Evaluating Effectiveness of Implementing G.fast Technology in Ukraine's Broadband Access Networks

Vitaliy Balashov, Vasyl Oreshkov, Iryna Barba, Dmytro Stelya, and Ihor Makarov

State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine

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Abstract — The article examines the feasibility of implementing the G.fast technology in the process of modernizing fixed broadband access networks operated in Ukraine. An analysis of international experience in the field and of national broadband development strategies is provided. The data rates achievable by G.fast transmission systems relying on profile 106a over multi-pair TPP and UTP Cat. 5e cables are evaluated, with intrasystem interference and crosstalk taken into consideration as well. The effectiveness of applying the vectoring crosstalk compensation system to increase G.fast transmission rates is assessed. Based on the research results, recommendations are formulated for the effective deployment of G.fast in Ukraine's broadband access networks.

Keywords — broadband access, interference, multi-pair TPP cables, transmission rate, UTP Cat. 5e cable, vectoring

1. Introduction

Today, broadband Internet access is a fundamental telecommunication feature driving economic growth, facilitating social services and boosting e-Governance. One of the key challenges faced in Ukraine's digital transformation process consists in ensuring common access to high-speed Internet, regardless of the user's place of residence.

The development of broadband networks in general and fixed broadband access (FBB) networks in particular – with the latter based on copper subscriber cables (xDSL technologies) and optical solutions (FTTx or "fiber-to-the x" concepts) – is taking place under challenging conditions. These include technical disparities between regions, limited budgets for infrastructure projects, and the need for effective modernization of existing networks [1], [2].

In Ukraine, the development of FBB networks is of critical importance. Despite ongoing upgrades to the telecommunications infrastructure in urban areas, significant rural regions still have limited or no access to high-speed Internet [3], [4].

Furthermore, the large-scale war that has been ongoing since 2022 has posed additional challenges to the telecommunications infrastructure, demanding flexible solutions and the implementation of modern technologies, such as fiber to the home (FTTH), xDSL, DOCSIS, and fixed wireless access (FWA) [5].

Among the modern technologies that allow for a significant increase in the capacity of FBB networks without a complete replacement of the physical medium, G.fast takes notice [6], [7]. This technology enables transmission rates of more than 1 Gbps to be achieved on short network segments built using copper multipair telephone cables.

However, its effectiveness largely depends on the length of the subscriber line and the level of interference [8]. Thus, the application of G.fast is most appropriate when the fiber-to-the-distribution point (FTTDp) concept is relied upon, where the length of the copper segment does not exceed 250 m. In such deployments, G.fast-based FTTDp networks offer transmission rates comparable to those of fiber optic connections, while requiring significantly lower investments than full FTTH implementations [9].

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In this context, research on the characteristics of G.fast transmission systems (TS) based on the existing infrastructure of Ukraine's fixed broadband networks, as well as potential development and modernization paths for these networks, are crucial to evaluate the real potential of this technology.

The purpose of this article is to analyze the dynamics of the development of broadband Internet in Ukraine, considering the technical aspects of introducing advanced FBB technologies. Additionally, the article aims to evaluate the effectiveness of G.fast transmission systems (G.fast TS) within Ukraine's FBB networks by modeling the characteristics of G.fast TS using traditional multi-pair telephone (TPP) and

UTP Cat. 5e cables, as an option for modernizing subscriber lines.

2. Literature Review and International Experience

Research described in the literature indicates that technologies based on the use of copper multi-pair cables, such as VDSL2 and G.fast, remain relevant in countries with well-developed infrastructure, where full replacement with optical media is economically unfeasible or would require considerable investment efforts. Article [10] notes that G.fast can achieve speeds of up to 1 Gbps over short copper loops, making it an effective solution for upgrading existing networks without the need for complete replacement of the cable.

Study [11] addresses the co-existence of G.fast and VDSL2 in FTTDp and FTTC-type networks. The authors analyze spectrum optimization methods and the degree of protection of existing services, which is a critical aspect when introducing new technologies into functioning networks.

In [12], it is emphasized that G.fast is an ideal choice for operators because it works on the existing copper telecommunication infrastructure already installed at the users' premises. However, since this infrastructure was not designed for the high frequency transmission rates used by G.fast, signal leakage may occur during the process. This radiation may directly affect the quality and reliability of radio services operating in the same frequency range. The study provides an assessment of whether radiation generated by a telecommunications network using G.fast complies with the requirements of ITU-T Recommendation K.60 and whether it may be a source of interference for radio services using the same band.

The works referred to above highlight that the key factors limiting G.fast performance include high power spectral density (PSD) of noise caused by near-end crosstalk (NEXT), far-end crosstalk (FEXT), electromagnetic interference from external sources, and signal attenuation that depends on frequency and length of line. Researchers recommend considering the cable type and design features when evaluating G.fast efficiency, as noise characteristics can vary significantly depending on the cable used.

Report [13] underscores the importance of combining government regulations with private investment to bridge the digital divide. It emphasizes the need for strategic planning and support for innovative technologies to ensure equal access to broadband Internet.

In [14], the Broadband Forum presents methodologies for calculating losses and interference characteristics for category 5e cables, including recommendations on the maximum line lengths for 106a and 212a profiles. The documents highlight the need for accurate PSD function modeling and the use of empirical data, especially in cases in which pre-installed cables are re-used.

Thus, international experience demonstrates that effective development of fixed broadband access requires:

- strategic, national level planning,
- support for innovative technologies (particularly G.fast),
- investment in digital infrastructure,
- boosting competition among providers,
- reduction of the digital divide between urban and rural areas.

There is strong evidence in global practice supporting the feasibility of using the G.fast technology for short network segments, and the negative impact of interferences is thoroughly evaluated. The results of this research may be useful for planning the modernization of fixed broadband networks, especially in urbanized areas with existing cable infrastructure.

The following sections of this article analyze the current situation in Ukraine as well as evaluate the prospects for deploying and developing fixed broadband solutions, taking into account the approaches discussed above.

3. Current State of and Development Plans for FBB

According to the Ukraine's Strategy for the Development of the Electronic Communications Sector 2030, one of the priorities is to ensure universal access to high-speed Internet regardless of location, including in rural areas [1]. FBB is a key prerequisite for the development of Ukraine's digital economy, electronic services, and innovation-oriented infrastructure. In the context of post-war recovery and Ukraine's digital transformation, FBB becomes not only a tool for accessing digital services, but also a strategic prerequisite to attract investment and develop human capital.

In 2020, with the support of the World Bank, Ukraine drew up a National Broadband Development Strategy (2020 – 2025) which addresses strategic tasks such as:

- connecting 95% of socially significant facilities (schools, hospitals, administrative service centers) to fiber-optic Internet,
- providing government subsidies to operators for connecting rural settlements,
- launching an interactive geographic information platform presenting FBB coverage [2].

In 2021, the Ukrainian Cabinet of Ministers approved an Action Plan for the Development of Broadband Internet Access for 2021 – 2022, with the objective of improving infrastructure and accessibility of the Internet [15].

According to [16], at the end of 2023, there were 8.06 million fixed Internet access lines in Ukraine, with the said result being 12% higher than the year before. The most notable growth occurred in rural areas, with the increase amounting to 25.4% and reaching 2.12 million connections. Despite the positive dynamics, only 62% of households have fixed Internet access, indicating a persistent digital divide, especially evident in rural regions.

In 2025, the government will acknowledge problems with the insufficient pace of broadband access growth. In [17], several problems that hinder effective FBB deployment were highlighted [17]:

- lack of a unified digital platform for monitoring coverage, which complicates planning,
- fragmented responsibilities shared by different government authorities,
- limited funding, especially in the context of martial law and the need to restore damaged infrastructure,
- unequal technical resources available to specific operators – some providers are still using outdated equipment (e.g., ADSL).

According to [1], in the long-term Ukraine aims to achieve 100% nationwide broadband coverage, simultaneously aiming to complete the process of modernizing its gigabit technology infrastructure and relying on FBB to implement key national digital services.

4. Challenges and Opportunities Related to G.fast Technology

In the context of limited resources and the need for rapid network expansion, G.fast technology is seen as a promising solution to upgrade the existing copper infrastructure, especially in densely populated areas. This technology enables high data transmission rates over short distances, which is particularly relevant for apartment buildings and office centers.

However, the effectiveness of G.fast is largely dependent on the quality of the cable infrastructure and the length of the line. Ukraine's traditional public switched telephone network (PSTN) is built using multi-pair telephone cables of the TPP type. The most common telephone cable in the network is the TPP-10×2×0.4. The G.fast technology, following the FTTDp concept, utilizes the existing distribution segment of the PSTN cable infrastructure within buildings. The maximum line length within apartment buildings is limited to 250 m.

In many residential buildings, Internet connection requires modernization of the in-building network, including replacement of the cable infrastructure with twisted pair cables, typically of the UTP Cat. 5e variety. When deploying the G.fast technology, the question arises as to whether it is feasible to carry out such a modernization.

To address this issue, it is necessary to study the performance characteristics of G.fast when operating over multipair telephone cables of the TPP type and twisted pair cables, such as UTP Cat. 5e. Such a study is essential to evaluate the real potential of G.fast deployment in Ukraine, both under existing cable infrastructure conditions and in the context of its modernization, with the impact of cable infrastructure parameters (cable type, frequency and time domain characteristics, line length, and noise level) on the performance of G.fast TS taken into consideration as well.

In this study, it is assumed that the copper segments under analysis are not shared with other transmission systems such as VDSL or VDSL2. The G.fast system is deployed in a dedicated frequency band, consistent with the ITU-T recommendations, and interference from other copper-based services is excluded from the modeling.

The main criterion for determining the effectiveness of a TS is the data rate that can be achieved under specific operating conditions of the system. Therefore, to study the effectiveness of using G.fast TS in the Ukrainian FBB network and the feasibility of modernizing the cable infrastructure, it is necessary to define the initial data, determine the methods for evaluating the G.fast data rate, perform data rate calculations for G.fast based on the given initial data, analyze the results obtained, and formulate recommendations for the implementation of G.fast technology in Ukrainian fixed broadband networks.

The initial data must include the following:

- identification of the characteristics of the G.fast transmission system that will influence the data rate evaluation process,
- determination of the characteristics of TPP and UTP Cat. 5e cables necessary to assess the G.fast data rate,
- specification of the conditions under which the results of the data rate evaluation process for TPP and UTP Cat. 5e cables can be compared.

5. Data Rate Evaluation

The evaluation of the data rate of the G.fast TS was carried out based on the following initial constraints:

- spectral mask of the G.fast system complies with the ITU-T G.9700 standard [6],
- frequency plan up to 106 MHz,
- used channels $i = 43 \ldots 2047$,
- number of orthogonality interval samples $N = 4096$,
- number of guard interval samples $L = 320$,
- PSD level of external additive white Gaussian noise is assumed to be uniform –140 dBm/Hz,
- cable types – TPP-10×2×0.4 and twisted pair cable UTP Cat. 5e 4×2×0.51,
- line length l from 50 to 250 m,
- number of TS operating in parallel on the multipair cable – 1 and 4.

Cable characteristics were determined by measuring cable samples at the cable manufacturer's testing laboratory. The measurement results were summarized and used to derive approximation formulas for frequency characteristics within the frequency range of up to 100 MHz. Table 1 presents the results of the process of determining the frequency characteristics for a 100-meter line.

- α intrinsic attenuation (attenuation coefficient) [dB/100 m],
- β phase coefficient [rad/100 m],
- A_N near-end crosstalk (NEXT) [dB/100 m],
- A_{ELF} equal-level far end crosstalk (ELFEXT) [dB/100 m].

To determine the data rate of the G.fast TS, we use the methodology described in [18]. The data rate is determined

Tab. 1. Frequency characteristics approximation coefficients.

Parameter	α [dB/100 m]			β [rad/100 m]	A_N [dB/100 m]		A_{ELF} [dB/100 m]	
Approximation functions	$\alpha = a + bf^c$			$\beta = d\,f$	$A_o = x - y\log f$		$A_3 = x - y\log f$	
Approximation coefficients	a	b	c	d	x	y	x	y
Cat. 5e 4×2×0.51	1.121	1.110	0.59	2.681	89.49	22.6	81.15	17.59
TPP-10×2×0.4	0.59	0.98	0.7	2.776	60.281	17.19	68.2	22.5
Note: The frequency in the formula is expressed in MHz								

by means of the signal-to-noise ratio (SNR). The total noise includes the following components:

- thermal noise, defined as AWGN with a power spectral density level of –140 dBm/Hz,
- external additive noise, which depends on the specific electromagnetic environment (in previous studies, this was modeled by increasing AWGN uniformly across the entire operating frequency range),
- crosstalk interference (XTI), originating from TS operating in parallel within a multi-pair cable,
- intrasystem interference, which, for systems using parallel transmission rate, includes two components: intersymbol interference (ISI) and interchannel interference (ICI), is collectively referred to as IS+ICI.

Therefore, to determine the data rate of the G.fast TS, it is necessary to identify all noise components that affect the system's performance.

In the simulation, we assume that we only influence the baseline thermal and AWGN at –140 dBm/Hz. The influence of specific external systems such as power line communication (PLC), which can operate in overlapping frequency bands, was not taken into account but will be considered in future studies using real-world electromagnetic compatibility data.

To determine crosstalk interference, we use the technique described in [19]. This methodology also accounts for the application of a crosstalk cancelation system based on the implementation of the vectoring method [20].

It should be noted that the impact of crosstalk interference on the G.fast transmission rate when operating over TPP-10×2×0.4 and UTP Cat. 5e cables, as well as the effectiveness of the vectoring system in compensating XTI and increasing the G.fast transmission rate, were already evaluated in [21].

However, the study [21] cannot be considered complete, as it did not take into account IS+ICI interference. Consequently, it lacks results on its potential impact on the G.fast data rate. In this work, we aim to address this research gap.

To determine IS + ICI interference, we use the methodology outlined in [22]. Since the method is based on modeling interference in the time domain, it requires an additional transformation of channel frequency characteristics into time domain characteristics, determining the impulse response (IR). The IR of the transmission channel was calculated using the inverse fast Fourier transform (IFFT) of the channel characteristics in the measured frequency domain. This IR was then used to simulate inter-symbol and inter-channel

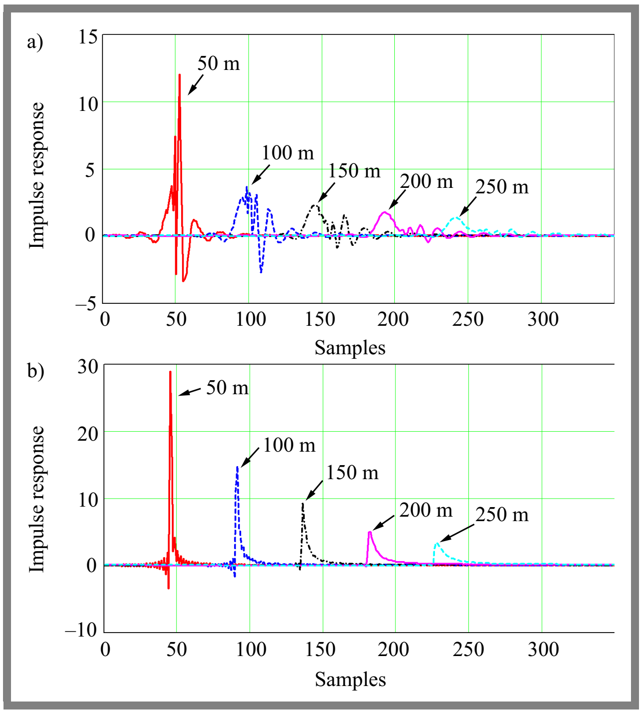

Fig. 1. Impulse response: a) to the TPP-10×2×0.4 and b) to the twisted pair cable UTP Cat. 5e 4×2×0.51.

interference components in the transmission rate calculations. Figure 1 presents the IRs for TPP and UTP cables of various lengths, illustrating signal dispersion and delay spread, i.e. parameters that are critical for IS+ICI estimation. The IFFT size corresponds to the transformation size of the modulation process in a G.fast system with a 106 MHz ($N = 4096$ samples).

6. Interference Component Analysis

Figures 2 and 3 present the calculated interference power distribution across the G.fast system channels when operating over TPP-10×2×0.4 and UTP Cat. 5e 4×2×0.51 cables with lengths of 50 and 200 m. The results demonstrate the dependence of the PSD level on the G.fast channel number $G(i)$, where the central frequency of channel i is defined as: $f_i = 51.75$ kHz $\cdot\, i$. The figures show three types of interference: –140 AWGN, IS+ICI, and XTI crosstalk interference, with their level calculated assuming parallel operation of four G.fast systems. Additionally, residual non-compensated

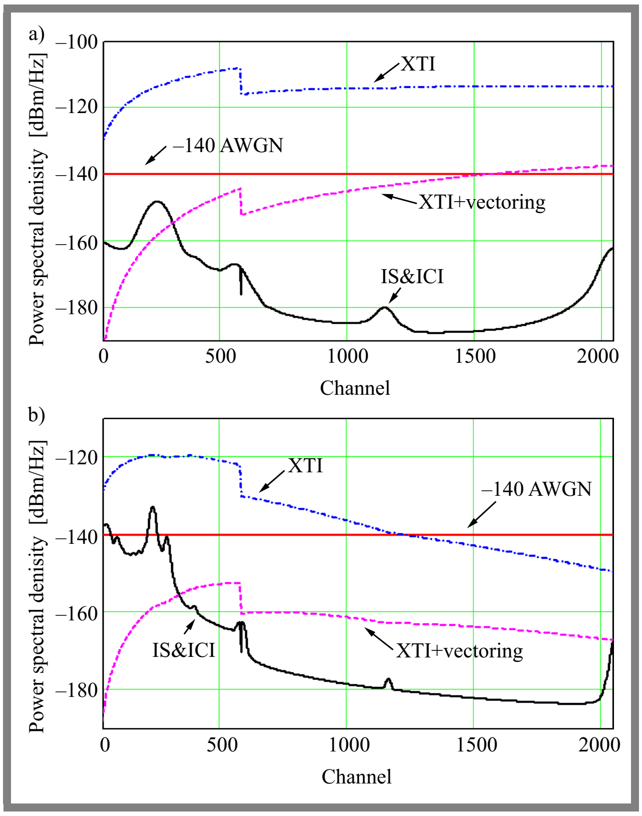

Fig. 2. PSD level of the G.fast system for: a) 50 m and b) 200 m TPP-10×2×0.4 line.

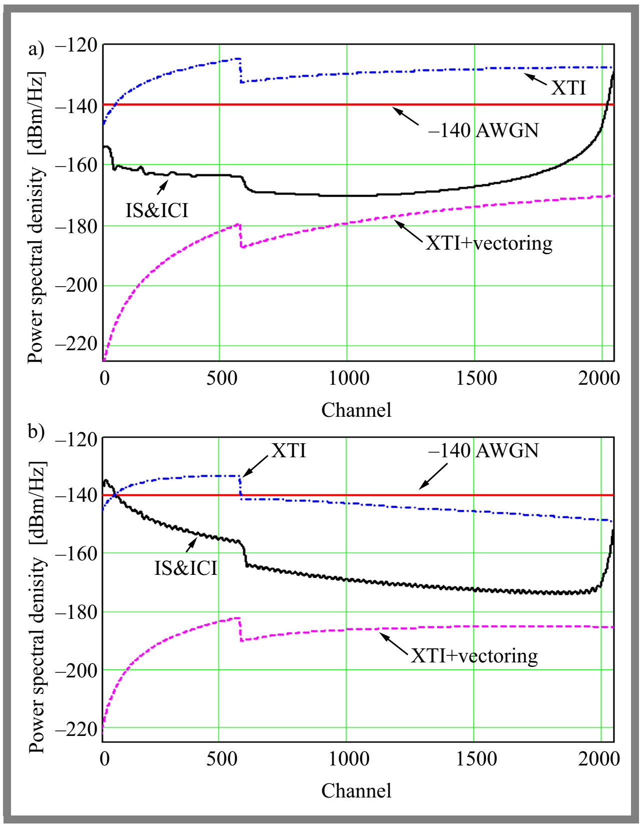

Fig. 3. PSD level of the G.fast system for: a) 50 m and b) 200 m UTP Cat. 5e line.

crosstalk is presented when the vectoring technique is applied (XTI + vectoring).

All interference power levels are compared to –140 AWGN, since under ideal TS conditions all types of interference are absent, with the exception of thermal noise, whose PSD level is –140 dBm/Hz. The presence of other interference sources increases the total interference power, and the contribution of each type of interference to the total outcome is determined by the ratio of its relative power.

The results presented in Figs. 2 and 3 allow us to conclude that cross-talk interference is the dominant type of interference, especially in the case of short lines. For a 50 m TPP cable, the PSD level of crosstalk interference exceeds thermal noise across almost all channels by approximately 25 dBm/Hz, while the IS+ICI level is significantly lower than that of –140 AWGN. The use of a crosstalk cancellation solution, such as the vectoring system, allows to reduce crosstalk levels to the –140 AWGN baseline.

For the 200-m line, a decrease in crosstalk interference is observed. However, for most G.fast channels, crosstalk still remains the dominant component, but the vectoring system lowers the crosstalk level below the –140 AWGN threshold. An increase in line length leads to greater linear distortion which, in turn, causes IS+ICI interference to rise on the lower channels over the –140 AWGN level.

For the UTP Cat. 5e cable, the qualitative conclusions remain the same. However, the quantitative assessments differ from those made for TPP, due to the distinct frequency characteristics of these cables (see Tab. 1). Lower intrinsic attenuation and higher crosstalk attenuation in the UTP Cat. 5e cable result in a lower impact of crosstalk interference (approx. 15 dB) and a higher effectiveness of the vectoring system (approx. 25 dB).

7. Analysis of G.fast Transmission Rate

In the next step, the achievable G.fast transmission rates over TPP-10×2×0.4 and UTP Cat. 5e 4×2×0.51 cables were evaluated under ideal conditions, i.e., in the absence of any interference other than thermal noise. This corresponds to the operation of a single TS (without crosstalk) over a line that is free from any linear distortions, i.e., without IS+ICI interference. The results of the transmission rate for line lengths ranging from 50 to 250 m are shown in Fig. 4.

G.fast operating on the UTP Cat. 5e cable shows a performance advantage in terms of the transmission rate. This is explained by the lower intrinsic attenuation of the UTP Cat. 5e cable. The result was expected, with the quantitative difference in transmission rates being the only unknown. In absolute values, the advantage of UTP Cat. 5e over TPP ranges from 14 to 250 Mbps, depending on the length of the line. In percentage terms, the advantage ranges from 1.2% for a 50-meter line to 73% for a 250-meter line.

Table 2 summarizes the results of the G.fast transmission rate calculations for operation over both cables. The transmission rate under ideal conditions, considering only thermal noise,

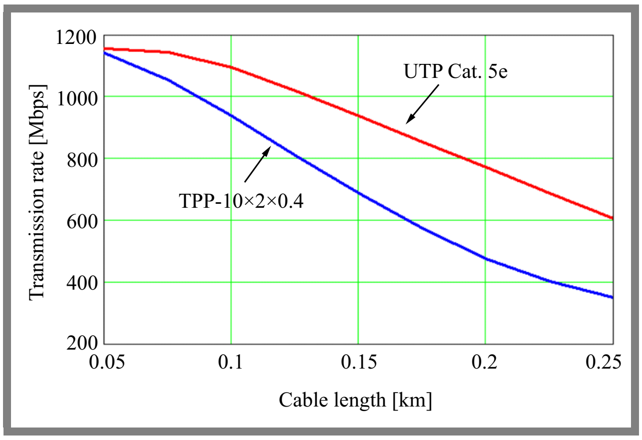

Fig. 4. G.fast system transmission rate over TPP-10×2×0.4 and twisted-pair UTP Cat. 5e cables in the absence of interference.

–140 AWGN is denoted by R_0. The remaining parameters are as follows:

- R_{IS+ICI} – transmission rate considering –140 AWGN together with linear distortions leading to IS+ICI interference,
- $R_{IS+ICI+XTI}$ – transmission rate considering –140 AWGN, IS+ICI interference, and XTI from four G.fast systems operating in parallel over the cable,
- $R_{IS+ICI+vec}$ – transmission rate considering –140 AWGN, IS+ICI interference, and residual (uncompensated) crosstalk interference after applying the vectoring system.

The R_{IS+ICI} and $R_{IS+ICI+XTI}$ transmission rates are intermediate results that enable to evaluate the impact that IS+ICI and XTI interference exert on the performance of G.fast TS.

As expected, IS+ICI interference has a negligible effect on the G.fast transmission rate. For both cables, the decrease in transmission rate for R_{IS+ICI}, compared to R_0, does not exceed 2%.

The TPP-10×2×0.4 cable contains 10 pairs of wires, allowing up to ten G.fast systems to operate simultaneously. In contrast, the UTP Cat. 5e 4×2×0.51 cable contains 4 pairs, thus supporting up to four G.fast systems. To ensure equal comparison conditions in terms of XT interference influence, the transmission rate was evaluated, in both cases, assuming the operation of four systems.

Crosstalk interference has a significant impact on the G.fast transmission rate represented by $R_{IS+ICI+XTI}$. For the TPP cable, the reduction in $R_{IS+ICI+XT}$ relative to R_0 ranges from 37% to 55%, depending on the length of the line. For the UTP Cat. 5e cable, the reduction is less significant due to better mutual coupling characteristics (A_N and A_{ELF}), ranging from 5% to 13% depending on the length of the line.

In the case of $R_{IS+ICI+XT}$ transmission rates, as line length increases from 50 to 250 m, the transmission rate for the G.fast system over the TPP cable decreases from 505 to 218.5 Mbit/s, while in the case of the UTP cable, it decreases from 1010 to 578.8 Mbit/s. Therefore, the G.fast system operating over the UTP cable achieves transmission rates that are 2 to 2.6 times higher than those obtained over the TPP cable.

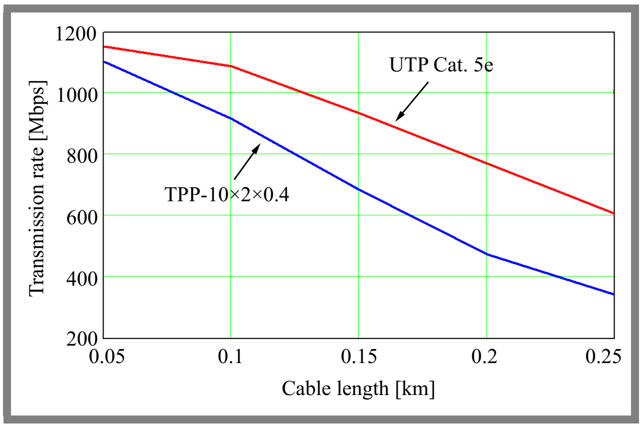

Fig. 5. G.fast system transmission rate over TPP and UTP cables, considering inter-symbol and inter-channel interference, with crosstalk interference compensation using the vectoring system (4 systems operating over a single cable).

Such a significant limitation of the transmission rate due to crosstalk has necessitated the use of a crosstalk mitigation solution, known as the vectoring system.

The last column in Tab. 2 presents the calculated transmission rates with vectoring applied to compensate for crosstalk interference. The comparison of G.fast transmission rates for the two cable types is also shown in Fig. 5. These results account for the effects of IS+ICI and the residual XT interferences after vectoring and represent the final performance assessment of G.fast over TPP-10×2×0.4 and UTP Cat. 5e 4×2×0.51 cables.

From Tab. 2, one may conclude that the vectoring system is an effective technique for suppressing crosstalk. Compared to ideal conditions R_0, IS+ICI interference and uncompensated XT interference have a negligible impact on the performance of the G.fast system. When operating over the TPP cable, the transmission rate loss in the $R_{IS+ICI+vec}$ case ranges from 1.2 to 38 Mbit/s, which does not exceed 3.3% of the R_0 rate. For the UTP cable, the results are even more impressive. The loss of transmission rate in the $R_{IS+ICI+vec}$ case ranges from 1 to 3 Mbit/s, which does not exceed 0.4% of the R_0 rate.

Next, the transmission rates with the application of the vectoring technique between the TPP and the UTP Cat. 5e cables are compared.

As line length increases from 50 to 250 m, the G.fast system data rate over the TPP cable decreases from 1103 to 342.6 Mbit/s, while in the case of the UTP cable, it decreases from 1152 to 604.3 Mbit/s. Thus, when operating over the UTP cable, the G.fast system achieves data rates 5% to 43% higher than those obtained when operating over the TPP cable. Therefore, due to its superior characteristics, the UTP Cat. The 5e cable allows to achieve for more efficient performance of the G.fast system under all equal conditions.

Tab. 2. G.fast transmission rates for both cables [Mbps].

Length [m]	R_0	R_{IS+ICI}	$R_{IS+ICI+XTI}$	$R_{IS+ICI+vec}$
TPP-10×2×0.4				
50	1141	1141	505.056	1103
100	935.808	935.76	417.552	917.424
150	686.832	686.822	354.288	683.52
200	473.712	473.616	278.208	472.56
250	349.728	343.008	218.592	342.672
UTP Cat. 5e 4×2×0.51				
50	1155	1152	1010	1152
100	1093	1089	925.632	1089
150	937.056	935.472	842.544	935.472
200	770.016	769.632	725.472	769.632
250	605.136	604.464	578.832	604.304

8. Conclusions

Effectiveness of the G.fast technology significantly depends on the type of cable used in the network. The UTP Cat. 5e 4×2×0.51 cable provides a higher data transmission rate for G.fast systems compared to the TPP-10×2×0.4 telephone multipair cable, due to its lower attenuation and better immunity to crosstalk interference. The speed advantage is minor over short distances of 50 – 100 m, but increases with line length, reaching up to 73% at 250 m.

When more than one G.fast TS operates over a multipair cable, crosstalk interference becomes the dominant factor affecting the transmission rate. In the case of four parallel G.fast systems, the data rate loss may reach up to 55% on the TPP cable and up to 13% on the UTP cable. In such cases, the application of cross-talk interference compensation systems, such as vectoring, is mandatory. Under certain conditions, vectoring is capable of restoring nearly the full transmission rate that was achievable in the absence of crosstalk interference, especially when using UTP Cat. 5e cables.

IS+ICI interference has an insignificant impact on the transmission rate. The reduction does not exceed 2%, which means these types of interference are not a critical factor for deploying the G.fast technology in Ukraine's broadband access networks.

Based on the obtained estimates of achievable G.fast transmission rates, the following recommendations can be made:

- it is advisable to deploy G.fast on BB networks without upgrading the existing in-building cable infrastructure (preserving the TPP cable) if potential users are satisfied with a transmission rate of up to 900 Mbps at a distance of up to 100 m and up to 300 Mbps at a distance of up to 250 m,
- if potential users require higher access rates, it is necessary to upgrade the in-building cable infrastructure using UTP Cat. 5e cables. In this case, users will be able to achieve data rates of up to 1 000 Mbps at distances of up to 100 m and up to 600 Mbps at distances of up to 250 m.

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Vitaliy Balashov, Professor
Department of Electronic Communications Systems
https://orcid.org/0000-0001-6122-4647
E-mail: vitaliybalashov8@gmail.com
State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine
https://en.suitt.edu.ua

Vasyl Oreshkov, Ph.D.
Department of Electronic Communications Systems
https://orcid.org/0000-0001-9796-0216
E-mail: Oreshkov_VI@ukr.net
State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine
https://en.suitt.edu.ua

Iryna Barba, Ph.D.
Department of Electronic Communications Systems
https://orcid.org/0000-0002-6751-0086
E-mail: irinabarba82@gmail.com
State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine
https://en.suitt.edu.ua

Dmytro Stelya, M.Sc.
Department of Electronic Communications Systems
https://orcid.org/0009-0007-7330-6261
E-mail: dmutro-gepard@ukr.net
State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine
https://en.suitt.edu.ua

Ihor Makarov, M.Sc.
Department of Electronic Communications Systems
https://orcid.org/0000-0002-4351-5122
E-mail: mackg9009@gmail.com
State University of Intelligent Technologies and Telecommunications, Odessa, Ukraine
https://en.suitt.edu.ua