Selection of Digital Subscriber Lines Ready for Next Generation Access

Jiri VODRAZKA, Petr JARES

Department of Telecommunication Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Technicka 2, 160 00 Prague, Czech Republic

jiri.vodrazka@fel.cvut.cz, petr.jares@fel.cvut.cz

DOI: 10.15598/aeee.v13i4.1459

Abstract. *Nowadays, in the EU a lot of project concerning broadband access to the Internet for end users is being developed. The aim of those projects is to support the creation of access communication networks that can meet defined performance criteria for providing the broadband services. Such networks are in general called Next Generation Access. One of the first tasks is to identify appropriate transmission technologies that could meet the required performance criteria. For each transmission technology, it is necessary to carry out a detailed performance analysis of the transmission depending on certain transmission conditions. To perform a detailed analysis means to carry out modelling of transmission's specific conditions for each technology. This article, specifically, discusses hybrid optical networks, which in conjunction with digital subscriber lines are one of the possible solutions for Next Generation Access. In the access network topology that combines copper and optical cables, it is necessary to optimize the mutual ratio of both infrastructures' length. Therefore, the article also describes this issue that refers to a certain technology for the Next Generation Access. Specific performance criteria of transmission for access network in the Czech Republic are considered and the optimized location of the external node digital line access multiplexer is discussed.*

Keywords

FTTx, hybrid access network, next generation access, transmission performance, xDSL.

1. Introduction

Technology development and public demands of Internet services determinate Next Generation Networks (NGN) solution. Existing access telecommunication network are considered as today's infrastructure bottleneck that significantly affects the performance of data transmissions. Therefore currently ongoing development projects aim at building a new type of access network known as Next Generation Access (NGA). Definitions of NGA networks are currently accepted by access communication networks that are not purely optic fibre based. Part of the communication infrastructure can be implemented with the use of copper cables. In result, it is possible to create the NGA networks using digital subscriber line xDSL or cable TV networks CaTV, if defined performance criteria are met. In justified cases, it will be possible to use wireless connections.

1.1. Technologies and Parameters of NGA in Czech Republic

In the Czech Republic (according to the „National plan for the development of next generation networks" document), NGA network is a network that meets the following two performance criteria:

- allows high-speed Internet access with downstream transmission rate of at least 30 Mbps. This objective is intended for existing upgraded communication infrastructures for broadband Internet access. For improved networks there is an assumption that optical elements will be used at least partially,
- allows broadband/high-speed Internet access with downstream transmission rate up to 100 Mbps. This objective is intended for newly built fully optical network infrastructure (FTTH or FTTB concept).

With regard to the penetration of transmission technologies, established performance criteria and geographic conditions in the Czech Republic, the transmission technologies have been identified and divided into seven groups: xDSL, FTTH, FTTB, FTTCab, CaTV, wireless WiFi, wireless FWA.

The individual groups are further differentiated according to achievable efficiency of downstream transmission rate:

- less than 30 Mbps,
- 30 Mbps or more, less than 100 Mbps,
- more than 100 Mbps.

For each transmission technology, it is necessary to carry out a detailed performance analysis of the transmission depending on certain transmission conditions. To perform a detailed analysis means to carry out modelling of transmission's specific conditions for each technology that include cable topology and environmental influence. The result of the analysis is a model configuration and necessary transmission conditions for the nominal rate of 30 and 100 Mbps in downstream.

1.2. Hybrid Access Network with Digital Subscriber Lines

For FTTCab topology, it is possible to use digital subscriber lines (xDSL). Their broadband access market share is around 30 % in the Czech Republic. It is therefore the most common transmission technology for access networks in the country.

The version VDSL2 (Very High Speed Digital Subscriber Line 2 [1]) is one of the latest standards of xDSL broadband communications. It has been designed to support wide deployment of triple play services, such as voice, video, data, high definition television and interactive gaming.

The VDSL2 (ITU-T G.993.2) could prospectively offer transmission rate of tens of Mbps in both directions. However, the crosstalk and other disturbances in metallic cables represent the main problem for achieving this transmission rate. While the influence of near-end (NEXT) crosstalk can be partially limited by using several different frequency bands for both directions (FDD – Frequency Division Duplex; there are several various frequency plans and scenarios for VDSL2 lines), the influence of far-end crosstalk (FEXT) cannot be reduced so easily. Therefore FEXT represents the dominant source of disturbance in current digital subscriber lines. The elimination of FEXT crosstalk could be possibly provided by the Vectored DMT modulation (VDMT).

The VDMT modulation was designed especially for FEXT crosstalk cancelation. Real use is intended specifically for the VDSL2 lines (ITU-T G.993.5). The VDMT is an extension of classical modulation with multi carriers DMT (Discrete Multi-tone). Principle of the VDMT modulation lays in idea to adjust transmitted signal in such a way, that after it goes through the subscriber line, where it is influenced by the crosstalk disturbance and cable attenuation, it could be well detected on reception side without problems.

The VDMT modulation significantly affects the maximum transmission rate of the VDSL2 lines. The increase of transmission rate can be also achieved with a greater number of the parallel channel using inverse multiplexing principles: two lines, two lines plus phantom circuit. Implementation of the VDMT modulation is essential, if the phantom circuits are considered [5].

2. Transmission Performance of VDSL2 Modelling

In the metallic part of the hybrid access network the transmission performance depends on the conditions of the transmission environment. Transmission conditions are determined by the parameters of transmission medium and the environment influence. The frequency bands with a value up to 30 MHz for modelling parameters of transmission medium typically use 13 parametric British Telecom model. When modelling environment influence different sources of interference are considered. It is mainly background noise, NEXT crosstalk and FEXT crosstalk. Modelling procedures can be found in many sources [3], [4], [6].

2.1. VDSL2 Technologies for NGA

Input parameters of simulation are comparable to technical parameters of the VDSL2 lines in the telecommunication network of the incumbent provider in the Czech Republic – O2 Czech Republic a.s. [12]. Therefore, for the simulation of the VDSL2 line with the frequency profile 998ADE17 and mask of power spectral density (PSD) „B8-12" was considered. The simulations were performed for a typical local quad cable TCEPKPFLE $75 \times 4 \times 0.4$ mm, according to O2 Czech Republic a.s. specification.

The simulation No.1 was calculated for the standard VDSL2 line according to recommendation [1]. The tested line was under the influence of crosstalk disturbances from concurrent lines in the same cable. On the surrounding twisted pairs 50 % of VDSL2 lines and an additional 20 % of ADSL2+ lines were considered. In accordance with the terms of real access network, a pa-

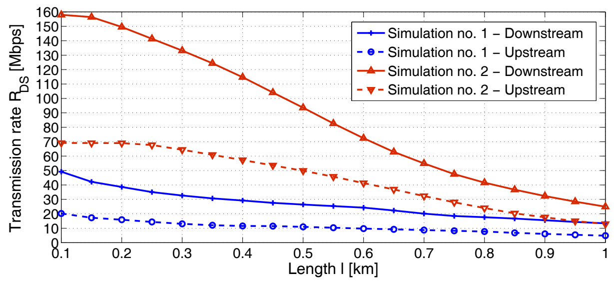

Fig. 1: Modelled results for the VDSL2 transmission rate dependence for NGA network.

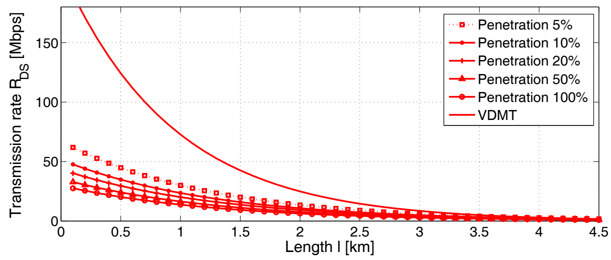

Fig. 2: Model of the VDSL2 length transmission rate dependence for downstream.

rameter Additive White Gaussian Noise (AWGN) was increased to N_{AWGN}=−136 dBm·Hz^{-1}.

For both directions of the transmission, results of simulation No.1 are shown in Fig. 1 and Tab. 1. The simulation No.2 was calculated for the VDSL2 line that uses the VDMT modulation [2] for crosstalk cancelation. The results for both directions of transmission are shown again in Fig. 1. In Fig. 1 the typical length of the metallic lines that meet the performance criteria for 30 Mbps and 100 Mbps downstream can be seen. Simulation parameters (AWGN, VDSL2 frequency band, etc.) and VDSL2 line topology are the same for the simulation No.1 and No.2.

Table 1 shows also the results for a number of digital subscriber lines (indicated in percentage), which are currently placed within desired distance from the last network element of the connection provider. The last network element is usually a phone exchange with DSLAM (Digital Subscriber Line Access Multiplexer) network element. This topology is called FTTEx (Fiber To The Exchange) and it is a present topology of the access network, which nowadays uses only symmetrical metallic pairs.

If other lines should meet the NGA performance criteria, it is necessary to use optical fibres and access network topology FTTCab (so-called external node DSLAM).

2.2. External DSLAM Optimal Location for NGA Modelling

More demanding NGA performance criteria are met only by a small number of VDSL2 lines. That is why, it is obvious that the access network topology has to use FTTCab topology and VDSL2 lines have to use VDMT modulation. Therefore, a new problem occurs; how to define the location of the external node DSLAM. To solve the problem of the optimal position, it is possible to use data about the length of the subscriber local loop published by O2 Czech Republic a.s. [12].

The model presented in [10] has been obtained as an average from all types of locations in Czech Republic. For a theoretical description of the number of digital subscriber lines in dependence on their length l, it is possible to create a statistical model of distribution, which is defined by the cumulative distribution function (CDF):

$$F(l) = 1 - p_2 \cdot e^{-p_1 l}. \quad (1)$$

Cumulative distribution function Eq. (1) corresponds to Probability Distribution Functions (PDF):

$$f(l) = p_1 \cdot p_2 \cdot e^{-p_1 l}. \quad (2)$$

Values for parameters in both equations for the Czech Republic access network are $p_1 = 0.7723$ km^{-1} and $p_2 = 1.1484$; l is the local loop length.

To search the position of external node DSLAM, modelling of the VDSL2 line transmission performance with VDMT modulation depending on the length of subscriber local loop was carried out. The simulation's input parameters correspond to the parameters of the real access network. The modelling was done for VDSL2 frequency plan 998ADE17, mask B8-12, metallic quad-star cable TCEPKPFLE 75×4×0.4 mm from Prakab Prague Cable company and noise value −140 dBm·Hz^{-1}. During the modelling, it was assumed that in the cable only transmission systems of the same type (in the sense of spectral compatibility) are present, so that full FEXT crosstalk cancelation [7], [8], [9] could be simulated. Results are shown in Fig. 2.

Particular curves in Fig. 2 show the decrease of the transmission rate in dependence on the local loop length. Another simulation parameter was also the number of disturb VDSL2 lines in the surrounding twisted pairs. The penetration of the number of disturbing VDSL2 lines was from 5 % to 100 %. The 100 % means that all twisted pairs are used for VSDL2 technology, without any crosstalk cancelation. Figure 2 shows a clear increase in transmission rate when using full coordination with VDMT modulation. The results for transmission rate of VDSL2 with the VDMT modulation can be approximated by simple exponential function in Mbps:

Tab. 1: Options of VDSL2 line transmission performance.

	Criterion 30 Mbps		**Criterion 100 Mbps**	
	Length (m)	Number of VDSL2 for FTTEx (%)	Length (m)	Number of VDSL2 for FTTEx (%)
Simulation No.1 (without VDMT)	350	10	cannot be realized	cannot be realized
Simulation No.2 (with VDMT)	920	43	470	18

$$R_{DS}(l) = p_4 \cdot e^{-p_3 l}, \tag{3}$$

where $p_3 = 1.0708\ \text{km}^{-1}$ and $p_4 = 212.4$ Mbps.

2.3. Optimization of External DSLAM Position Result

If a modern provider wants to offer its services to as many end users as possible, from Fig. 2 it is clear that the metallic local loop length may be between 0.5 km and 1 km at maximum. According to the data from O2 Czech Republic a.s. only 47 % of users are in the distance of 1 km. For access network providers it is necessary to optimize the length of the FTTCab copper and fibre infrastructure, which means to find a position of external DSLAM. If the external DSLAM is closer to the end user, the metallic local loop length will be decreased. It causes an increase of the xDSL transmission performance. Change of the external DSLAM position has also the disadvantages; it reduces the number of the xDSL lines that can be connect to DSLAM. The ratio of infrastructures length may be determined, for example, in dependence on maximizing the total transmission rate of all users in a particular segment of the access network. If the criterion of the maximum total transmission rate will be considered, it is possible to calculate the suitable position of external DSLAM according to the following Eq. (4). The results are shown in Fig. 3:

$$\begin{aligned}\vec{R}_{DS}(x) = \int_{l_{min}}^{x} R_{DS}(l)\, f(l)\, \mathrm{d}s + \\ + \int_{x}^{l_{max}} R_{DS}(l-x) \cdot f(l)\, \mathrm{d}l,\end{aligned} \tag{4}$$

where x is the position of the external DSLAM, l is the length of a subscriber local loop, $R_{DS}(l)$ is the dependence of transmission rate in downstream direction on length, $f(l)$ is the PDF for length of subscriber local loops by Eq. (2), l_{min} is minimum length of a subscriber local loop, l_{max} is maximum length of a subscriber local loop.

The curve in Fig. 3 shows the position of the external DSLAM and mean transmission rate of all users in the downstream. The graph interpretation indicates that the optimal location of external DSLAM (maximum of data rate) is about 0.8 km. Founded maximum is relatively flat. This allows further optimization of the position with regards to other criteria, such as economic, for example.

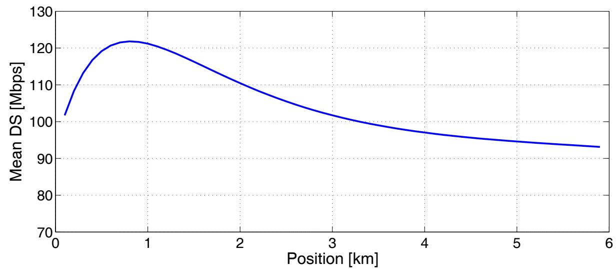

Fig. 3: The total VDSL2 downstream transmission rate on location of external DSLAM dependence.

3. Conclusion

Next generation access is the important network segment for the telecommunication services solution. Creating fully optical networks FTTH and FTTB is still hindered by high investment costs. Without using the VDMT principles for FTTEx option, the performance criteria are met by only 10 % of existing lines. Therefore, building NGA networks with alternative topology FTTCab is more than probable. In the Czech Republic, the VDSL2 lines are taken into consideration for FTTCab topology, as their transmission performance can meet NGA performance criteria.

More demanding of NGA performance criteria are met by only a small number of VDSL2 lines. That is why the access network topology has to use FTTCab and the VDSL2 lines have to use the VDMT modulation. For finding the optimal position of external DSLAM a number of criteria can be used. One of them is the mean transmission rate of all users in a particular segment of the access network. Suitable optimization of the access network, therefore optimization of the topology and network elements and effective use of the VDSL2 potential with VDMT modulation will help in the development of NGA networks.

Acknowledgment

This work was supported by the Grant of the Ministry of the Interior of the Czech Republic, No. VG20132015104, „Research and development of secure and reliable communications network equipment to support the distribution of electric energy and other critical infrastructures", and was researched in cooperation with TTC Telecomunikace.

References

[1] ITU-T Recommendation G.993.2. *Very high speed digital subscriber line transceivers 2 (VDSL2)*. Geneva: ITU-T, 2006.

[2] ITU-T Recommendation G.993.5. *Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers*. Geneva: ITU-T, 2010.

[3] STARR, T., J. M. CIOFFI and P. J. SILVERMAN. *Understanding Digital Subscriber Line Technology*. Upper Saddle River: Prentice Hall, 1999. ISBN 0-13-780545-4.

[4] BRADY, M. H. and J. M. CIOFFI. The Worst-Case Interference in DSL Systems Employing Dynamic Spectrum Management. *EURASIP Journal on Advances in Signal Processing*. 2006, vol. 2006, no. 1, pp. 1–11. ISSN 1687-6180. DOI: 10.1155/asp/2006/78524.

[5] JARES, P. and J. VODRAZKA. Modelling of Data Stream Time Characteristics for Use of Inverse Multiplexer. *Advances in Electrical and Electronic Engineering*. 2014, vol. 12, no. 4, pp. 260–264. ISSN 1336-1376. DOI: 10.15598/aeee.v12i4.1201.

[6] VODRAZKA, J., P. JARES and B. SIMAK. More Accurate Modelling of Digital Subscriber Lines with Inhomogeneity. *Communications*. 2013, vol. 15, no. 2A, pp. 129–133. ISSN 1335-4205.

[7] LAFATA, P. and J. VODRAZKA. Simulation of Far-end Crosstalk based on Modified Matrices of Transmission Line. *Elektronika Ir Elektrotechnika*. 2011, vol. 116, iss. 10, pp. 39–44. ISSN 1392-1215. DOI: 10.1109/LCOMM.2013.012213.121955.

[8] LAFATA, P. Realistic Modeling of Far-End Crosstalk in Metallic Cables. *IEEE Communications Letters*. 2013, vol. 17, no. 3, pp. 435–438. ISSN 1089-7798. DOI: 10.5755/j01.eee.116.10.876.

[9] GINIS, G. and J. M. CIOFFI. Vectored Transmission for Digital Subscriber Line Systems. *IEEE Journal on Selected Areas in Communication*. 2002, vol. 20, no. 5, pp. 1085–1104. ISSN 0733-8716. DOI: 10.1109/JSAC.2002.1007389.

[10] VODRAZKA. J., P. JARES and J. HRAD. Optimal Position of External Node for Very-high-bitrate Digital Subscriber Line. In: *34th International Conference on Telecommunications and Signal Processing*. Budapest: IEEE, 2011, pp. 175–177. ISBN 978-1-4577-1411-5. DOI: 10.1109/TSP.2011.6043748.

[11] CEPA, L., M. KOZAK and J. VODRAZKA. Innovation of methods for measurement and modelling of twisted pair parameters. *Advanced in Electrical and Electronic Engineering*. 2011, vol. 9. iss. 5. pp. 220–224. ISSN 1336-1376. DOI: 10.15598/aeee.v9i5.539.

[12] Reference offer (in Czech). Zpristupneni ucastnickeho kovoveho vedeni spolecnosti Telefonica O2 Czech Republic: Priloha 16: Sprava spektra. *O2 Czech Republic a.s.* [online] 2010. Available at: `http://www.o2.cz/public_part/1b/d/230441_417484_RUO_6._5_Priloha_16___Sprava_spektra_s_VDS_finalL.pdf`.

About Authors

Jiri VODRAZKA was born in Prague, Czech Republic in 1966. He joined the Department of Telecommunication Engineering, Faculty of Electrical engineering (FEE), Czech Technical University (CTU) in Prague in 1996 as a research assistant and received his Ph.D. degree in electrical engineering in 2001. He has been the head of the Transmission Media and Systems scientific group since 2005 and became Associate Professor in 2008. He participates in numerous projects in cooperation with external bodies. Currently he acts also as vice-head of the Department.

Petr JARES is an assistant professor at the Department of Telecommunication Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague. He received his doctor (Ph.D.) degree in 2008 at FEE, CTU in Prague, specializing in Telecommunication Engineering. For past few years he has worked on various projects in the transmission systems. His current focus of interest is on data transmission in the metallic and optical access networks.