УДК 621.391

EFFICIENCY EVALUATION OF THE "VECTORING" SYSTEM APPLICATION ON THE CONNECTING LINES DURING MODERNIZATION OF THE RURAL TELEPHONE NETWORK

Oreshkov V.I.

O.S. Popov Odesa National Academy of Telecommunications,
1 Kuznechna St., Odesa, 65029, Ukraine.
Oreshkov_VI@ukr.net

ОЦІНКА ЕФЕКТИВНОСТІ ЗАСТОСУВАННЯ СИСТЕМИ "ВЕКТОРИНГ" НА З'ЄДНУВАЛЬНИХ ЛІНІЯХ ПРИ МОДЕРНІЗАЦІЇ СІЛЬСЬКОЇ ТЕЛЕФОННОЇ МЕРЕЖІ

Орєшков В.І.
Одеська національна академія зв'язку ім. О.С. Попова,
65029, Україна, м. Одеса, вул. Кузнечна,1.
Oreshkov_VI@ukr.net

ОЦЕНКА ЭФФЕКТИВНОСТИ ПРИМЕНЕНИЯ СИСТЕМЫ "ВЕКТОРИНГ" НА СОЕДИНИТЕЛЬНЫХ ЛИНИЯХ ПРИ МОДЕРНИЗАЦИИ СЕЛЬСКОЙ ТЕЛЕФОННОЙ СЕТИ

Орешков В.И.

Одесская национальная академия связи им. А.С. Попова,
65029, Украина, г. Одесса, ул. Кузнечная,1.
Oreshkov_VI@ukr.net

Abstract. The urgency of the "digital divide" problem is a global problem. That the problem is in particular and acute in Ukraine, is described in the article. It is proposed to use VDSL2 technology for modernization of the rural telephone network connecting lines, as the most efficient by the criterion of the transmission rate maximization. The simulation of the transmission system using VDSL2 technology operating over connecting lines, which are constructed using the КСПП – 1 х 4 х 1,2 type cable, is performed. In this work, research of the VDSL2 systems achievable transmission rates dependence on the rural telephone network connecting lines parameters is performed. The expediency of the "vectoring" crosstalk compensation system application in parallel operation mode of VDSL2 systems in order to improve the connecting lines modernization efficiency is proved. The analysis of the rural telephone network connecting lines operation life and respectively parameters degradation influence on the achievable transmission rates of VDSL2 systems is completed.

Key words: digital divide, infocommunication services, transmission system, connecting line, crosstalk, "vectoring" system, transmission rate.

Анотація. У статті обґрунтовано актуальність задачі "цифрового розриву" як загальносвітової проблеми, так зокрема і проблеми, яка гостро стоїть в Україні. Проаналізовано варіанти модернізації існуючих з'єднувальних ліній сільської телефонної мережі з використанням технологій xDSL для забезпечення технічної можливості вирішення проблеми «цифрового розриву» для населення сільських територіальних громад України. Запропоновано використовувати для модернізації з'єднувальних ліній сільської телефонної мережі технологію VDSL2, як найбільш ефективну за критерієм максимізації швидкості передавання. Проведено моделювання роботи системи передачі за технологією VDSL2 по з'єднувальних лініях, що побудовані з використанням кабелю типу КСПП - 1 х 4 х 1,2, характеристики якого відповідають нормам на початок експлуатації та термін експлуатації яких складає 25 років. У статті досліджені залежності досяжних швидкостей передавання систем VDSL2 від параметрів з'єднувальних ліній сільської телефонної мережі: довжини з'єднувальних ліній, перехідних загасань при паралельній роботі систем VDSL2, потужності адитивних завад. Обґрунтовано доцільність застосування системи компенсації перехідних завад "векторинг" при паралельній роботі систем VDSL2 для підвищення ефективності модернізації з'єднувальних ліній сільської телефонної мережі. "Векторинг" дозволяє забезпечити достатнє придушення перехідних завад при роботі двох систем VDSL2 кабелем КСПП за якого ефективність модернізації підвищується практично вдвічі порівняно з варіантом роботи однієї системи VDSL2. Доведено підвищення ефективності модернізації з'єднувальних ліній за рахунок оптимізації параметрів систем VDSL2 – доцільним є збільшення потужності сигналу при застосуванні системи "векторинг". Зроблено аналіз впливу терміну експлуатації з'єднувальних ліній, відповідно погіршення їх параметрів, на досяжні швидкості передавання систем VDSL2. Застосування системи компенсації перехідних завад "векторинг" є обов'язковим для варіанта роботи кабелями, що тривалий час знаходяться в експлуатації.

Ключові слова: цифровий розрив, інфокомунікаційні послуги, система передачі, з'єднувальна лінія, перехідні завади, система "векторинг", швидкість передавання.

Аннотация. В статье обоснована актуальность задачи "цифрового разрыва" как общемировой проблемы, так в частности и проблемы, которая остро стоит в Украине. Предложено использовать для модернизации соединительных линий сельской телефонной сети технологию VDSL2 как наиболее эффективную по критерию максимизации скорости передачи. Проведено моделирование работы системы передачи по технологии VDSL2 по соединительным линиям, которые построены с использованием кабеля типа КСПП - 1 х 4 х 1,2. В работе выполнено исследование зависимости достижимых скоростей передачи систем VDSL2 от параметров соединительных линий сельской телефонной сети. Обоснована целесообразность применения системы компенсации переходных помех "векторинг" при параллельной работе систем VDSL2 для повышения эффективности модернизации соединительных линий. Выполнен анализ влияния срока эксплуатации соединительных линий сельской телефонной сети, соответственно ухудшения их параметров, на достижимые скорости передачи систем VDSL2.

Ключевые слова: цифровой разрыв, инфокоммуникационные услуги, система передачи, соединительная линия, переходные помехи, система "векторинг", скорость передачи.

One of the important problems of the modern stage of telecommunication development is the problem of "digital divide": unequal access to infocommunication services (ICS) for different segments of the population. This problem is especially acute for the inhabitants of rural areas and remote settlements, which are limited in the possibilities to use modern infocommunication technologies (ICT) and services. At present, this problem has already gone beyond the purely telecommunication problem and has acquired great economic and social significance, the importance of which the world community has already well understood [1].

The International Telecommunication Union (ITU), along with politicians and economists pays great attention to solving the digital divide problem. Thus, in his commentary to «The Measuring the Information Society» (MIS) ITU Report for 2017, ITU Secretary-General Houlin Zhao said [2]: «This year's report shows that ICTs have the potential to make the world a better place and contribute immensely to the attainment of the Sustainable Development Goals. However, despite the overall progress achieved, the digital divide remains a challenge which needs to be addressed. This is important because information and communication technology and the digital economy have the potential to transform the lives of billions of men, women and children. The digital revolution can transform nations – entire continents – but only if digital resources are accessible. This report will help to support countries to do just that».

The problem of "digital divide" also exists in Ukraine. According to statistics the number of fixed telephone lines in the rural areas is on average only 16% of that of cities, and users with access to the Internet – less than 3% that of city dwellers [3]. For inhabitants of many rural settlements, modern ICEs are almost inaccessible, even the possibility of traditional telecommunication usage is limited. The low availability of modern ICEs is one of the factors that deepens the socio-economic decline of the Ukrainian village. Consequently, one of the important steps to improve the socio-economic situation should be the construction of the modern infocommunication infrastructure in rural areas, which will provide the population with modern and accessible ICUs. The Prime Minister of Ukraine noted [4]: «We are doing this. Seriously enough. In order to create a system to stimulate the elimination of digital divide and digital discrimination, that is, the access of all settlements to this infrastructure, we will use the existing infrastructure of operators for this. But one thing must be understood is that the access to the Internet should be provided not only for schools, but for the entire locality».

It should be noted that the government of the country plans to use the existing infrastructure of telecommunication operators in the "digital divide" elimination program. One of the options to overcome the "digital divide" that corresponds to this program is the usage of existing cable infrastructure of the rural telephone network, and, firstly, the connecting lines between the district local exchange (DLE) and the villages. It can be noted that when constructing a telecommunication network, the largest share of CAPEX is the cost of cable and the expenses for their laying, so this option is economically attractive.

The rural telephone network modernization in Ukraine has already been implemented. However, only the SHDSL-technology [5] from the whole family of xDSL technologies was used. This is due to the fact that the modernization was carried out only for tasks of the telephone traffic exchange between the DLE, which requires symmetric data transmission by the connecting line. But for modern ICEs (access to the Internet, IP-TV, etc.), a situation is typical where the rate in the direction to the user is significantly higher than the rate in the direction from the user. That is, such services require asymmetric data streams that are typical for ADSL and VDSL technologies.

Comparison of symmetric and asymmetric xDSL technologies usage variants and the technical efficiency evaluation of such variants were carried out in [6]. The feasibility of VDSL2 technology usage for rural telephone network connecting lines (CL) modernization was substantiated. However, it was noted that crosstalk significantly reduce the modernization efficiency. It is known that the "vectoring" system [7] is used for crosstalk suppression on the xDSL-access networks, which allows a significant increase in the transmission rate when there are parallel operation of the xDSL transmission systems [8].

The purpose of this article is the evaluation of the efficiency of the "vectoring" crosstalk compensation system application during the rural telephone network connecting lines modernization using VDSL2 technology as a part of activities to bridge the "digital divide" in Ukraine.

The most informative technical characteristic for assessing the modernization efficiency is the throughput increase of the communication line – the ratio of the transmission rate, which can be achieved after the modernization, with the rate that was provided before the modernization. Consequently, it is necessary to perform the simulation of the transmission systems using VDSL2 technology (VDSL2-systems) operation over CL. The result of this should be a determination of the achievable transmission rate by VDSL2-systems depending on the parameters of the connecting line (line length, type of cable, the additive noise power, crosstalk values, taking into account the life of the line and, as a consequence, the deterioration of the line due to aging). More than 50% of the lines have a length of less than 16 km, so calculations are limited to this length. This will allow estimating which transmission rate can be achieved without the use of intermediate regenerators. From the practical point of view, in order to minimize the cost of modernization, intermediate regenerators should be placed only in already equipped locations, in particular, in the places where the PCM-30 regenerators are installed. This will allow the avoidance of the linear-cable works and the improvement of the cost-effectiveness of modernization. Since, as a rule, КСПП - 1 x 4 type cables with the wire diameters equal to 0,64; 0,9 and 1,2 mm are used on connecting lines, then the modeling takes into account the parameters of these cables types. In view of this, particular interest is the calculation of the VDSL2-systems transmission rate with the regeneration section length of 4,4 km (cable КСПП - 1 x 4 x 1,2).

The simulation of the VDSL2-systems operation over connecting lines was accompanied by the following tasks:

– research of the dependence of the achievable transmission rates on the parameters of connecting lines (CL length, cable type, crosstalk attenuation in parallel operation of the systems, additive noise power);

– efficiency improvement of the CL modernization by optimizing VDSL2-systems parameters;

– analysis of the influence of the CL operation duration, corresponding to the deterioration, on the achievable transmission rate of the VDSL2-systems; and

– research into the possibilities of the "vectoring" crosstalk compensation system application in parallel operation mode of VDSL2-systems to improve the efficiency of rural telephone network CL modernization.

VDSL2-system with the frequency plan B7-5 (997-M2x-A), which uses a bandwidth of up to 12 MHz to simulate the operation over connecting lines, was selected [9].

Characteristics of КСПП type rural cables were defined from [10]. In order to research the impact of the connecting lines operation life on the VDSL2-system transmission rate, deterioration of the cable was taken into account, which occurs during the 25 years period of operation.

During transmission rate calculation it is taken into account that on the CL, unlike the subscriber lines of the access networks, the error probability is two orders smaller and is equal to $p_{err} = 10^{-9}$.

The calculations were made at the power spectral density (PSD) level of the additive noises (AWGN) in the range of minus 140...minus 100 dBm/Hz according to the method described in [10].

The signal PSD for VDSL2-systems was determined in accordance with the ITU-T Recommendations [9]. The signal spectrum mask (maximum acceptable level) and the nominal signal PSD, which is 3,5 dB smaller than the mask given by the Recommendations, is optimized to provide the electromagnetic compatibility of the xDSL-systems, which operates in parallel over multi-pairs telephone cables, and the number of such systems can reach several hundred.

No more than two transmission systems can operate on CL over КСПП cable at a several times longer distance than subscriber lines, so it was expedient to research the possibility of the VDSL2-systems transmission rate increase due to increase of signal power. Calculations were made at nominal, maximum (for mask) and increased on 3,5 dB from the maximum signal power.

The VDSL2-system uses the two-wire method of the two-direction communication, unlike the PCM-30, which uses the four-wire method. This difference allows the set up of two VDSL2 systems instead of one PCM-30. Respectively, there is an opportunity to increase the efficiency of CL modernization. However, the crosstalk in the parallel operation of two systems leads to a significant transmission rate reduction over every system, as proved in [6].

The electromagnetic interactions model, given in [10], was used for the crosstalk impact research on the achievable transmission rates, that the number of parallel operating systems is limited by two. Also, for the crosstalk suppression and thus modernization efficiency increase, we used the model of the "vectoring" system developed in [8] for the cable ТПП - 10 x 2, on condition that $n = 2$.

The transmission rates, comparing results respectively for the downstream (DS) and upstream (US) of the single VDSL2-system and two VDSL2-systems in the parallel operation (two variants: with and without the "vectoring" crosstalk compensation system application), if there is no external additive noise (AWGN = –140 dBm/Hz), when VDSL2-systems are working over new КСПП - 1 x 4 x 1,2 cables ($T = 0$ years) and cables that have been in service for a long time ($T = 25$ years) are shown in Fig. 1 and 2.

The obtained results prove that the crosstalk significantly reduce the transmission rate in parallel operation of two VDSL2-systems over КСПП cables. Moreover, if the transmission rate reduction is observed for a new cable at a line length of up to 4 km and does not exceed 23% for downstream and 44% for upstream stream, then the deterioration of cable due to aging leads to ≈2 times transmission rate reducing in comparison with the new one for DS and 1,6 ... 3 times for the

US. In comparison with the operation of one system the reducing reaches 2,4 and 4 times respectively for DS and US.

Note that the 2 times transmission rate reducing in parallel operation means that the usage of two VDSL2-systems gives the same total rate as a single system, and therefore is not effective.

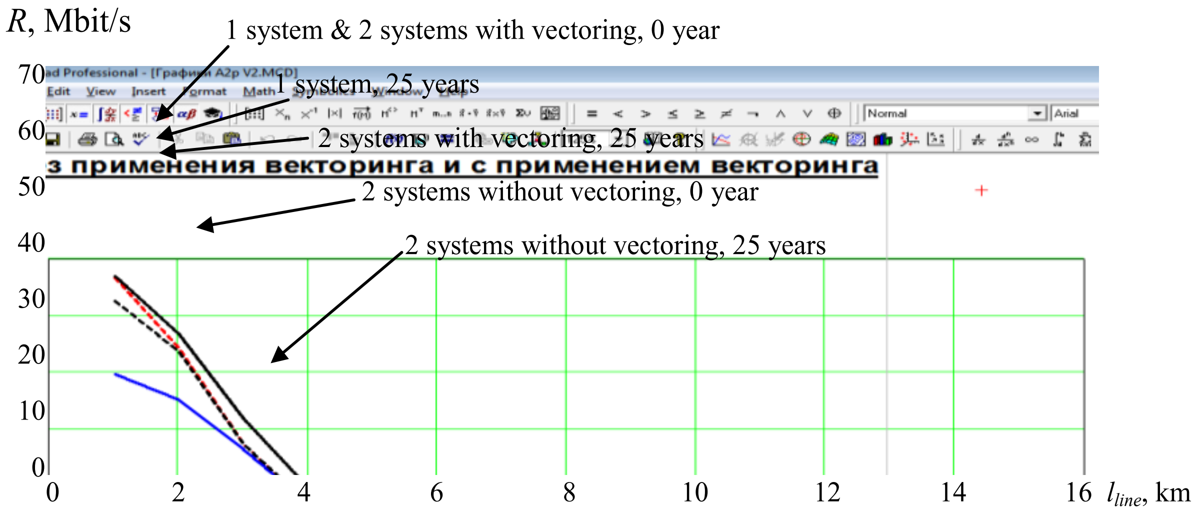

Figure 1 – Transmission rate of the VDSL2-system DS at the nominal signal power (КСПП – 1 x 4 x 1,2; AWGN = –140 dBm/Hz)

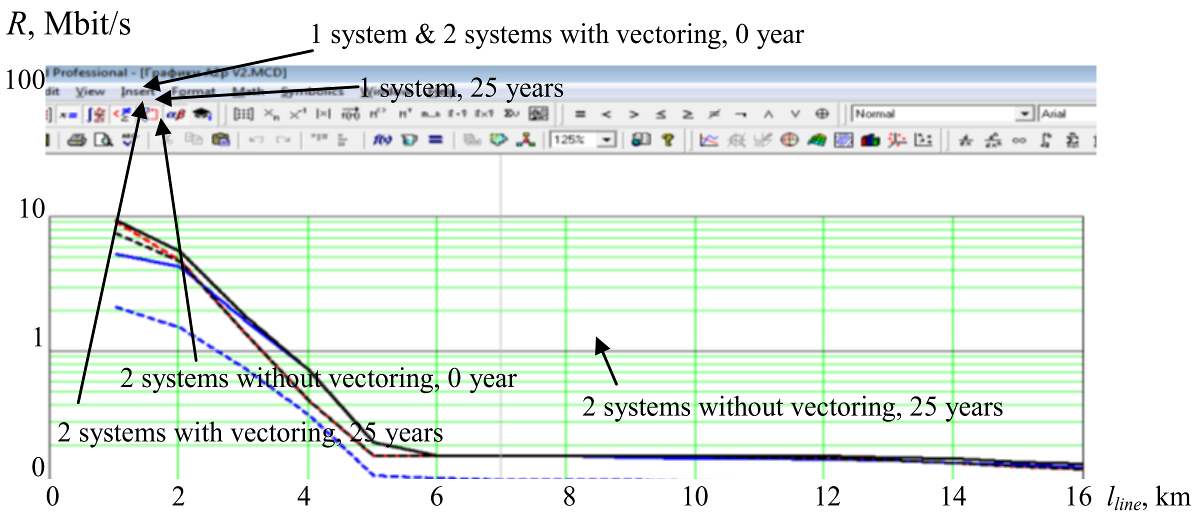

Figure 2 – Transmission rate of the VDSL2-system US at the nominal signal power (КСПП - 1 x 4 x 1,2; AWGN = –140 dBm/Hz)

The "vectoring" system application allows ensuring sufficient crosstalk suppression during the operation over new КСПП cable, in which the transmission rate during the operation of two VDSL2-systems for each of them is equal to the version of the one system operation. That is, the modernization efficiency in this case is doubled. For a cable that has been in longtime operation with a line length less than 2 km with "vectoring", there is the rate drop of no more than 7% for DS and 16% for US in relation to the variant of the one system operation. For a line length of more than 2 km, the efficiency has a double increase also.

The transmission rates comparing results respectively for DS and US during two VDSL2-systems parallel operation (with and without the "vectoring" system application) over КСПП - 1 x 4 x 1,2 cables that have been in service for a long time, depending on the external additive noise PSD level, are shown in Fig. 3 and 4.

The results shown in Fig. 3 and 4 illustrate that if the external additive noise PSD level is increased to minus 120 dBm/Hz, then transmission rate reduction can reach 30% for the option without vectoring usage and more than 50% for the option with vectoring usage downstream. The reduction is even more significant for upstream – in certain cases the rate may be reduced by 4. The external additive noise becomes dominant when its PSD level is equal to minus 100 dBm/Hz, respectively as for the option without vectoring and with vectoring the rate is practically the same. In this case the modernization of CL becomes ineffective.

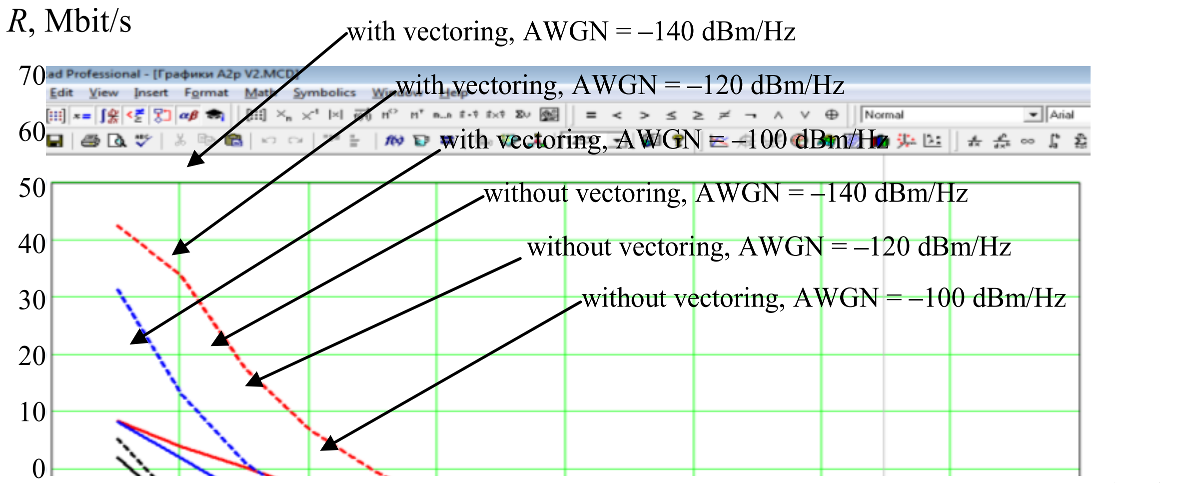

Figure 3 – Transmission rate of the VDSL2-system DS depending on the noise PSD level (КСПП - 1 x 4 x 1,2; $T \approx 25$ years; nominal signal power)

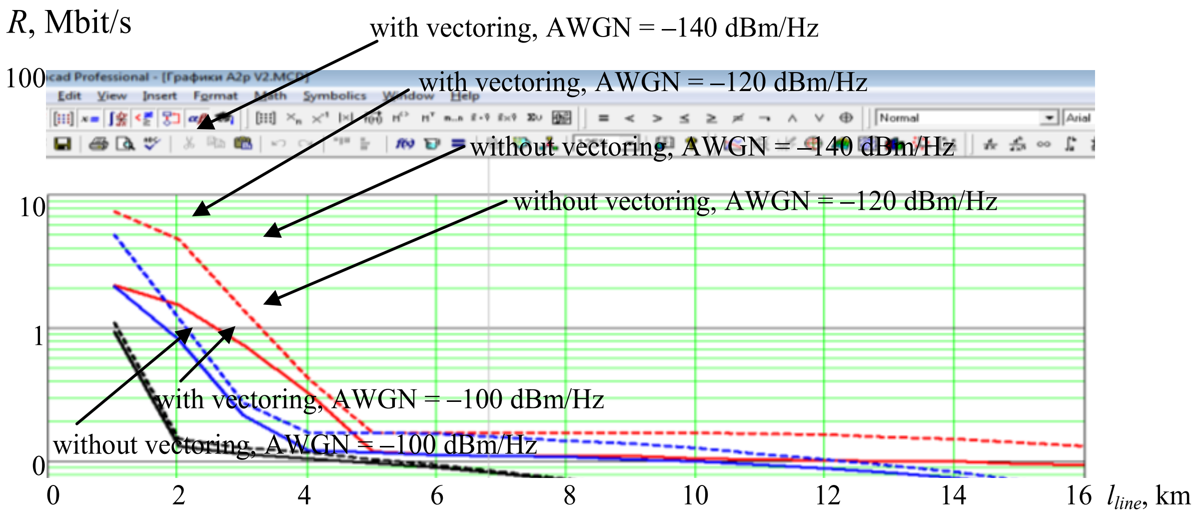

Figure 4 – Transmission rate of the VDSL2-system US depending on the noise PSD level (КСПП - 1 x 4 x 1,2; $T \approx 25$ years; nominal signal power)

The transmission rates comparing results respectively for DS and US during two VDSL2-systems parallel operation mode (with and without the "vectoring" system application) over КСПП – 1 x 4 x 1,2 cables that have been in service for a long time, depending on signal power, in the absence of external additive noise are shown in Fig. 5 and 6. Also, as during the single system operation, variants with nominal, maximum and increased transmitter signal power were considered.

The obtained results show that without crosstalk compensation the signal power increase practically does not lead to the transmission rate increase (increase is observed only at a certain line length: for the DS the maximum of the rate increase is observed at 5 km length and is 4% when comparing variants with nominal and increased power, for the US the rate increase reaches 80% at 4 km length). The "vectoring" application allows to get the transmission rate increase for DS at any line length of about 8 ... 17%, for the US increase is observed at the line length up to 6 km and reaches 83%.

Consequently, in contrast to the variant without crosstalk compensation with the variant with the "vectoring" system application, the signal power increase is appropriate and provides the additional efficiency increase of the rural telephone network connecting lines modernization.

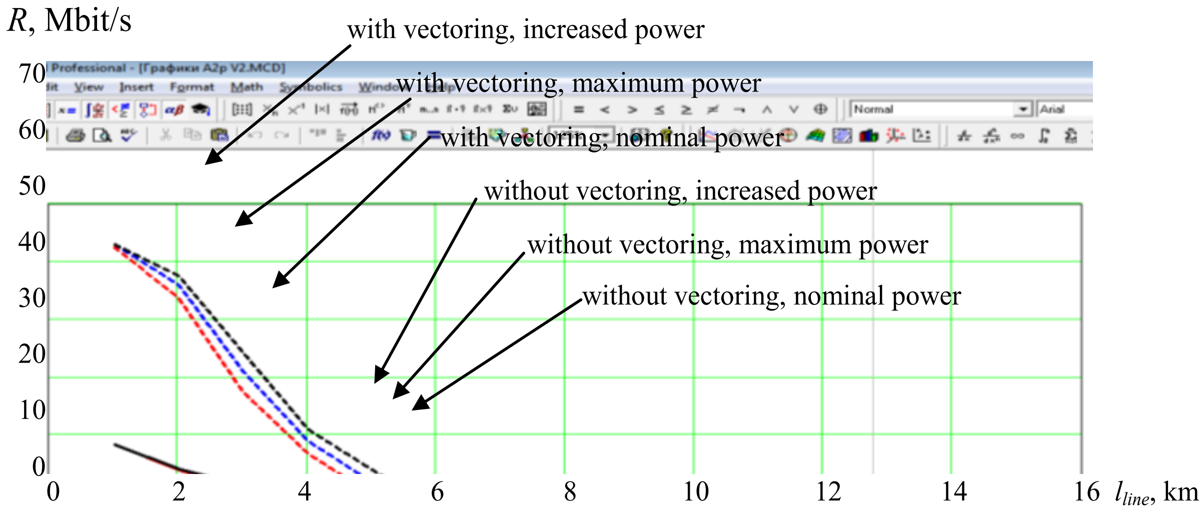

Figure 5 – The transmission rates comparison of the VDSL2-system DS depending on the signal power (КСПП - 1 x 4 x 1,2; $T \approx 25$ years; AWGN = –140 dBm/Hz)

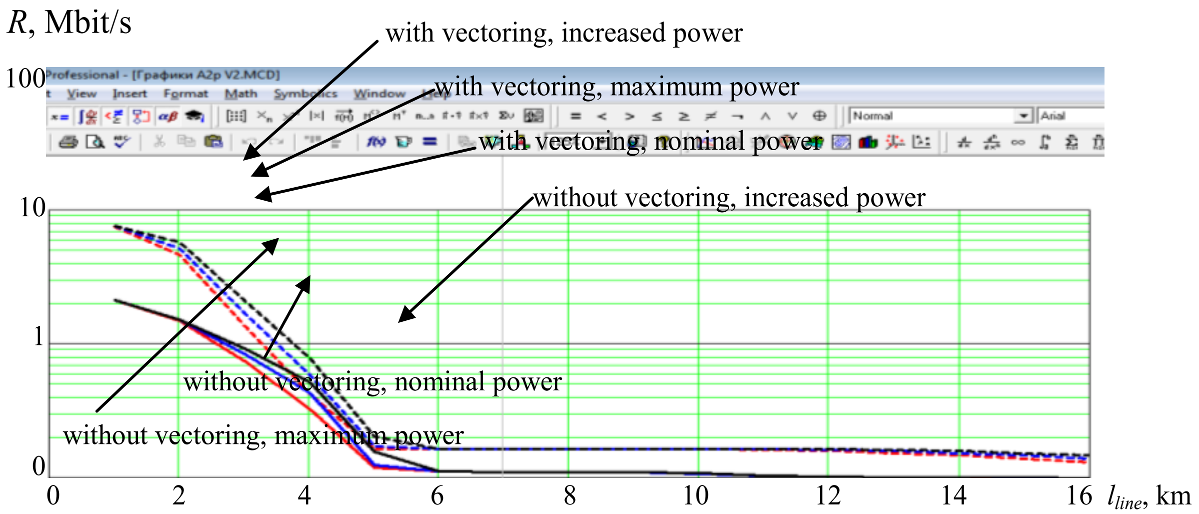

Figure 6 – The transmission rates comparison of the VDSL2-system US depending on the signal power (КСПП - 1 x 4 x 1,2; $T \approx 25$ years; AWGN = –140 dBm/Hz)

The simulation results of parallel operation of two VDSL2-systems with and without "vectoring" crosstalk compensation system application at the standard regeneration section length of PCM-30 working over КСПП - 1 x 4 x 1,2 cable depending on the CL lifetime and the signal power are given in Table 1. For comparison, the calculation results of the transmission rate in case of the crosstalk absence (one system operation variant) are provided.

The calculation results of VDSL2-system transmission rate, taking into account the crosstalk at the standard regeneration section length of PCM-30, and their comparison with the calculations during the operation of one system, indicate the significant increase possibility of the throughput of the rural telephone network connecting lines under the condition that two VDSL2-systems are used. At the same time, the "vectoring" crosstalk compensation system application is fundamental for the variant of operation over the cables that have been in service for a long time (this is the only variant to be considered, because of the fact that new lines are built using fiber optic cables today). Thus, for the variant of operation over new cables, the difference between the rate without "vectoring" and with "vectoring" does not exceed 15% for the DS and 3% for the US. For the variant of operation over cables with a 25-years lifetime the difference reaches 75% for the DS and 35% for the US.

Table 1 – The VDSL2-system transmission rate at the standard regeneration section length of PCM-30 (КСПП - 1 x 4 x 1,2; l_{line} = 4,4 km), Mbit/s

Signal power	Crosstalk	Transmission direction	Noise PSD, dBm/Hz					
			–140	–120	–100	–140	–120	–100
Operation time *T*, years			0			25		
Nominal power	without crosstalk	DS	27,108	13,764	4,6	23,816	11,308	3,528
		US	4,212	1,62	1,148	2,392	1,62	1,1
	without vectoring	DS	24,696	13,376	4,596	14,924	9,024	3,46
		US	4,184	1,62	1,148	1,828	1,188	1,024
	with vectoring	DS	27,108	13,764	4,6	23,804	11,308	3,528
		US	4,212	1,62	1,148	2,392	1,62	1,1
Maximum power	without crosstalk	DS	29,092	16,076	5,82	26	13,22	4,584
		US	5,788	1,62	1,268	3,26	1,62	1,228
	without vectoring	DS	26,132	15,456	5,808	15,56	10,008	4,432
		US	5,72	1,62	1,26	2,548	1,188	1,092
	with vectoring	DS	29,092	16,076	5,82	25,98	13,22	4,584
		US	5,788	1,62	1,268	3,256	1,62	1,228
3.5 dB higher than a maximum power	without crosstalk	DS	31,084	18,572	7,148	28,008	15,304	5,764
		US	7,7	1,62	1,392	4,496	1,62	1,352
	without vectoring	DS	27,42	17,664	7,128	15,92	11,056	5,448
		US	7,548	1,62	1,376	3,384	1,188	1,128
	with vectoring	DS	31,084	18,572	7,148	28	15,304	5,764
		US	7,7	1,62	1,392	4,496	1,62	1,352

Conclusion. The signal power level increase in predicted results leads to the transmission rate increase (of 17% for the DS and of 91% for the US in case of external noises absence at the standard regeneration section length of PCM-30).

The deterioration of cable due to aging (long service life) results in additional loss of transmission rate, especially for the variant without crosstalk compensation (45% for DS and 55% for US). Consequently, during determining the efficiency of the rural telephone network connecting lines modernization, it is necessary to take into account both the levels of signal and noises, as well as the lifetime of every particular connecting line.

The PCM-30 transmission system replacement into two VDSL2-systems with the "vectoring" crosstalk application at the same standard regeneration section length allows to the increase of the CL throughput of up to 28 times in the direction to the user and up to 4,5 times in the opposite direction if the signal power is increased and the external noises are absent.

REFERENCES:

1. Problema «tsifrovogo razryva» mezhdu lyud'mi nosit global'nyy kharakter – D.Abayev [Electronic resource] / Prime Minister of the Republic of Kazakhstan. Offic. site. – Access mode: https://primeminister.kz/ru/news/13/problema-«tsifrovogo-razryva»-mezhdu-ljudmi-nosit-globalnyj-harakter-dabaev /. – Access date: 16.02.2018.
2. ITU reveals latest global ICT Development Index country ranking with release of Measuring the Information Society 2017 report [Electronic resource] / ITU 2018. – Access mode: https://www.itu.int/en/mediacentre/Pages/2017-PR60.aspx /. – Access date: 02.03.2018.
3. Stan rozvytku zvyazku v Ukrayini za 2016 rik. / Derzhavna sluzhba statystyky Ukrayiny // Statystychnyy byuleten. – K., 2017. – 26 s.
4. Pravitel'stvo reshit problemu tsifrovogo razryva dostupa k Internetu [Electronic resource] / TOV «INFO-24». – Access mode: https://tvi.ua/novini/uryad-virishit-problemu-cifrovogo-rozrivu-dostupu-do-internetu.html /. – Access date: 12.04.2018.
5. Kabanov M.V. Ispol'zovaniye oborudovaniya SHDSL pri modernizatsii STS / M.V. Kabanov, D.S. Maslov // Vestnik svyazi. – 2007. – №12. – S. 50–53.
6. Balashov V.O. Kharakterystyky zyednuvalnykh liniy silskykh telefonnykh merezh za tekhnolohiyamy xDSL / V.O. Balashov, L.M. Lyakhovetskyy, V.I. Oryeshkov // Zv'yazok. – 2012. – № 2. – S. 8–13.
7. ITU-T. Recommendation G.993.5 : Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers. – Appr. 2015, January. – Geneva, 2015. – 100 p.
8. Balashov V.O. Kharakterystyky shyrokosmuhovoho dostupu za tekhnolohiyeyu VDSL2 iz zastosuvannyam systemy kompensatsiyi perekhidnykh zavad «vektorinh» / V.O. Balashov, L.M. Lyakhovetskyy, V.I. Oryeshkov // Nauchnye trudy SWorld.– Yvanovo: Nauchnyy myr, 2015. – № 3 (40). – Tom 3. – S. 4–11.
9. ITU-T. Recommendation G.992.3 : Asymmetric digital subscriber line transceivers 2 (ADSL2). – Appr. 2009, April. – Geneva, 2009. – 404 p.
10. Perspektyvni telekomunikatsiyni tekhnolohiyi merezh shyrokosmuhovoho dostupu: monohrafyya / [V.O. Balashov, A.H. Lashko, L.M. Lyakhovetskyy, V.I. Oryeshkov, V.V. Pedyash, O.S. Reshetnikova, A.V. Soldatkina]. – Odesa: KUPRIYENKO SV, 2016 – 200 s.: 118 rys., 35 tabl.ISBN 978-966-2769-98-2.

ЛІТЕРАТУРА:

1. Проблема «цифрового разрыва» между людьми носит глобальный характер – Д.Абаев. [Электронный ресурс] / Премьер-Министр Республики Казахстан. Офиц. сайт. – Режим доступа: https://primeminister.kz/ru/news/13/problema-«tsifrovogo-razryva»-mezhdu-ljudmi-nosit-globalnyj-harakter-dabaev /. – Дата доступу: 16.02.2018.
2. ITU reveals latest global ICT Development Index country ranking with release of Measuring the Information Society 2017 report [Электронный ресурс] / ITU 2018. – Режим доступа: https://www.itu.int/en/mediacentre/Pages/2017-PR60.aspx /. – Дата доступу: 02.03.2018.
3. Стан розвитку зв'язку в Україні за 2016 рік / Державна служба статистики України // Статистичний бюлетень. – К., 2017. – 26 с.
4. Правительство решит проблему цифрового разрыва доступа к Интернету [Электронный ресурс] / ТОВ «ІНФО-24». – Режим доступа: https://tvi.ua/novini/uryad-virishit-problemu-cifrovogo-rozrivu-dostupu-do-internetu.html /. – Дата доступу: 12.04.2018.
5. Кабанов М.В. Использование оборудования SHDSL при модернизации СТС / М.В. Кабанов, Д.С. Маслов // Вестник связи. – 2007. – №12. – С. 50–53.
6. Балашов В.О. Характеристики з'єднувальних ліній сільських телефонних мереж за технологіями xDSL / В.О. Балашов, Л.М. Ляховецький, В.І. Орєшков // Зв'язок. – 2012. – № 2. – С. 8–13.
7. ITU-T. Recommendation G.993.5 : Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers. – Appr. 2015, January. – Geneva, 2015. – 100 p.
8. Балашов В.О. Характеристики широкосмугового доступу за технологією VDSL2 із застосуванням системи компенсації перехідних завад «векторінг» / В.О. Балашов, Л.М. Ляховецький, В.І. Орєшков // Научные труды SWorld.– Иваново: Научный мир, 2015. – № 3 (40). – Том 3. – С. 4–11.
9. ITU-T. Recommendation G.992.3 : Asymmetric digital subscriber line transceivers 2 (ADSL2). – Appr. 2009, April. – Geneva, 2009. – 404 p.
10. Перспективні телекомунікаційні технології мереж широкосмугового доступу: монография / [В.О. Балашов, А.Г. Лашко, Л.М. Ляховецький, В.І. Орєшков, В.В. Педяш, О.С. Решетнікова, А.В. Солдаткіна] – Одеса: КУПРІЄНКО СВ, 2016 – 200 с.: 118 рис., 35 табл. ISBN 978-966-2769-98-2.