must be adjusted.

The signal-to-noise ratio for the subband given by the lowest f_{LOW} and the highest f_{HIGH} frequencies can be expressed as

$$SNR = \frac{\int_{f_{\mathrm{LOW}}}^{f_{\mathrm{HIGH}}} PSD_S(f)\mathrm{d}f}{\int_{f_{\mathrm{LOW}}}^{f_{\mathrm{HIGH}}} PSD_N(f)\mathrm{d}f} \tag{1}$$

where $PSD_S(f)$ is the VDSL signal power spectral density and $PSD_N(f)$ is the noise power spectral density.

3 EXPERIMENTAL PART

3.1 The bit allocation for particular subbands

The ratio E/N_0 is marked as a ratio of the signal energy E to the noise density N_0. Here, it is suitable to make clear a relationship between the E/N_0 and the SNR

$$\frac{E}{N_0} = \frac{ST}{N_0} = \frac{S}{R_S N_0}\frac{W}{W} = \frac{S}{N}\frac{W}{R_S} \tag{2}$$

where S is the median modulation power, T is the time duration of one symbol, $R_S = 1/T$ is the symbol rate and $N = N_0 W$ is the noise power in the frequency bandwidth W.

Table 1. Frequency allocations with the maximum utilization of the SCM subbands

Subbands	Symbol rate R_S (Mbaud)	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)
1D $f_1 - f_2$	2.16	2.2275	0.93	3.52
2D $f_3 - f_4$	2.16	6.885	5.59	8.18
1U $f_2 - f_3$	0.954	4.5225	3.96	5.09
2U $f_4 - f_5$	2.16	10.53	9.23	11.83

For the SCM, the bandwidth for particular directions of transmission is given as a difference between highest and lowest frequencies $W = f_{\mathrm{HIGH}} - f_{\mathrm{LOW}}$, (Tab. 1). In Table 1, the symbol rate R_S is introduced for particular subbands. For the MCM, the subchannel bandwidth is 4.3125 kHz and the DMT symbol rate is 4000 baud. Using these values of parameters, we can complete a relationship (3).

As the best criterion for evaluating of modulation techniques performances seems to be a dependence of the bit error probability on the ratio E/N_0. The transmitted energy in the M-state QAM is variable in that its instantaneous value depends on the particular symbol transmitted. Then it is more logical to express $p_{b\,\mathrm{QAM}}$ in terms of the average value E_{av} of the transmitted energy than the value E. The relationship between E_{av} and E can be found in [6]. For the bit error probability of the M-state QAM modulation $p_{b\,\mathrm{QAM}}$ (supposed the Gray encoding), we can therefore use a relationship including the Q-function [9]

$$p_{b\,\mathrm{QAM}} = 4\frac{\sqrt{M}-1}{\sqrt{M}}\,Q\left(\sqrt{\frac{3}{M-1}\frac{E_{av}}{N_0}}\right) \tag{3}$$

where E_{av}/N_0 is the average SNR per symbol and M is the number of states. For various levels of the M-state QAM modulation ($M = 2^k$, k is the number of bits per one symbol), we can calculate the bit error probability for each SCM subbands or for each MCM subchannel.

The first part of the analysis is dedicated to the bit allocation for particular subbands in the SCM and MCM for the homogeneous lines with real parameters in the access network in Slovakia. According to the maximum bit error rate BER_{MAX} and using required values of the $p_{b\,\mathrm{QAM}}$, we can determine the number of maximum bits N_b that can be modulated on the concrete carrier by the VDSL modem. In [2], the maximum bit error is given as $BER_{\mathrm{MAX}\,1} = 10^{-7}$, but there are also applications (for example videosignal distribution) with the required maximum bit error rate $BER_{\mathrm{MAX}\,2} = 10^{-9}$. It is obvious that a demand on lower bit error rates leads to decreasing of transmission rates. In our analysis, we consider the simultaneous influence of 24 ADSL disturbers and 9 VDSL disturbers. In Fig. 1a and 1b, graphical results of the bit allocations for particular SCM subbands for lines with the line length $l = 0.5$ km and various core diameters are presented. In Fig. 2a and 2b, graphical results of the bit allocations for particular MCM subchannels for lines with the line length $l = 0.5$ km and various core diameters are presented. For results shown in Fig. 1a, 1b and 2a, a spectral mask for the FTTEx variation is used. This spectral mask has the increased power level -40 dBm/Hz in frequency areas overlapping the ADSL spectrum. For comparison, the bit allocation for the FTTCab variation spectral mask is shown in Fig. 2b.

3.2 The bit rate dependence on the line length

The second part of the analysis is dedicated to the bit rate dependence on the line length for the homogeneous lines with real parameters in the access network in Slovakia. The total transmission rate can be calculated as a product of the symbol rate R_S and the total number of

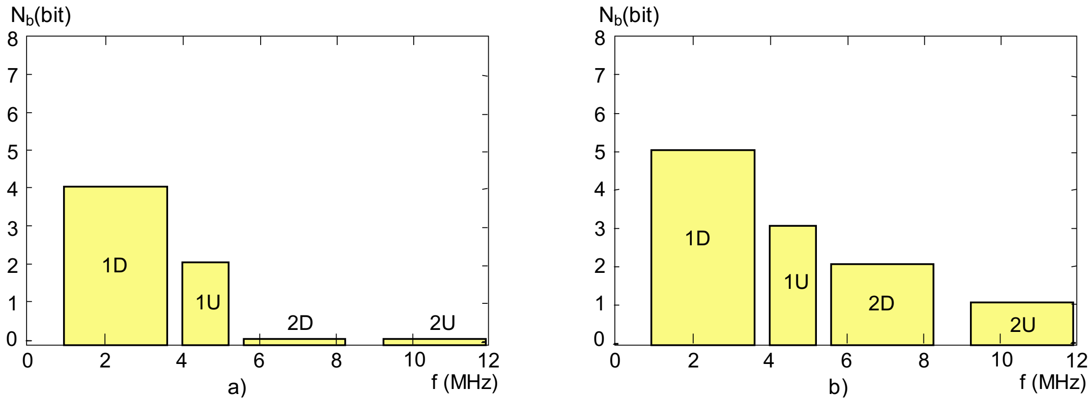

Fig. 1. The bit allocation for particular SCM subbands for lines with the FTTEx spectral mask, a) core diameter $\phi = 0.4$ mm, b) core diameter $\phi = 0.63$ mm

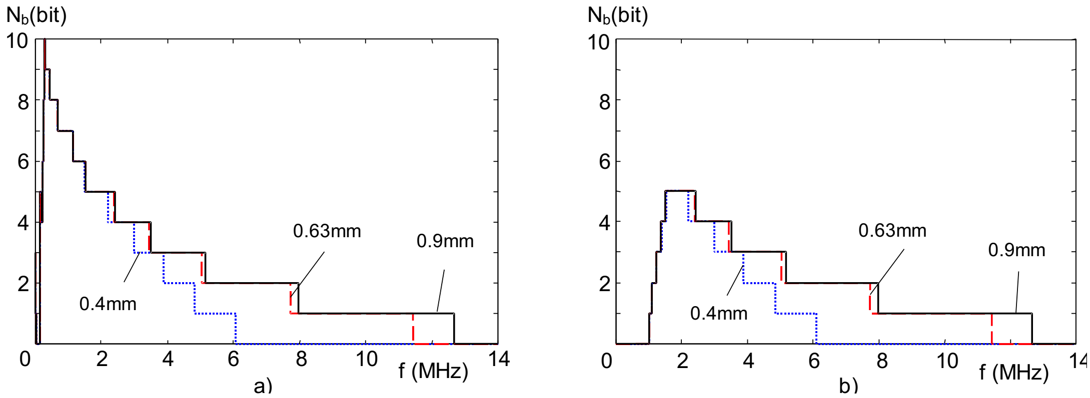

Fig. 2. The bit allocation for particular MCM subbands for lines with various core diameters, a) the FTTEx spectral mask, b) the FTTCab spectral mask

bits N_b allocated for particular subbands using a following relationship

$$R_b = \sum_{k=0}^{X_{\rm CH}} N_b(k)\, R_S(k) \qquad \text{bit/s} \tag{4}$$

where X_{CH} is the number of used subbands (respectively subchannels), $R_S(k)$ is the symbol rate for the subband k and $N_b(k)$ is the number of bits allocated for the subband k. In Fig. 3 and 4, dependences of total transmission rates (downstream and upstream directions) on the line length in the SCM and MCM for lines with various core diameters are graphically presented. This environment is characterized by the absence of ADSL and VDSL disturbers. In these ideal conditions, two variations of the number of MCM subchannels can be used.

The results presented in Fig. 3 and 4 can be used for a demonstration of the FEXT crosstalk influences at various numbers of disturbers. On the basis of results of the first analysis, one important conclusion can be introduced. Because the FEXT crosstalk level from another subscribers is too high in the FTTCab spectral mask, a possible utilization of this mask is intended to shortened metallic lines. Therefore, in our analysis we use only the FTTEx spectral mask amplified to the - 40dBm/Hz level in the frequency range of the ADSL signal. In Fig. 5a and 5b, power spectral characteristics of signals and noises for lines with the line length $l = 0.3$ km, the core diameter $\phi = 0.4$ mm and 24 ADSL disturbers are presented. Because the FEXT crosstalk is resulted from only ADSL subscribers, the ADSL influence in the frequency range up to 2MHz is expressively higher than the AWGN noise. This influence results in extensive decreasing of the SNR ratio in particular subbands and subsequently in decreasing of total transmission rates. In Fig. 6 and 7, dependences of transmission bit rates on the line length for lines with the core diameter $\phi = 0.63$ mm in the presence of 0 or 24 ADSL disturbers are graphically presented. For the SCM, the ADSL influence affects only the downstream transmission rate. A reason is that the FEXT crosstalk of ADSL disturbers interferes in only 1D subband that is reserved for the downstream direction of the transmission. For the MCM, the FEXT crosstalk of ADSL disturbers decreases transmission rates approximately about 10M bit/s in comparison with the no FEXT presence case. In favorable conditions, the number of MCM subchannels can be enhanced from 2048 to 4096 with the same 4.3125 kHz bandwidth.

The coexistence of ADSL and VDSL technologies in the same cable binder causes specific problem for operators. It is known that the FEXT crosstalk level is lower for longer line lengths because disturbing signals are attenuated at the end of the transmission paths. However, the VDSL modem must utilize narrower bands at longer

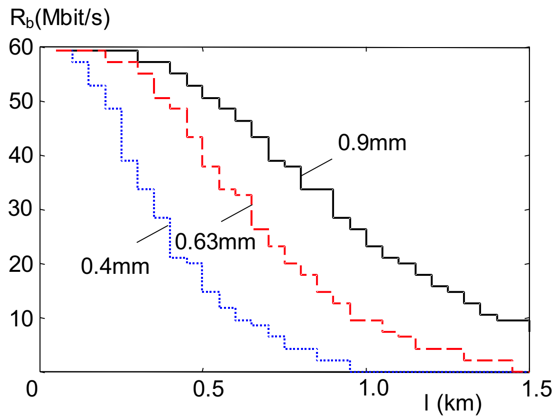

Fig. 3. Total transmission rates in the SCM for lines with various core diameters

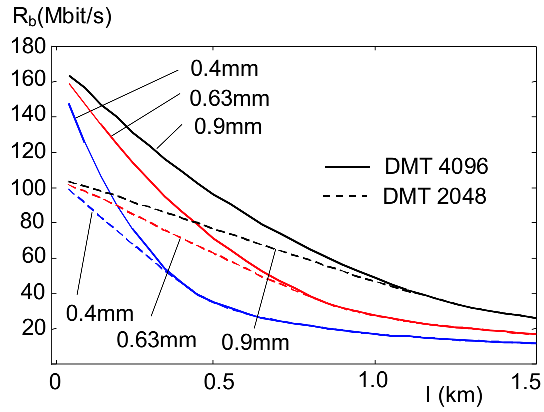

Fig. 4. Total transmission rates in the MCM for lines with various core diameters

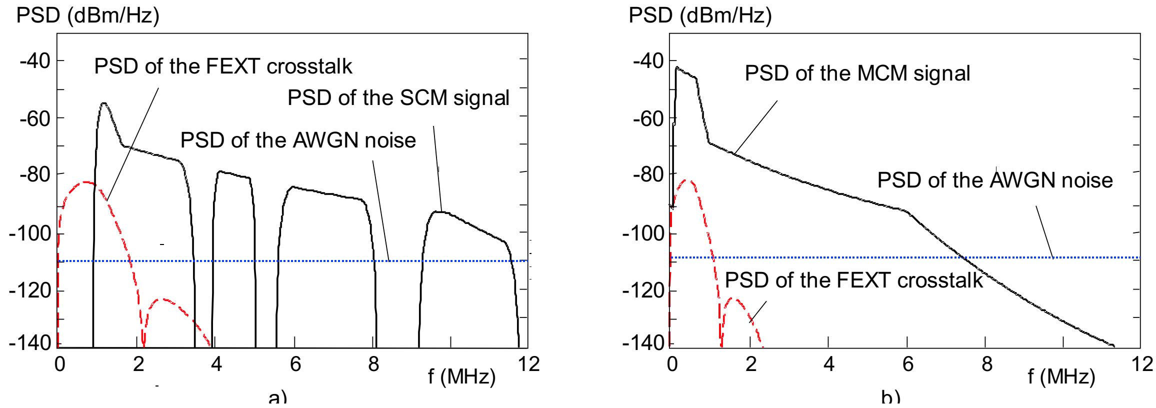

Fig. 5. The PSD characteristics of signals and noises attenuated at the end of the line, a) the SCM signal, b) the MCM signal

line lengths. Then, the FEXT crosstalk from ADSL subscribers (a bandwidth is approximately 2MHz) takes up a relatively large part of the effective utilized bandwidth of the VDSL signal. Moreover, an attenuation of the transmission line is relatively low in the frequency range of the ADSL signal at length around 1km. Moreover, we must consider also crosstalks from VDSL subscribers. In our analysis, we suppose a number of VDSL subscribers to be smaller than a number of ADSL subscribers and concrete numbers of disturbers at various traffic types in the same cable binder are presented in Tab. 2.

In Fig. 8 and 9, dependences of the total transmission rates (downstream and upstream directions) on the line lengths for lines with various core diameters in the SCM and MCM modulations for ideal, median and large traffic types in the cable binder are presented for the homogeneous lines with real parameters in the access network in Slovakia.

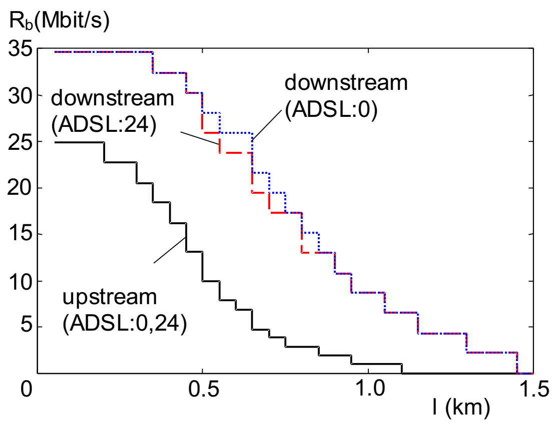

Fig. 6. Downstream and upstream transmission rates in the SCM for lines with various ADSL disturbers

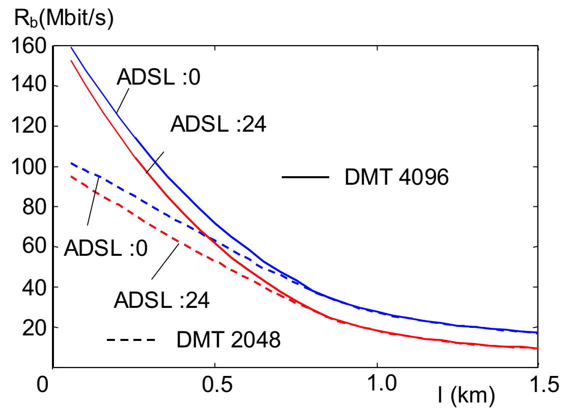

Fig. 7. Total transmission rates in the MCM for lines with various ADSL disturbers

The VDSL technology can be effectively utilized not only in a case of transmission rates above 10Mbit/s providing, but also in a case of symmetric transmissions of 8Mbit/s - this type of the service cannot be supported by the ADSL technology that can provide asymmetric transmission rates approximately up to 8Mbit/s. Then, we can determine maximum possible reaches of the VDSL service according to various traffic types (Tab. 3).

4 DISSCUSION

The first part of the analysis results in following conclusions. For the SCM, the effective utilized bandwidth is highly dependent on the core diameter. For smaller diameters, only 1D and 1U subbands can be utilized. For larger diameters, all 4 established frequency subbands are used. For the MCM, the effective utilized bandwidth is increasing with larger core diameters and can exceed 12 MHz for larger diameter also in a disturbed environment. In the comparison of different FTTEx and FTTCab spectral masks we can see that the FEXT crosstalk from ADSL subscribers expressively cuts down the number of modulated bits per subchannel below the margin of 1MHz. We must consider that the ADSL modem unlike the VDSL uses higher signal power level - 40dBm/Hz. It is therefore obvious that the FTTCab spectral mask is intended only to utilizing for homogeneous lines with shorter lengths and the FTTEx spectral mask is better to use in practical implementations of the VDSL technology.

Table 2. Traffic types according to numbers of disturbers in the cable binder

Traffic types in the cable binder	No of ADSL disturbers	No of VDSL disturbers
Ideal traffic	0	0
Median traffic	24	9
Large traffic	49	24

Table 3. Maximum reaches according to various traffic types

	Max. reach SCM (km)			Max. reach MCM (km)		
Core diameter (mm)	0.4	0.63	0.9	0.4	0.63	0.9
Traffic type:						
Median utilization	0.6	0.8	1.2	0.9	1.3	1.5
Large utilization	0.5	0.75	0.9	0.8	1.1	1.5

The second part of the analysis results in following conclusions. Total transmission rates are increasing with larger core diameter, especially for longer line lengths. For the SCM, the FEXT crosstalk of ADSL disturbers influences only the 1D frequency subband and therefore only the downstream transmission rate is decreased by the ADSL influence. For the MCM, a relative high difference between total transmission rates can be acquired by increasing of the number of subchannels in favorable conditions. Generally, SCM modulations can achieve lower total transmission rates than the MCM modulations. The reason is that 4 SCM subbands can't provide so high granularity in the bit allocation as 2048 (respectively 4096) MCM subchannels. SCM modems can also provide a programmable adjustment of the carrier frequency and the symbol rate in limits of defined subbands. It is possible to optimally shift the carrier frequency to lower positions and to decrease the symbol rate for providing smaller jumps of total transmission rates.

At the VDSL deployment and installation in the access network in Slovakia, we must take into account median and large traffic types in the same cable binder. It is evident that total transmission rates are decreasing with larger numbers of disturbers to a great extent. The VDSL technology is suitable to develop if the allowable total transmission rate exceeds the margin of 10Mbit/s. Then, it is useful to know maximum possible reaches of the effective VDSL utilization according to various traffic types and different core diameters. In the comparison of different core diameters we can see that the simplest VDSL deployment will be in new constructed metallic access networks. The VDSL deployment in older cable binders will be possible only if metallic homogeneous symmetric lines with the core diameter 0.4 mm or more and the line length up to 500 m will be utilized.

5 CONCLUSIONS

Conclusion of our previous analysis indicated that an effort for the proposal of new modulation techniques utilized by xDSL modems has to be more intensive. Conclusion of our current analysis is that modems utilizing the MCM modulations can acquire higher total transmission rates that the SCM modems. As well, the MCM modems can provide a high flexibility at the bit allocation in frequency subbands for both directions of transmission. Because synchronization problems between several stand-alone operators, it will be presumptive to utilize asynchronous versions of MCM modulations. Thus, as the most advantageous modulation techniques for the VDSL signal transmission seem to be the asynchronous Zipper DMT. In our analysis, we didn't involve the nonorthogonal NEXT crosstalk, frequency apertures and the activity of the DFE equalizer. These spheres of interest are objects of our following analysis. Effective utilization of metallic lines for the VDSL signal transmission can allow fast and relatively inexpensive expansion of very high-speed data and multimedia services for a large amount of subscribers.

Appendix - abbreviations

• ADSL —Asymmetric Digital Subscriber Line • AWGN —Additive White Gaussian Noise • DMT — Discrete Multitone • FDD — Frequency Division Duplex • FEXT — Far End Crosstalk • FTTCab — Fiber To The Cabinet

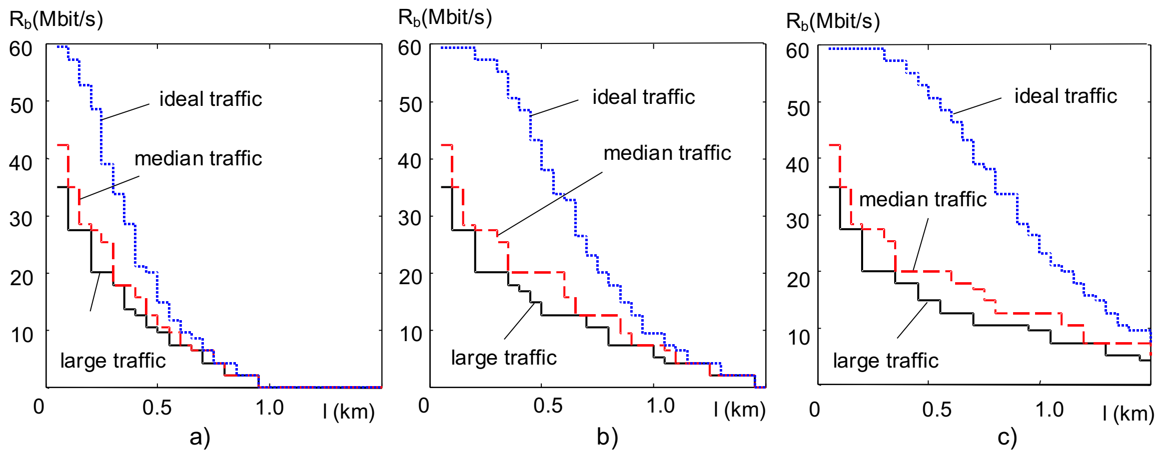

Fig. 8. Total transmission rates in the SCM for various traffic types, a) core diameter $\phi = 0.4$ mm, b) core diameter $\phi = 0.63$ mm, c) core diameter $\phi = 0.9$ mm

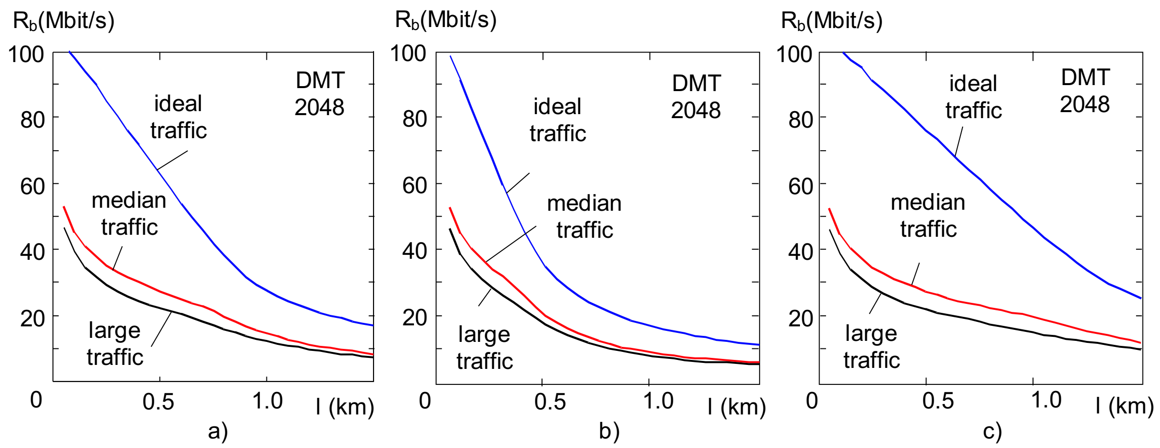

Fig. 9. Total transmission rates in the MCM for various traffic types, a) core diameter $\phi = 0.4$ mm, b) core diameter $\phi = 0.63$ mm, c) core diameter $\phi = 0.9$ mm

• FTTEx — Fiber To The Exchange • ISI — Intersymbol Interference • LE — Linear Equalization • MCM — Multicarrier Modulation • NEXT — Near End Crosstalk • PSD — Power Spectral Density • RFI — Radio Frequency Interference • SCM — Singlecarrier Modulation • SNR — Signal to Noise Ratio • TDD — Time Division Duplex • VDSL — Very high bit rate Digital Subscriber Line

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