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5G mobile data transmission and fiber optic: complementarity or substitutability?

Mobilna transmisja danych 5G a światłowód: komplementarność czy substytucyjność?

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Abstract:

Research objectives and hypothesis/research questions

The aim of the study was to answer the question: do the data transfer parameters using mobile networks and fiber optics support the hypothesis of substitutability between the two media? If both techniques produced comparable results, the development of fiber optic networks would be unjustified, as the network providing mobile internet access covers 98% of Poland's territory.

Research methods

Comparison – in 2024, 5,400,000 tests of fixed-line internet parameters and 615,000 tests of mobile internet delivered over 5G technology were conducted, initiated by speedtest.pl users. Each test is unique, as it examines network parameters at the time of testing. Each has unique parameters: download time, upload time, and ping.

Main results

The number of fiber-optic network users increased by approximately 27% between 2019 and 2023, demonstrating the demand for stable, fixed-line internet delivered via fiber. During this same period, we observed an average 11% decline in the number of copper network (xDSL) users, while the number of Docsis users (a medium used for cable TV) remained stable. Both technologies will remain complementary in the long term, because while mobile data transfer speeds result from their technical parameters and do not exceed 300 Mb/s, FTTx networks are limited to 8 Gb/s, and the most popular packages, such as 300 Mb/s, are offered for marketing purposes. There is no justification for offering faster transfer rates to mass consumers.

Implications for theory and practice

The most important are the practical implications described in the article: optical fibers offer much more stable data transmission, especially for business users, in areas with lower population density, where it is possible to receive data provided by mobile operators, the FWA (fixed wireless access) technique may be an alternative to optical fibers.

Keywords: regulation, fiber, telecommunications, 5G, FTTx

Abstrakt:***Cel badań i hipotezy/pytania badawcze***

Celem badania była odpowiedź na pytanie: czy parametry transferu danych za pomocą sieci mobilnych i światłowodów sprawiają, że postawiona została hipoteza o substytucyjności obydwu mediów? W przypadku gdyby obydwie techniki dawały porównywalne wyniki, rozwój sieci światłowodowych byłby nieuzasadniony ze względów ekonomicznych, gdyż sieć zapewniająca dostęp do internetu mobilnego pokrywa 98% terytorium Polski i zapewnia porównywalną prędkość pobierania danych.

Metody badawcze

Porównanie – w roku 2024 przeprowadzono 5400 tysięcy testów parametrów internetu stacjonarnego oraz 615 tysięcy testów internetu mobilnego dostarczanego w technice 5G zainicjowanych przez użytkowników portalu speedtest.pl. Każdy z testów jest unikalny, gdyż dotyczy sprawdzenia parametrów sieci w momencie testowania. Każdy z nich ma unikalne parametry: czas pobierania, czas wysyłania oraz ping.

Główne wyniki

Liczba użytkowników sieci światłowodowych wzrosła o ok. 27% w latach 2019-2023, co pokazuje, że jest zapotrzebowanie na stabilny internet stacjonarny dostarczany za pomocą światłowodów. W tym samym czasie obserwujemy spadek liczby użytkowników sieci miedzianych (xDSL) średnio o 11% oraz utrzymywanie się liczby użytkowników korzystających z Docsis (medium używane w telewizjach kablowych). Obydwie techniki w długim okresie pozostaną komplementarne, gdyż o ile prędkość transferu danych mobilnych wynika z ich parametrów technicznych i nie przekracza 300 Mb/s, dla sieci FTTx ograniczeniem jest 8 GB/s, a najpopularniejsze pakiety typu 300 Mb/s są oferowane ze względów marketingowych, nie ma uzasadnienia oferowania klientom masowym szybszego transferu.

Implikacje dla teorii i praktyki

Najważniejsze są implikacje praktyczne opisane w artykule: światłowody oferują znacznie stabilniejszą transmisję danych, zwłaszcza dla odbiorców biznesowych, na terenach o niższej gęstości zaludnienia, na których jest możliwość odbioru danych dostarczanych przez operatorów mobilnych, technika FWA (*fixed wireless access*) może być alternatywą do światłowodów.

Słowa kluczowe: regulacja, światłowod, telekomunikacja, 5G, FTTx

Introduction

Between 2019 and 2024, Poland witnessed two key transformation and modernization processes in its telecommunications infrastructure: (1) increasing the reach of modern fibre-optic networks (hereinafter referred to as FTTx or FTTH), providing high-speed fixed-line internet access, and (2) providing mobile internet operators with access to mobile data transmission in the 3,400-4,800 MHz band, known as the C-band in 5G technology. These phenomena apply not only to the Polish market but also to most European countries where 5G mobile data transmission has been implemented.

Practitioners, representatives of institutions involved in the digitalization of the state, and academics alike are asking about the substitution of wired and wireless data transmission, i.e., the substitution of mobile internet and fiber-optic internet. The answer to this question may contribute to a more effective allocation of public funds that are used to finance the construction of internet infrastructure. In the past, such a program was the Digital Poland Operational Program (POPC 2014-2020), currently such programs are: the National Recovery Plan (KPO 2021-2026) and the Operational Funds for Digital Development (FERC 2021-2027).

Moreover, this issue is crucial for selecting the address points to which fibre optic internet will be delivered. If both transmission techniques are fully substitutable, additional investments in fibre-optic lines, especially in sparsely populated areas, may prove economically unjustified, especially if such investments are subsidized by EU funds or other forms of government intervention. Instead of fibre optic internet access, operators could provide fixed wireless internet access (FWA) using SIM cards capable of receiving 5G signals. FWA is a wireless connection that provides broadband internet access at a specific location via a modem equipped with a SIM card. It allows users to connect to the network and access high-speed internet via a radio signal, without the need to install fiber optic lines.

1. Purpose of the study

In this article, we will answer the question of whether these technologies are complementary or substitutable, presenting research and measurement results for the Polish market. Both mobile data transmission and FTTx are becoming common services in Poland. Fibre optic technology is becoming a substitute for other fixed-line data transmission techniques. The authors' goal was to demonstrate the differences in data transfer speeds using mobile (5G) and fiber-optic (FTTx) data transmission. The scientific literature lacks studies comparing data transfer between the two techniques due to limited access to source data. Therefore, this article presents a research gap in comparative studies of both data transmission techniques. The research results described in this article can form the basis for decisions regarding support for investments in fiber-optic networks in rural areas, where fibre optic data transmission can be replaced by FWA.

The article demonstrates that in everyday use, FWA technology, i.e., fixed-line internet access based on a modem equipped with a SIM card, can be a viable alternative to FTTx. However, the comparison focuses on data transfer speeds, not the economic effectiveness of the investment. The research results, including filling the research gap in this area, are also important for the Office of Electronic Communications, which is responsible for shaping the telecommunications market to ensure the highest possible quality of internet use for end users.

2. Literature review

The literature describing the use of data transmission can be divided into two main groups of publications. The first concerns changes in the telecommunications market, the privatization of operators in Spain (Bel, Trillas, 2005), Italy, including Poland (Zygadlewicz, 2017), and the evolution of the role of the incumbent operator, also known as the national operator, or "incumbent".

2.1. Regulatory issues

The second part of the publication addresses the changing relationship between the state and the privatized national operator, as well as regulatory issues, both in the context of monopoly, oligopoly, and monopolistic competition (Stigler, 1964), and the state's influence on telecommunications companies, especially those with significant market power, as discussed by R. Śliwa (2015) and H. Bronk (2009). Renata Śliwa focuses on the following concepts that constitute incentive-based regulation in the telecommunications sector: performance-based regulation, price caps, incentive-based regulation, and credibility in the performance-based regulation process. The author discusses the need for stable regulation within the parameters of a telecommunications operator's operations and the regulator's influence on these parameters. While Śliwa writes about parameters, Bronk discusses regulatory paradoxes.

In 2009, H. Bronk wrote about the regulatory paradox in economic policy. He stated that "The regulatory paradox demonstrates that there is no stable regulatory situation in economic practice. This finding is explained by the constant fluctuations in economic policy between regulation and liberalization. Discussions about regulation in a market economic system reveal a phase of deregulation, and especially liberalization. This means seeking solutions through regulation that will improve ultimate market outcomes. This goal is achievable; however, the degree to which regulation is necessary must first be recognized". It is the responsibility of science to demonstrate this paradox in economic practice, and economic policy should prevent this deregulatory paradox from occurring in economic practice.

Counteracting monopolistic practices, ensuring wholesale network access, and consequently, sectoral regulation, and methods for setting and achieving targets for regulated operators are important elements of discussion not only in academia but also among practitioners involved in regulatory impact assessment (Kostecka-Jurczyk, 2015) and social sciences (Kamiński, 2010). Discussions on regulation, including those related to network sectors, have been ongoing in the literature since the 1970s. This discussion highlights the directions of regulatory development and the impact of regulation and the regulator on the economy.

Network sectors constitute a specific form of natural monopoly. Wholesale network access (railway, energy, telecommunications) should be provided to other businesses by the network owner, and regulations should define the means by which this access is ensured. In infrastructure sectors, ensuring network access and the ability to provide services based on the shared networks becomes more important than the prices of wholesale services, because without access, a market cannot be created. Providing network access allows multiple businesses to provide services to end customers, creating a competitive market based on the existing infrastructure.

Only the emergence of a competitive market allows for price competition between entities providing services to end customers (retail – both households and businesses) based on this network. Filling the information gap in internet quality assessment by comparing download, upload, and ping parameters can influence government policy, as exemplified by the Republic of Poland, regarding financial support for the construction of telecommunications networks.

The issue of regulation and changes in the way it influences and the search for best practices by operators (Orange Polska SA, 2025), state administration bodies (Ministry of Digital Affairs, 2017), and independent market regulators operating in mature markets such as France (Arcep, 2025) or in Poland, which can still be perceived as an emerging market (Office of Electronic Communications, 2024) demonstrates the importance of broad availability of telecommunications networks and preventing operators from exploiting monopolistic positions in national markets – the internal markets of individual countries – not only for the academic community but also, and above all, for practitioners. This data demonstrates the directions and pace of FTTx network development in individual countries, as the degree of mobile internet coverage is comparable in each.

Research on network development in national markets is collected by telecommunications operators associated with the FTTH Council and published annually by this organization as a conference publication following the FTTH Conference (FTTH Council, 2025). The term FTTH refers to providing access to data transmission delivered to the end customer, understood as a household, via fiber optic networks. This term refers to the transmission standard, as operators can use various techniques to ensure data transmission to retail customers' receiving devices (Nowak, Murphy, 2005). Renowned device manufacturers, such as Ericsson AB, have their own research and development centres and use the results of their research to create commercially available solutions for mobile communications operators (Ericsson AB, 2025).

Technological advancements also make it possible to substitute data transmission methods for the customer, understood as a household. Customers can choose between wired and wireless data transmission. According to data from the Office of Electronic Communications (2024), wireless data transmission is available across 98% of Poland, providing a standard that allows access to all services available via the internet. Under the C-band reservation, each mobile internet operator is obligated to cover 99% of the country, where 99% of households are located, within 60 months with a network that offers a throughput of 95 Mb/s and a latency (ping) of no more than 10 Ms. A mobile network with these parameters offers significantly lower speeds than a fiber-optic network. It cannot be a substitute; it can be complementary to a fiber-optic network.

2.2. Technical issues

According to the literature, data transmission via terrestrial lines, based on fiber optic technology, is considered the primary means of data transmission for building an information society (Dramski, Gutowski, 2010). Data transmission via terrestrial lines provides stability and speed that can contribute to the development of a modern economy based on information processing. Mobile data transmission via cellular networks is developing in parallel to terrestrial networks. In this case, a significant portion of the publication summarizes research related to the development of technology (Batalla, Sujecki, Oko et al., 2022), ensuring network optimization for data transmission and synergy between the development of fixed (terrestrial) and mobile networks (Mohammadreza, Mansour, Arash, 2021). This technology enables interoperability between fixed and mobile networks to ensure the stability and speed of data transmission by the latter (Roslyakov, 2022).

Network coexistence and interoperability are becoming an increasingly important element of integrated data transmission systems (Takai, Yamauchi, 2009), ensuring interference-free data transmission regardless of the medium used by the end user, including FWA (fixed wireless access), which involves providing a radio signal to users by a fibre optic network operator (Alimi, 2025).

The development of fibre optic networks is primarily discussed in sources related to technology. There are few sources describing capital expenditures (CAPEX) and maintenance costs of fiber optic networks. Sources describe investments in the British market (Jana, Srivastava, Lord et al., 2023) and Greek markets (Skoufis, Chatzihanasis, Dede et al., 2022). The Polish market is described in terms of investments in fiber optic projects co-financed through investment support programs by the Polish government or EU funds (Żurek, 2024).

2.3 Research gap

A literature review indicates a gap in the research area regarding the comparison of data transfer speeds achieved by users. The goal of terrestrial network modernization (xDSL, Docsis, FTTx) is to provide end users with the highest possible data transfer quality, and consequently, ensure the highest possible internet experience.

Therefore, a research gap appears, which can be filled by research and statistics presented by commercial entities. One such entity is V-Speed, the operator of the speedtest.pl service, which obtained certification for providing internet quality measurement services from the Office of Electronic Communications (UKE), the telecommunications market regulator, in 2019 (Office of Electronic Communications, 2019). An alternative is collaboration in research between commercial entities and the scientific community (Office of Electronic Communications, 2025).

Alternatively, qualitative research on data transfer can be conducted by scientific institutions and then commercialized. Filling the research gap will allow us to gain knowledge on the comparison of data transmission quality via alternative media such as mobile internet and fibre optic networks.

3. Materials and methods

3.1. Data sources

The primary data source is consumer tests conducted via the website www.speedtest.pl (V-SPEED Sp. z o.o., 2025) in 2024. These tests cover download and upload speeds, as well as the latency (ping) of sending and receiving data in telecommunications networks. The data used in this article was downloaded from the speedtest.pl website, from the tab: <https://www.speedtest.pl/ranking>; all data used is publicly available. Next, the data for fiber optic and mobile data transmission technologies was compared and conclusions were drawn.

Description of how to perform tests on the speedtest.pl website. Each test was conducted by the network user on their own initiative. Test results were shared with the tester and also stored on the servers of the owner of the speedtest.pl website (V-SPEED Sp. z o.o., 2025).

V-SPEED has been certified by the Office of Electronic Communications (UKE) as a provider of internet access quality monitoring for 2020-2022, meaning that the PRO Speed Test platform was previously used for monitoring purposes by the Office of Electronic Communications (UKE), a regulatory authority whose goal is to provide citizens with access to modern telecommunications and postal services in a developing market and dynamic international environment. Therefore, network parameter tests will be published periodically, and their results may influence government policy regarding support for the construction of telecommunications networks.

3.2. Justification of the research method

The basic elements justifying the choice of research method were: (1) the number of tests and their distribution over 12 months of 2024, (2) independence of the tests – the tests were initiated by network users, and the time and location of the device used to perform the data transmission tests were random. Internet speed tests were independent of the data transfer service provider, which was not informed of the test or its results. Some consumers initiating the tests may not have been aware of their data transmission service access. The goal was to estimate data transfer speeds. The lack of temporal concentration of the tests, performed throughout the year, results in higher representativeness of the research results.

3.3. Limitations of the research method

The research method described above has several limitations: tests can be repeated multiple times by a single user, potentially yielding different download, upload, and ping speeds each time. Speed changes may result from changes in physical parameters at the time of testing. The lack of standardization and the diversity of devices and software installed on them (operating system, web browser) among consumers may result in variability in network parameter readings.

Another methodological limitation is the lack of consistent testing times throughout the day, month, and year. The research method also limits the use of data provided by V-SPEED Sp. z o.o. and the manner in which it is presented.

There is no information available about “portal cleaning”, this means that the single user may make numerous tests, however lack of the portal cleaning procedure does not affect the test results or their representativeness. The similar tests may also be made on the international speed test portal – www.fireprobe.net, international data may be also researched at another global site <https://www.speedtest.net/global-index> (V-SPEED Sp. z o.o., 2025). The results presented in this source describe the speed test for global locations

4. Results

The most important parameter for end users is the download speed, which provides access to content and multimedia. Data describing average download and upload speeds are presented in Mb/s in both Table 1 and Table 2.

Table 1 shows the distribution of data for tests initiated by landline internet users via the speedtest.pl portal, broken down by calendar month in 2024. The “download” column shows the average download speed of data from the network to the receiving device in megabytes per second, while the “upload” column describes the speed of sending information from the user’s device to network servers. The difference in download and upload speeds results from (1) differences in device power and (2) network settings by providers, who prioritize downloads to ensure better file quality for users. Some technologies, such as xDSL, naturally have asymmetric connections, resulting in higher download speeds. xDSL technology is based on copper networks and is described in Table 6. Prioritization means that network parameters have been automatically set so that data is transmitted first (download) and then sent (upload).

Table 1. Presentation of average parameters of fixed-line internet delivered via optical fiber to end users

Month	Download	Upload	Ping	Number of tests (thousands)
January 24	264.13	143.40	10.50	490
February 24	267.45	145.10	10.25	471
March 24	265.45	141.65	10.50	458
April 24	259.08	137.93	11.00	418
May 24	262.75	139.83	11.00	397
June 24	261.43	138.53	10.25	377
July 24	262.73	142.95	11.00	429
August 24	263.65	142.48	10.50	438
September 24	271.20	144.30	10.25	422
October 24	277.88	142.33	10.25	472
November 24	278.78	140.65	10.25	490
December 24	278.93	138.23	10.75	538

Source: own study based on: V-SPEED Sp. z o.o., 2025

Ping is a command used to diagnose network connections. During the “ping” procedure, a data packet is sent from the user’s computer to another device, and then a response is received from the device receiving the data. Based on the feedback sent by the device receiving the data, diagnostics and measurement of network connection parameters are performed. The most important information obtained after entering the ping command in the command line is the data transmission delay. A low ping is defined as a delay of no more than 30 ms. At this level of delay, there will be no negative effects related to the delay in packet transmission between the computer and the server. Values around 60-70 ms can be considered high, and certainly if the delay exceeds 100 ms.

Ping measurements for both techniques are described in Table 1 and Table 2. These results do not exceed 30 milliseconds, meaning the data transmission delay is imperceptible to the user. In both cases, this is considered a low ping. The difference in latency between fiber-optic and mobile networks may seem significant, but in practice, it is imperceptible.

Table 2. Presentation of average parameters of mobile data transmission delivered in 5G technology and received on mobile devices

Month	Download	Upload	Ping	Number of tests (thousands)
January 24	122.93	27.00	26.05	41
February 24	171.58	28.90	25.25	40
March 24	188.50	29.15	24.75	48
April 24	186.93	28.15	24.25	48
May 24	179.05	27.43	23.75	49
June 24	175.48	26.18	24.00	48
July 24	178.50	26.13	24.50	52
August 24	179.50	20.95	24.50	55
September 24	197.63	26.70	24.00	54
October 24	211.60	27.30	23.25	58
November 24	212.95	27.53	24.75	59
December 24	218.38	27.33	23.25	63

Source: own study based on: V-SPEED Sp. z o.o., 2025

Table 2 shows the changes in average 5G data transfer speeds across all four mobile internet operators in Poland. From January to December 2024, data transfer speeds using 5G devices increased from 122.93 Mb/s to 218.38 Mb/s, with these values being averaged. Based on this data, transfer speeds increased by 77% over the 12-month period. Some measurements taken in the fourth quarter of 2024 show data transfer speeds on the Orange Polska and T-Mobile Polska networks of 271.9 Mb/s and 292.6 Mb/s, respectively. At the end of 2023, virtually the entire country (99%) was covered by mobile internet with a maximum speed of at least 100 Mb/s, ensuring sufficient download speeds.

These parameters are comparable to those obtained during measurements for data downloads via fiber optics. A significant increase in average download speeds between January and February is noteworthy. This is due to operators beginning to install C-band transmitters enabling data transfer based on radio licenses issued by the President of the Office of Electronic Communications. These investments stem from operators' obligations resulting from the allocation of a portion of the 3400-3800 MHz telecommunications band to them.

The comparability of results for both technologies stems from the fact that the most popular commercially available data transmission package via fiber optics is 300 Mb/s. This is not limited by the technical parameters of the fiber optic cable.

Therefore, this package offers users a very good ratio of data transfer speed to service price. According to data provided by the Office of Electronic Communications, internet access with a download speed of 300 Mb/s was available in 2,457 municipalities across Poland as of December 31, 2023.

The average download speed for 5G devices increased by 79% from 122.83 Mb/s to 218.38 Mb/s over the first 12 months of 2024, while download speeds via fiber optics remained stable. Mobile internet is moving towards standard download speeds via FTTx installations. Both technologies offered comparable download speeds in December 2024, with a 27.7% difference in download speeds. The average download speed via fiber optics was 27.7% higher than via mobile networks.

Table 3. The results of global speed tests

Global average speed test	Mobile	Broadband
Average download	90.69	104.43
Average upload	13.06	56.59
latency	25 ms	8 ms

Source: own study based on: V-SPEED Sp. z o.o., 2025

Table 3 Shows the global speed test results provided by speedtest.net (V-SPEED Sp. z o.o., 2025), the results shown in Table 3 are lower than in Poland, however this is the global average, which is technically agnostic. Many countries use a variety of data transfer techniques, both zero-band and mobile. Therefore, global results are worse than those measured in Poland.

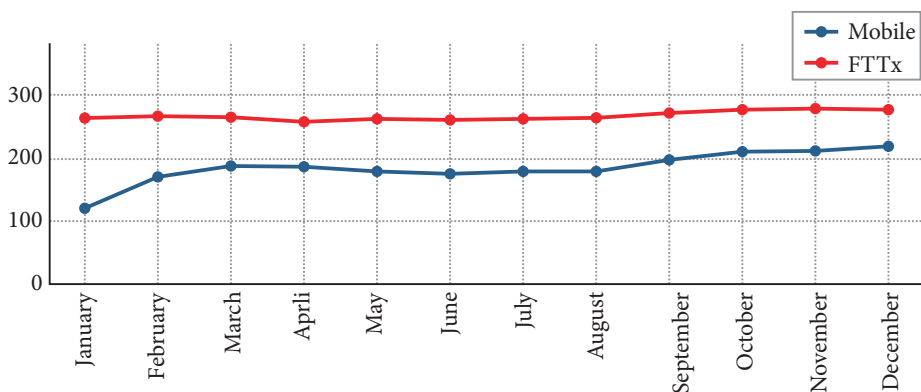


Fig. 1. Comparison of average data download speeds using 5G and FTTx technology, average monthly in 2024

Source: own study based on: V-SPEED Sp. z o.o., 2025

Figure 1 shows the average download speeds for fiber optics (blue line) and 5G mobile internet. Mobile devices are currently unable to achieve average download speeds using fiber optics. The difference in average download speeds is narrowing; in December 2024, this difference was 60 Mb/s, or 27.7% of the average download speed using fiber optics. According to the global speed tests performed in August 2025. The basic information about the broadband data transfer technology is in Table 6.

4.1. Fiber Optics and Other Wired Data Transmission Techniques

The popularity of fiber optics in Poland is growing. Data on the number of users of individual wired data transmission technologies is presented in Table 4. The increase in the number of fiber optic users and the very slight changes in the number of DOCSIS users show that users are interested in using a technology that allows download speeds of approximately 300 Mb/s with low latency. For the same reason, the number of fixed-line internet users using xDSL technology is decreasing, by an average of 11.70% annually from 2019 to 2023.

The rapid growth in the number of fiber optic internet users was made possible by the support of investments in their construction from funds available under the POPC Programme, which financed investments between 2014 and 2023 in 2,350 municipalities. In these municipalities, over 1.8 million addresses were covered, which translated into the availability of broadband internet to approximately 2.2 million households (Office of Electronic Communications, 2024).

Table 4. Number of landline internet users, broken down by technology

Technology	2019	2020	2021	2022	2023	CAGR
xDSL	1,819,183	1,708,708	1,490,735	1,286,531	1,106,111	-11.70%
DOCSIS	2,847,063	2,894,716	2,708,464	2,977,502	2,826,651	-0.18%
Ethernet	420,044	548,136	306,319	365,206	346,814	-4.68%
FTTx	1,654,766	2,273,298	2,858,478	3,529,448	4,314,367	27.07%
FWA	20,930	25,910	19,740	22,358	20,951	0.03%
Other	330,765	251,460	549,483	236,291	256,089	-6.20%
Suma	7,092,751	7,702,228	7,933,219	8,417,336	8,870,983	5.75%

Source: Office of Electronic Communications, 2024

The largest number of users in Poland use fiber-optic internet: as of December 31, 2023, 4,314,367, or 48.63% of landline internet users in Poland. During the period under review, the number of fiber-optic users increased from 1,654,766 to 4,314,367, representing an average annual growth of 27.07%. The overall number of internet users increased by 5.75% during the same period.

Changes in the structure of technologies used by end users stem from the expectation of constant internet access, enabling not only data searches but also the ability to watch high-definition videos. Mobile networks can be a substitute for FTTx technology, but they are not a complete alternative.

The results of data transmission speed studies using alternative technologies (FTTx, 5G) may lead to the introduction of regulations requiring fiber optic network operators to release data transfer speed restrictions and abandon market segmentation for marketing reasons. Data transmission and download speed studies are qualitative studies of data transmission.

Table 5. Percentage of landline internet users, broken down by technology

Technology	2019	2020	2021	2022	2023
xDSL	25.65%	22.18%	18.79%	15.28%	12.47%
DOCSIS	40.14%	37.58%	34.14%	35.37%	31.86%
Ethernet	5.92%	7.12%	3.86%	4.34%	3.91%
FTTx	23.33%	29.51%	36.03%	41.93%	48.63%
FWA	0.30%	0.34%	0.25%	0.27%	0.24%
Other	4.66%	3.26%	6.93%	2.81%	2.89%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

Source: Office of Electronic Communications, 2024

The percentage of fixed-line internet users delivered via fiber optics increased from 23.33% in 2019 to 48.63% in 2024. The compound annual growth rate (CAGR) was 27.07%. During the same period, the percentage of users using DOCSIS decreased from 40.14% to 31.86%, and xDSL decreased from 25.65% to 12.47%. This comparison demonstrates the substitution of wired data transmission technologies and the displacement of DOCSIS and xDSL by fiber optics.

4.2. Technology development

Data transfer speed and latency are key parameters for users. Therefore, we can observe the substitution of xDSL connections with fiber optic and DOCSIS connections.

The basic differences between these internet connections are shown in Table 6. It shows the maximum data transfer speed for each technology, with the fiber optic network having the highest parameters, enabling data transfer speeds of up to 8 gigabits per second. This speed is unattainable for both DOCSIS and xDSL technologies. Due to the coexistence of three wired data transmission technologies, the transmission speed in fiber optic technology is artificially limited; the offered

parameters are sufficient for consumers. The list of the 20 most popular internet services in Poland includes YouTube.com (ranked 2nd) and TikTok.com (ranked 12th) (Sochacki, 2024). Access to audiovisual content is a key element of both services. The download speeds in both technologies allow for the reception of video content at comparable speeds. An increase in data download speeds in mobile networks may result in an increase in transfer speeds in FTTx networks or the elimination of such limitations.

Table 6. Comparison of parameters of data transmission techniques in the wired Internet

Technology	FTTx	DOCSIS	xDSL
Data transmission method	Fiber to the “x”: A connection using fiber optics. “x” refers to the method of connecting the customer, i.e., the last mile. In the case of FTTx, the fiber optic cable is connected directly to the end user’s premises. FTTB refers to fiber optic cable routed to the building. FTTC refers to the fiber optic cable routed to the immediate surroundings of the building.	Data Over Cable Service Interface Specification. A technique for transmitting large amounts of data via a television cable used with a cable connection. This is often the data transmission standard currently enabling data transfer in HFC networks (a broadband, bidirectional shared media transmission system). Optical fibers are used between the headend and the nodes, while coaxial cables (usually made of copper) are responsible for delivering the signal from the node to the client. This means hybrid cables combining optical fibers and coaxial cables are used. Current variants allow for real data transfer speeds exceeding 1 Gbps, comparable to FTTx.	Using copper cables. Originating in 1980, the xDSL standard is actually a collective name for a group of standards. These include: ADSL (Asymmetric Digital Subscriber Line) is the most popular version of xDSL. It involves dividing the data stream unevenly, asymmetrically. This results in significantly higher transmission speeds from the provider to the end user (downstream) than from the customer to the provider (upstream).
Data transfer speed	Up to 8 Gb/s, the most popular commercial package is 300 MB/s	Up to 1 GB/s	Typical speeds for ADSL are 1.5-9 Mb/s to the user and 64 KB/s-1.5 Mb/s from the user.

Source: Office of Electronic Communications, 2024

Discussion

The development of mobile data transmission technology and the future implementation of the sixth-generation data transmission standard may contribute to increased competitiveness between cellular and fiber optic data transmission. Increasing throughput and reducing latency in mobile data transmission may blur the distinction between the two types of data transmission.

Currently, the best solution for the development of data transmission in Poland appears to be the integration of mobile and FTTx networks, as this can optimize network construction investment, especially in less densely populated areas. Network synergy models and the use of a fiber optic network, which will provide a signal distributed via radio devices – FWA (Alimi, 2025). Research on the substitutability and complementarity of both techniques was carried out in Indonesia (Gunarta, Nurdianto, 2024) and shows that the FWA technique based on 5G networks can successfully replace fiber optic networks, especially in places where the construction of fiber optic networks is unprofitable, i.e. in areas with lower density and greater population dispersion, however, an appropriate data transfer speed must be ensured, especially the speed described as “download”.

Conclusions

Data transfer parameters over fibre optic networks mean that both consumers and operators prefer to use FTTX networks as their primary source of wired data transmission. Fibre optic is becoming a substitute for other wired data transmission techniques. The data transfer parameters offered via fibre optics ensure the ability to work and play audio visual files without interruption. Technically, fibre optics can transmit data at speeds of up to 8 Gbps, but current data transfer applications do not justify making such speeds available to consumers. Limiting data transfer speeds by operators is a result of their commercial policy, not technical limitations.

The increase in data transfer speeds in 2024 is due to the modernization of mobile communications networks and the introduction of services in the 3400-3800 MHz band. The maximum download speed for mobile devices is increasing, but due to technical limitations, it is lower than that of fibre optic networks. Due to current applications, these networks can be considered substitutes, but increasing data transfer speeds via fibre optic cables will make mobile networks complementary to fibre optic networks.

Improving the parameters offered by mobile networks may lead to an increase in the number and market share of FWA installations operating based on SIM cards. The percentage of FWA users is 0.24%. The development of mobile networks

may result in the substitution of internet access services, i.e., replacing xDSL and DOCSIS networks with FWA services. The transfer parameters offered by mobile networks are higher than those offered by both of these networks. In case of FWA the global market share of this data transfer technic amounts to 2.67% (Kaczmarek, 2025), while in Poland FWA amounted to 0.24%. This discrepancy in results may result in increased interest in the development of FWA in Poland as an alternative to fiber optic networks. FWA can actually become an additional substitute for FTTx in Poland. The development of FWA services may be possible thanks to the development of mobile data networks in the 5G standard. FWA could be a technique that connects fixed-line and mobile networks in terms of user perception, offering the convenience of using fixed-line internet with the parameters of mobile data transmission. FWA becomes important technology in USA especially in rural areas (GSMA Intelligence, 2025).

REFERENCES

- [1] ALIMI, S., 2025. *5G Fixed Wireless Access*, Cham: Springer Nature AG.
- [2] ARCEP, 2025. <https://en.arcep.fr/arcep/arcep-manifesto.html> (accessed: 22.08.2025).
- [3] BATALLA, J.M., SUJECKI, S., OKO, J., KELNER, J.M., 2022. *Cost-effective Measurements of 5G Radio Resources Allocation for Telecom Market Regulator's Monitoring*, New York: Association for Computing Machinery.
- [4] BEL, G., TRILLAS, F., 2005. Privatization, corporate control and regulatory reform in case of Telefonica, *Telecommunications Policy*, No. 29.
- [5] BRONK, H., 2009. Regulacja czy deregulacja w gospodarce narodowej, *Zeszyty Naukowe Akademii Morskiej w Szczecinie*, No. 16 (88).
- [6] DRAMSKI, M., GUTOWSKI, P., 2010. Technologia FTTH jako stymulator rozwoju społeczeństwa informacyjnego, *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Ekonomiczne Problemy Usług*, No. 57.
- [7] ERICSSON AB, 2025. *5G RAN explained*, <https://www.ericsson.com/en/ran> (accessed: 19.08.2025).
- [8] FTTH COUNCIL, 2025. *Fibre vs. 5G: The Convergence of Fibre and Wireless*, <https://www.ftth-council.eu/resources/blog/ftth-vs-5g-fibre-and-wireless-convergence> (accessed: 17.08.2025).
- [9] GSMA INTELLIGENCE, 2025. *The Mobile Economy 2025*, <https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-economy/> (accessed: 25.08.2025).
- [10] GUNARTA, I.K., NURDIANTO, N., 2024. Identifying QoS impacts on the 4G LTE and 5G FWA integration using 2300 to 2400 MHz band reallocation for high-speed internet alternative to traditional fiber, *Eastern Europea Journal of Enterprise Technologies*, Vol. 5, No. 9 (131).
- [11] JANA, R.K., SRIVASTAVA, A., LORD, A., MITRA, A., 2023. Optical cable deployment versus fiber leasing: an operator's perspective on CapEx savings for capacity upgrade in an elastic optical core network, *Journal of Optical Communications and Networking*, No. 15 (8).
- [12] KACZMAREK, S., 2025. 1. kwartał 2025: sprzęt szerokopasmowy w dół, WiFi 7 i FWA rosną, <https://www.telko.in/1-kwartal-2025-sprzet-szerokopasmowy-w-dol-wifi-7-i-fwa-rosna> (accessed: 17.08.2025).
- [13] KAMIŃSKI, F., 2010. Regulacja sektorowa Ex Ante a efekty pośrednie telekomunikacji, *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Ekonomiczne Problemy Usług*, No. 57.

-
- [14] KOSTECKA-JURCZYK, D., 2015. Regulacje sektorowe a prawo konkurencji na przykładzie telekomunikacji, *Internetowy Kwartalnik Antymonopolowy i Regulacyjny*, No. 4/6.
- [15] MINISTRY OF DIGITAL AFFAIRS, 2017. Komunikat Komisji Europejskiej – W kierunku europejskiego społeczeństwa gigabitowego, <https://www.gov.pl/web/cyfryzacja/komunikat-komisji-europejskiej-w-kierunku-europejskiego-spoleczenstwa-gigabitowego> (accessed: 17.08.2025).
- [16] MOHAMMADREZA, A., MANSOUR, N.J., ARASH, D., 2021. Techno-economic model of fibre-to-the-home as 5G fronthaul: evaluation of capital expenditures, *IET Communications*, No. 14 (2).
- [17] NOWAK, D., MURPHY, J., 2005. FTTH: the overview of existing technologies, *SPIE OPTO-Ireland*, June.
- [18] OFFICE OF ELECTRONIC COMMUNICATIONS, 2019. *Certyfikowany mechanizm monitorowania internetu*, <https://uke.gov.pl/akt/certyfikowany-mechanizm-monitorowania-internetu,217.html> (accessed: 17.08.2025).
- [19] OFFICE OF ELECTRONIC COMMUNICATIONS, 2024. *Raport o stanie rynku telekomunikacyjnego w 2023 roku*, <https://bip.uke.gov.pl/raporty/raport-o-stanie-rynk-u-telekomunikacyjnego-w-2023-roku,89.html> (accessed: 17.08.2025).
- [20] OFFICE OF ELECTRONIC COMMUNICATIONS, 2025. *SMJI: Podpisanie dokumentu rekomendującego przyznanie certyfikatu systemowi SamKnows*, <https://www.uke.gov.pl/akt/smji-podpisanie-dokumentu-rekomendujacego-przyznanie-certyfikatu-systemowi-samknows,587.html> (accessed: 17.08.2025).
- [21] ORANGE POLSKA SA, 2025. *KPI_website_pl_4Q2024_final*, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.orange-pl%2Fwp-content%2Fuploads%2F2025%2F04%2FKPI_website_pl_4Q2024_final.xlsx&wdOrigin=BROWSELINK (accessed: 15.08.2025).
- [22] ROSLYAKOV, A., 2022. *Fiber development index to implement the FTTE concept in F5G networks*, <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12295/1229503/Fiber-development-index-to-implement-the-FTTE-concept-in-F5G/10.1117/12.2627012.short> (accessed: 10.08.2025).
- [23] SKOUFIS, A., CHATZIHANASIS, G., DEDE, G., FILIPOPOULOU, E., KAMALAKIS, T., MICHALAKELIS, C., 2022. Technoeconomic assessment of an FTTH network investment in the Greek telecommunications market, *Telecommunication Systems*, Vol. 82.
- [24] ŚLIWA, R., 2015. Przyczynek do badań na temat efektywności regulacji, *Telekomunikacja i Techniki Informacyjne*, No. 1-2.
- [25] SOCHACKI, W., 2024. *Najpopularniejsze strony internetowe w Polsce – TOP20 Ranking popularnych stron*, <https://rw7.pl/najpopularniejsze-strony-internetowe-w-polsce-top20-ranking-popularnych-stron/> (accessed: 17.08.2025).
- [26] STIGLER, G.J., 1964. A theory of Oligopoly, *The Journal of Political Economy*, No. 72 (1).
- [27] TAKAI, H., YAMAUCHI, O., 2009. Optical fiber cable and wiring techniques for fiber to the home (FTTH), *Optical Fiber Technology*, No. 15 (4).
- [28] V-SPEED SP. Z O.O., 2025. *Speed Test – test prędkości Internetu*, <https://www.speedtest.pl/> (accessed: 10.08.2025).
- [29] ŻUREK, A., 2024. *Polacy zostaną spleądani światłowodem. Znikną białe plamy*, <https://spiderweb.pl/2024/12/ministerstwo-cyfryzacji-436-mln-zl-inwestycja-swiatlowod.html> (accessed: 18.08.2025).
- [30] ZYGADLEWICZ, M., 2017. Prywatyzacja branży telekomunikacyjnej w Polsce a pozycja konkurencyjna Grupy Orange, *Catallaxy*, No. 2 (2).

