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Deployment of Fiber-Based Access in the Kosovan Telecommunications Market

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ABSTRACT

The existing fiber-based optical access technologies in the Republic of Kosovo are reviewed in this article. A historical background to the wireline technologies is provided with the focus on fiber-based technologies. This is combined with a description of the current deployments and the future prospects for fiber-based optical access technologies. In addition, the market share in the Kosovan telecommunications market is presented. The leading telecom companies are described as well as the impact that competition, government, and the regulatory authority have on Kosovo's wireline market.

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Hybrid fiber coaxial network; ADSL; fiber to the home; point-to-point links; *gigabit passive optical network*

1. Introduction

The Republic of Kosovo has a population of just under 2 million, with around 50% of the being under 30 years of age [1]. Kosovo has an average of 5.9 family members per private household, and a total of 297,090 households [1]. Kosovo's economic and technological developments in the past three decades have been closely related to its political development. Kosovo, as a constitutional part of the former Socialist Republic of Yugoslavia, has gone through difficult political and economic times, culminating in the war of 1999. After the end of hostilities, a new era began with the constitution of the newest state in Europe, which also marked a new era of technological development of Kosovo.

In the Republic of Kosovo, based on the statistics of the Regulatory Authority of Electrical and Post Communications (RAEPC), in the third quarter of 2019, there were 352,659 internet users, which compared to the second quarter of 2019 represents an increase of 7.5% or a total of 24,620 more users. The fixed-internet penetration per 100 households is 118.7%, and the penetration per capita is 19.24%. These numbers are slightly contradictory, because on the one hand, we have more than 100% penetration of the wireline broadband services, and on the other hand, we have less than 20% penetration per capita. However, there is a reasonable explanation for these numbers. First of all, such a high percentage of internet penetration per household does not necessarily mean that all households have access to the fixed broadband internet. In fact, in some parts of Kosovo, because of geographical configurations, the deployment of the network is very limited, due to the expense and difficulties that are encountered during implementations. Another reason is that some families do not have sufficient knowledge to use internet services. In

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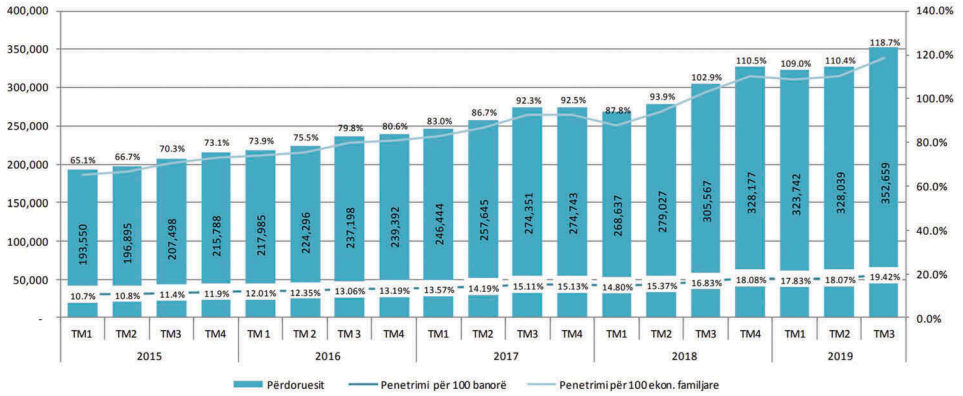

Figure 1. Number of user connections in Kosovo during 2015–2019 [2].

addition, there is the price of these services, bearing in mind that in Kosovo unemployment is very high. However, in major cities the number of service providers operating in the same regions is more than five.

Details of the numbers of users, the penetration in percentage per household and per capita for the period 2015–2019 is presented in Figure 1 [2].

From the results presented in Figure 1, we can see that we have a constant growth in the number of internet-service users. This comes from the fact that the number of internet service providers (ISPs) has been increasing constantly, in particular in the "white" areas (those without infrastructure), where the so-called "bigger telecoms" operating in Kosovo did not believe it was reasonable, from the financial perspective, to invest in those regions. Coverage of the white areas by smaller ISPs has helped to increase the percentage in terms of penetration as well as user base.

Kosovo's wireline market is made up of more than 55 ISPs, which are registered at RAEPC. The market share is more homogenous than the existing number of ISPs, where more than 80% of the total number of users is shared among four ISPs. The leading telecoms company in the fixed-access network is IPKO Telecommunication LLC, with a 35.58% market share, followed by Kujtesa, with a 24.56% market share, the third company is Artmotion holding, with 14.66% of the market share, and the fourth is Telekom of Kosovo (TK) (Telekomi i Kosovës), with 8.01%. The rest of the market is shared among local ISPs that operate in Kosovo [2].

This article provides an overview of Kosovo's wireline access network and is an upgrade of the information presented in [3]. We start by providing a historical overview of the fiber-based wireline access network in Kosovo, with a focus on providing essential information regarding the historical development of fiber-to-the-home (FTTH) in the Kosovan market by underlining the major factors that contributed to the development of the fiber access network. In Section 3, a more detailed overview of the existing fiber-based wireline technologies is presented from the technological perspective. In Kosovo, there are various wireline access networks, with the main market share being among the four ISPs. In Section 4, we provide the current and future technological solutions and trends that are more suitable for the migration of a fiber-based access network. Roadmaps of the passive optical network (PON) and the hybrid fiber-coaxial (HFC) are given in the Appendices.

2. Historical background to the wireline access technologies

Kosovo's technological development in general and the telecoms sector in particular is closely related to Kosovo's political and economic developments and can be divided into the period before the 1999 war and after. Before 1999 in Kosovo there was only one telecom company, with national coverage, known as the Post, Telephone and Telegraph (PTT) of Kosovo, established in 1959. The PTT offered a plain-old-telephone service (POTS) through a copper-based twisted-pair network. However, the internet services where provided in very limited form, mostly in the main cities of Kosovo, and were mostly connected state institutions, but there was no broad use of internet services among residential users.

After the war finished in 1999, Kosovo was left devastated in terms of its economic infrastructure, which had an impact on the development of the telecoms sector, combined with the fact that knowledge about internet services at that period among the Kosovar population was limited.

The first major step that paved the way for the development of the telecoms sector in general and internet services for widespread use in particular was in 2003 when the Assembly of Kosovo adopted the telecommunications law to regulate the telecom sector, which brought the needed legislative infrastructure to develop the telecoms sector and enabled liberalization of the telecommunications market. The adoption of the telecommunications law created the conditions to establish the Telecommunications Regulatory Authority (TRA), in 2004, which was a huge step toward promoting an independent and competitive market, and this paved the way for the development of the information society of Kosovo [2]. The existing telecommunications law and TRA, whose rights and obligations where defined under the telecommunications law, where far from perfect, and to minimize the flaws in the telecommunications law, which was adopted in 2003, a new law was adopted in 2012, known as the law for electronic communications. With the new law in place, the competences of the regulatory body where redefined, paving the way for the establishment of the RAEPC (formerly the TRA) by giving more obligations and rights to the regulatory body.

The above-mentioned movements accelerated the development of the telecoms sector, in particular the private sector, where we witnessed significant investments. It is very important to underline that during the period between 1999 and 2004, we had a noticeable increase in knowledge among the population about internet services, putting the local service providers under pressure to invest in developing their network for broader use and upgrading their existing network.

Until 2005, even though the developments in terms of infrastructure coverage and network upgrade where noticeable among the local ISPs, the only company with national coverage was the state-owned company TK. TK was the owner of the copper-based twisted-pair network, which was inherited from the former PTT of Kosovo, and this had an impact on the future development of the TK wireline access network. At that period most of the internet connections were realized through dial-up internet connections implemented by TK. The alternative was wireless connections provided by a local ISP; however, the price per installation was very high and for most of the residential users this was unaffordable. The capacities provided at that time where in the range 40–50 kbit/s.

The great breakthrough in Kosovo's telecommunications market came in 2006, when Telecom Slovenije (TS) acquired IPKO Net, which at that time was one of the local ISPs operating in the Pristina region. The impact of this development was twofold. On the one hand, it greatly boosted IPKO's development and within the next couple of years IPKO gained the status of a telecommunications company with national coverage, adding to the fact that IPKO choose HFC as its main wireline access network solution. We have to be aware that HFC was the state-of-the-art solution for the time. On the other hand, HFC had a great impact on the competition, where we also saw a rapid development by the third ISP, Kujtesa, which opted for the same HFC technological solution as IPKO.

Within 5 years, three telecoms companies were well established in Kosovo, IPKO, and Kujtesa from the private sector and TK a state-owned company. In this period, we also saw the establishment of a few more local ISPs. These local ISPs deployed their networks in the areas located outside towns and cities – rural areas, where the three main telecoms companies did not believe it was feasible to invest. In terms of the network capacities offered to users, we noticed a great increase: from 125 kbit/s provided in 2007, leading companies were offering packages in the range of megabit capacities in 2011.

Even though the HFC network is partly made up of optical fiber, and can be considered as some form of Fiber to the Node (FTTN) solution, the FTTH solution soon started to appear in Kosovo's market. The FTTH solution can be found in both topological solutions, i.e., point-to-point (P2P) and point-to-multipoint (P2MP). Until 2014, the FTTH in the form of P2P was offered exclusively to business users. With such a solution telecom companies made sure to offer their business users a reliable and secure service.

The technological developments inevitably had an impact on the continuous demands for higher internet speeds with low latency. Such demands forced the telecom sector to continuously seek out future-proof access solutions. After 2014, there were some pilot projects with the fiber-based P2MP topology, which marked the beginning of the broader use of the optical solution for residential users.

On the other hand, the government has identified electronic communications as a critical component in the economic development of the country. Information and communication technology (ICT) is seen as a means of increasing the international commercial relationships and increasing the knowledge of society. Therefore, in 2013 the "Digital Agenda for Kosovo 2013–2020" was issued [4]. Three priorities were included in this agenda: the development of ICT, the development of the electronic and service content and the enhancement of the Kosovo residents' ability to use ICTs. This agenda was also in agreement with "Europe's Digital Agenda" issued in 2010 [5], which was a blueprint for the FTTH expansion in countries such as Slovenia, which today has one of the most developed optical access networks [6]. One of the main targets was that all of Kosovo's residents had to have access to internet services of at least 30 Mbit/s or higher by 2020.

The major problem associated with fulfilling the demands set by this agenda was the deployment of a FTTH network in rural areas, which had some technical but mostly financial restrictions. Therefore, in 2018, the government started a project to expand the FTTH network in rural white areas, where for the telecoms sector it was not feasible to expand the wireline network, mainly due to the small number of households and the very high costs of infrastructure implementation in these countryside locations. In the second half of 2018, after intensive work between the Ministry of Economic Development (MED),

the telecom sector and the World Bank (WB), which was acting as a facilitator in this project, the MED successfully opened a tender with a list of 25 villages, planned for coverage with a FTTH solution, which were divided into 8 lots. This project was a co-investment in a 50:50 partnership, where 50% of the investments were covered by the government and the other 50% were covered by the winning telecoms company for each lot. After successfully completing the project, the government of Kosovo and the WB began major projects. Therefore, in 2019, the expansion of the FTTH network in country-side areas, unreached by the telecoms sector, continued successfully [7]. The building of the broadband network is planned to be concluded by 2021. It is envisaged that all the rural areas of Kosovo will be covered by a fixed-access network and offer broadband services to the households located outside the towns and cities.

3. Fiber-based wireline technology solutions in Kosovo

Worldwide technological advances have had an impact on the development of Kosovo's telecommunications sector. The continuous technological advancements in television (TV) services, such as ultra-high-definition television (UHD TV), high-quality streaming platforms, and the increased number of devices connected per household have forced the telecoms sector to provide high-speed internet with low latency. This has accelerated the development activities of the telecoms sector, with the focus being on the field of optical communications [8]. Advantages such as capacity, distance reach and "future-proofness" have made fiber optic the preferred choice for wireline access technology. In today's telecommunications market it is very common to find commercial dedicated capacities in range of 10 to 100 Mbit/s, with the top service tier having 2–3 times higher capacity, albeit with an unspecified capacity.

Today, in Kosovo's market, the top service packages offer internet speeds of up to 1 Gbit/s, with the most common packages offering internet speeds up to 250 Mbit/s. The need to provide gigabit capacities has put the ISPs in Kosovo on alert, and FTTH is seen as an appropriate technological solution that provides insurance in offering capacities in the Gbit/s range, in both asymmetric and symmetric ratios [9].

3.1. *Wireline access technologies present in Kosovo*

In Kosovo, today we find three main wireline access technologies. In addition to the old copper-based twisted-pair network with a digital subscriber line (DSL) technology, the modern HFC and the future-proof FTTH are also penetrating. For each technological deployment, there is an economic and technological reason why the ISP opted for the particular solution, having in mind also the period when each solution was deployed.

3.1.1. *HFC and xDSL*

In HFC technology, as the name indicates, the network is made up of two main parts: the fiber optic part and the coaxial part (as presented in Figure 2). The typical HFC configuration in Kosovo uses a pair of single-mode fibers to provide the connection between the central office (CO) and the last-mile part of the network, which is the coaxial part. In Kosovo it is the practice to have the average fiber optic distance from the CO to the optical node (ON) over 10 km. Sometimes, in extreme cases, the fiber-optic part is up to 30 km.

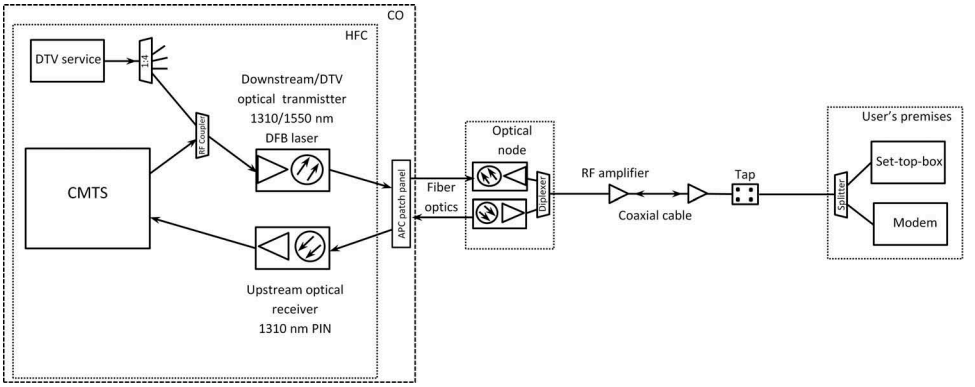

Figure 2. IPKO's HFC Network Topology [10].

The ON is an opto-electrical converter, the purpose of which is to convert the optical signal into a radio-frequency (RF) signal. From where the signal is launched to the last part of the network, the connection is made up of coaxial cables. For the optical part of the communications, a 1310-nm transmission wavelength is applied on each fiber, for both downstream and upstream transmissions. The use of this wavelength, instead of 1550 nm, is preferable since the optical signal has a lower banding loss for a lower transmission wavelength. Angled physical contact (APC) connectors are used at the CO and ON locations to minimize the back reflections. For the same reason, all the other fiber joints are made by fusion splicing. A Fabry-Perrot (FP) laser or distributed feedback laser is used for the optical transmission, and photodetectors (PDs) are used for receiving the optical signal. In the coaxial part, it is common to use a RF amplifier to compensate for the losses imposed by the coaxial cables and at the electrical poles, as termination points are installed taps from where the installation is completed.

The asymmetric digital subscriber line (ADSL) network technology uses a twisted pair in the last part of the network for the connection of the users to a DSL Access Multiplexer (DSLAM). Based on the network coverage, the DSLAM is located in the CO or in the field.

A physical connection between the CO and the DSLAM, for the case when a DSLAM is installed in the field, is implemented in two forms, which are shown in Figure 3. When a fiber optic cable is available from the CO to the DSLAM, the connection is made

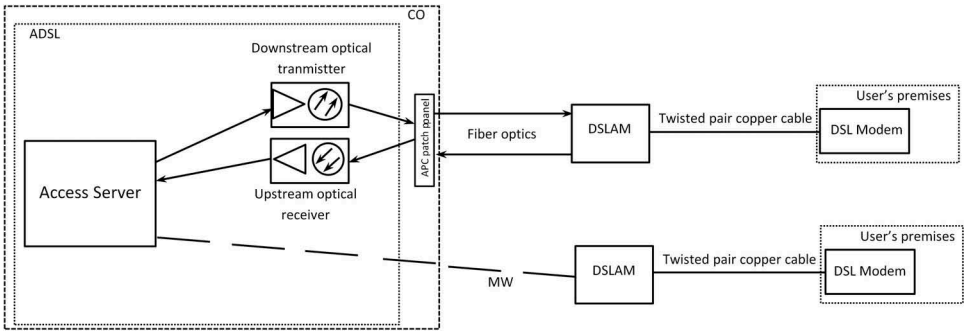

Figure 3. TK's simple ADSL topology.

through the fiber optic, but when there is no such optical option available, it uses a microwave link to connect the DSLAM with the CO. From the DSLAM to the DSL modem, twisted-pair cables are used for the connection. This solution provides a platform for future migration to the high-speed G.fast standard.

3.1.2. *FTTH solutions*

FTTH has become the preferred solution in many parts of the world, with the P2MP topology being favored. Kosovo is not an exception, but financial restrictions have prevented the deployment of the FTTH to satisfactory levels. Unfortunately, HFC is still the leading technology in Kosovo. Lately, a technological shift has been observed. Although HFC is an active access network, meaning that along the network, electricity is needed for power, it has a lot of operational problems. Because of repeated problems with electricity power outages, an ISP in Kosovo had to invest in back-up solutions and human resources to offer uninterrupted and high-quality services to its users. This led to many maintenance works on the HFC network, consequently increasing the expenditure of the company. One of the solutions would be FTTH, which provides a future-proof platform, and which will eliminate the problem of electricity outages, as well as increasing energy savings and reducing the operating expenses.

In Kosovo the P2P and P2MP topologies are used in the optical access network. P2PM is standardized in the solution of the PON, like in gigabit-capable passive optical networks (GPONs). When FTTH began to be deployed Kosovo, back in 2007, the P2P solution was seen as the preferred solution for several reasons. Although looking strictly from the technical perspective, the P2P solution offers several advantages over P2PM, i.e., dedicated physical connections between the CO and user premises, dedicated capacity, and higher security, to name just a few. One of the main drawbacks of P2P is to manage the large number of fibers in the CO, which requires a high level of fiber-management solution to minimize the real-estate requirements.

The P2P topology deployed in Kosovo by the main operators uses an Ethernet P2P solution, standardized by the IEEE 802.3ah working group, which supports capacities up to 1 Gbit/s and reaches distances of at least 10 km. The common physical connection uses two dedicated fibers between the CO and the user's equipment. For the transmission in the upstream and downstream directions, the same wavelength of 1310 nm is engaged, since a dedicated fiber is available for each direction. By using the 1310-nm wavelength for both directions, it was possible to employ a low-cost Fabry-Perot laser. For the connection of the fiber optics at the CO, patch panels are installed and at the user's premises, physical contact (PC) connectors are used.

In the past 5 years, the use of one single-mode optical fiber for bi-directional communications is not uncommon. For this solution, two different wavelengths are used. For upstream, 1310 nm is employed and for downstream, 1550 nm. Both solutions are presented in Figure 4.

It is worth underlining that P2P for the case of ISPs in Kosovo was exclusively for business users, and providing TV services was not common. Fixed telephony services are provided through the internet protocol (IP) telephony, commonly known as voice over IP (VoIP).

For residential users most of the ISPs have embraced the idea that the best technological FTTH solution is P2MP in the form of GPON. In Kosovo, we have two practices in the deployment of the GPON network, and the differences between these two practices are

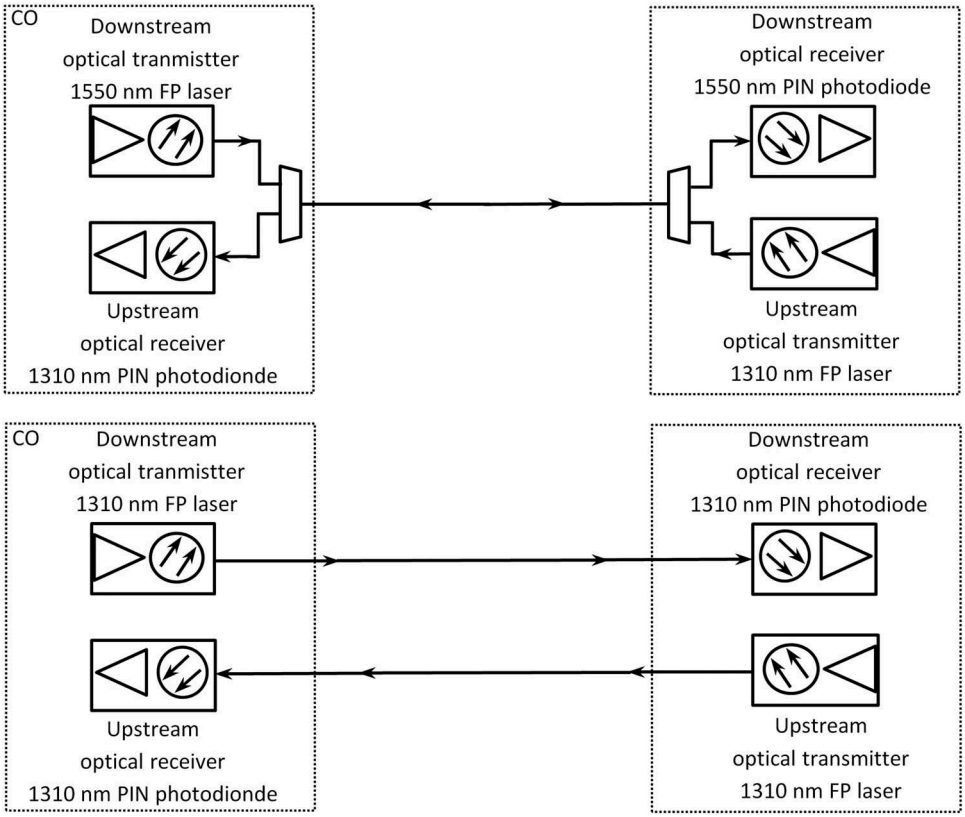

Figure 4. P2P solution for business users. (a) Separation of downstream and upstream data traffic between two optical fibers. (b) Combining traffic data transmission over a singe optical fiber.

how the TV service is provided to the customer. On the one hand, we have the GPON solution where TV services are an added service with the help of a RF overlay, and on the other hand, we have the GPON solution, where the TV service is provided for the IP Television video solution. Nevertheless, by far the dominant solution is GPON with an RF overlay solution. This solution is presented in Figure 5.

As depicted in Figure 5, GPON is made up of three main parts: the CO where the Optical Line Terminal (OLT) and the RF video overlay are installed; the distribution part where the optical splitter is installed; and the end-users part where the Optical Network Unit (ONU)/Optical Network Terminal (ONT) are located. Three different wavelengths are assigned: 1310 nm for upstream communication, 1490 nm for downstream communication and 1550 nm for the TV services. The multiplexing/demultiplexing of these three wavelengths is performed at the CO with the help of simple wavelength division multiplexing (WDM). The most common splitting ratio applied in the Kosovo case, which takes place in the distribution part of the GPON, is a one-step split ratio of 32 or 64 splitting ratios. However, in some rare cases, TK uses two-step split ratios, with the first level at the central office, with a split ratio of 1:4, and the second level, at the distribution cabinet, with a maximum splitting ratio of 1:16.

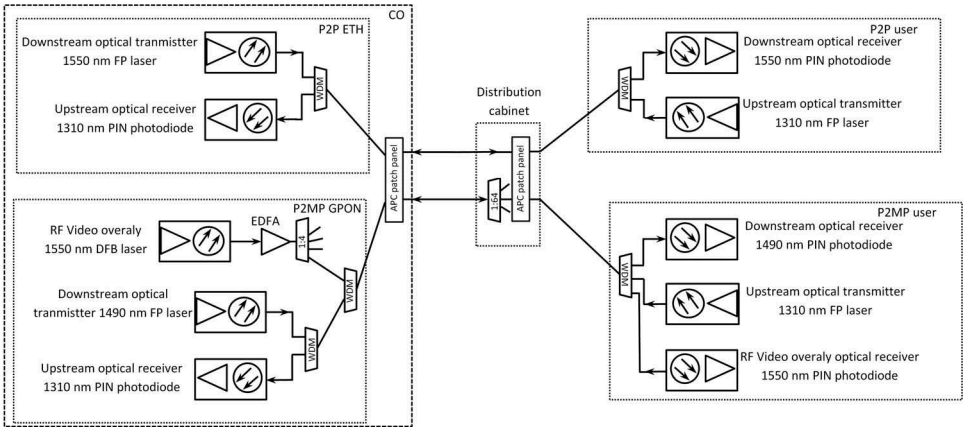

Figure 5. Most common FTTH (GPON) solution in Kosovo's wireline access technology.

3.2. *Current status of the market share in Kosovo*

3.2.1. *Leading ISP in the Kosovan market*

In Kosovo, in the RAEPC, there are more than 55 registered ISPs. However, 80% of market share is taken up by four ISPs: IPKO Telecommunication LLC, with 35.58% of the market share; followed by Kujtesa, with 24.56% of the market share; the third company is Artmotion, holding 14.66% of the market share; and the fourth is TK, with 8.01%. The rest of the market is shared among local ISPs that operate in Kosovo [2].

3.2.1.1. *IPKO telecommunication.* IPKO is one of the first ISPs in Kosovo, founded in 1999, just after the war. For several years IPKO operated as a local ISP, offering internet services through wireless P2P links, dedicated for business users. In 2005, IPKO started its first pilot project based on HFC, with the data over cable service interface specification (DOCSIS) standard. For the time, this was a very advanced technology and the FTTH solution was very expensive for widespread use. The rapid expansion of the HFC network started after IPKO became part of the TS group in 2006 [11]. FTTH technology was present in the IPKO portfolio from 2007, when IPKO started offering FTTH connections in the form of a P2P topology to its business users. From 2014, as part of the strategy to gradually upgrade the HFC network, IPKO started with the deployment of a FTTH network for widespread use.

3.2.1.2. *Kujtesa.* Kujtesa was established in 1995 as a small IT company that offered IT solutions, starting from PCs, printers, etc. After the war in 1999, Kujtesa was reestablished and started its activity as a local ISP in Pristina, connecting business users using wireless P2P links. Kujtesa's first experience with wireline technology was when they started offering original television technology that uses analog signals to transmit video and audio (analog TV) to some parts of Pristina through a coaxial network. Kujtesa started with the modernization of its network by offering internet services on top of the analog TV. Afterward, Kujtesa continued its investments in the access part of the network by deploying fiber optics, which enabled the migration from a coaxial network to a HFC network. This paved the way for an increase in capacity and high-quality services, as well

as greater coverage of the territory [12]. In a similar way to IPKO, Kujtesa is offering the FTTH solution, P2P topology for its business users, with greater capacities and high-quality services. The FTTH solution, shown in Figure 4, is only available to a limited number of users.

3.2.1.3. *Telekomi i Kosovës TK.* Telekomi i Kosovës (TK) is a public company. The roots of TK are the former PTT of Kosovo, established in 1959. Because PTT offered POTS through a copper-based twisted-pair network, TK as a company that derived from PTT Kosovo inherited PTT's assets, and consequently also its copper-based twisted-pair network. This fact was central to TK upgrading its access network by deploying ADSL technology [13]. TK is implementing a fiber-based P2P topology for business users. This has enabled TK to offer greater capacity and higher-quality services.

3.2.1.4. *Artmotin.* Artmotin is not new to the telecommunications market; it was established back in 2003. However, the real development started only in 2017, when the company was acquired by one the wealthiest companies in Kosovo, Devolli Group. This was a new start for Artmotion, and within two years for the local ISP they managed to become the third ISP in terms of market share. Like IPKO and Kujtesa, their main technology is HFC and in terms of the FTTH solutions they offer, they are deploying the P2P topology for business-user connections.

It is worth mentioning that in Kosovo, from 2018, there is also a new ISP, Telkos, which has opted for the FTTH solution in the form of GPON, and although currently it has only 3.83% of the market share, they hold an advantage over other ISPs, because they have leapfrogged broadband access solutions such as HFC or xDSL.

3.2.2. *Market share based on technologies*

As underlined in the previous section, even though FTTH solutions have been part of the telecommunications market in Kosovo for more than a decade, until 2014, FTTH was a solution that was exclusively for business users, and the topology used to implementation these connections was in the form of P2P. The main limitation for the broad expansion of FTTH was the cost of implementation. In Kosovo most of the wireline access network is an aerial network deployed in the Kosovo Energy Distribution Services (KEDS) electricity poles, which has made it nearly impossible to implement a new FTTH network in the existing over-crowded electricity poles. The option to build a new underground infrastructure was not feasible due to the very high costs, having in mind that when building FTTH technology, an underground infrastructure takes up to 70% of the overall cost of the project [14].

In Kosovo's market share, the dominant technology is HFC, which represents over 80% of the market share in terms of the technological solution. xDSL and FTTH share the same 9% market share, followed by wireless solutions, which represent 3% of connections. These results can be found in Figure 6 [2].

The main reason for this dominance of the HFC network is that the leading ISPs, i.e., IPKO, Kujtesa and Art Motion, have HFC as their main access network technology, which still represents the most cost-effective solution.

To give a clear indication of how all the existing technological solutions have progressed over the past 10 years, we have presented Figure 7.

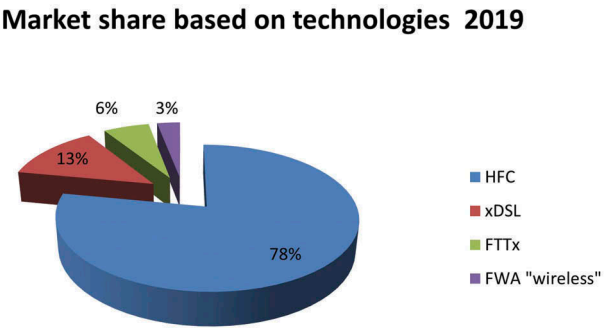

Figure 6. Market share based on technologies that are present in Kosovo's wireline access networks.

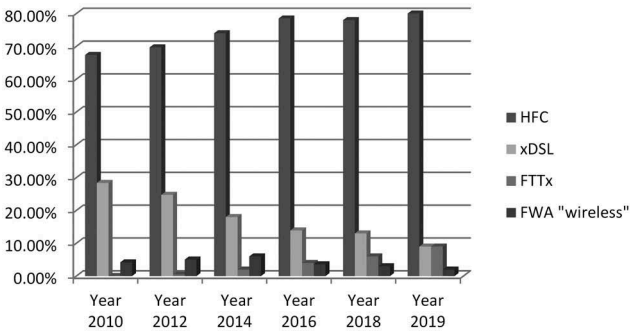

Figure 7. Market share based on the technologies deployed in Kosovo over a 10-year period.

From Figure 7, we can conclude that HFC is still the leading technology by a large margin, and it has seen constant progress, although in the last 3 years not with the same dynamic as in previous years. FTTH is the technology that has progressed the most in the last couple of years and this is a clear indication of the direction in which ISPs are looking to go in terms of finding ways to upgrade their existing access networks. Also, we can see that the number of xDSL users is slowly decreasing, in fact over the period of 10 years, this technology has lost over 70% of its market share. The presence of wireless connections is a consequence of the areas where none of the existing ISPs is present with their wireline access network.

In terms of broadband market share, in different continents the dominant technologies share different percentages. In North America, over 56% of the market share is occupied by HFC, followed by DSL and third is FTTH/B. Western Europe's market share is dominated by DSL solutions, with an over 74% share, followed by HFC with around 18%. The Asia Pacific market share is dominated by FTTH solutions, with large rollouts of FTTH services in recent years. In Australia and South America, the DSL solution holds the majority of the market share. In both cases, it is expected that there will be an increase of the HFC and FTTH user shares, with DSL expecting to lose its current market share [15].

4. Technological options for the Gbit/s-capacity needs for Kosovo's case

One of the most consistent predictions for over 36 years in terms of internet bandwidth, Nielsen's law, states that "A high-end user's connection speed grows by 50% per year" [16]. This means that by 2019, 325 Mbit/s will be required for high-end user's connections, and by 2022, ISPs will need to be able to provide Gbit/s capacities to high-end user's connections.

Another important metric when analyzing the possibilities for technological upgrades to access networks is the future needs of average speeds. From [17], the average global broadband speed in 2017 was 39 Mbit/s, with a projection to achieve double this in 2020 with 75.4 Mbit/s. In terms of average fixed-broadband speed, Table 1 presents fixed broadband speeds from 2017 with a projection to 2022.

The same trends apply to Kosovo's wireline access network and the fundamental question that arises is: what is the roadmap for technological upgrade to follow the worldwide trends? Having in mind that in Kosovo the main access network is HFC, having close to 80% of the market share; the following analysis is focused on the technological possibilities of HFC.

To upgrade the HFC network to fulfill Gbit/s needs, there are two common paths: the evolutionary path, where using technological progress the coaxial part the network is kept unchanged for as long as possible, and the second path is the more revolutionary approach, where the main solution could be one of the FTTH solutions [18].

The extreme upgrade solution, known as the revolutionary path, is migration to one of the FTTH solutions. In most cases when an ISP chooses this path, they build a parallel network alone [19]. The list of technological solutions that would fulfill Gbit/s-capacity needs includes both P2P and P2MP solutions: including TDM-PON, WDM-PON, and the hybrid version of time and wavelength division multiplexed, TWDM-PON. These technological solutions are foreseen to provide gigabit capacities at end-users with low latency and are seen as future-proof solutions. The more comprehensive explanation of the FTTH solution upgrade is presented under Appendix A as the PON roadmap.

The evolutionary path is a more cautious path and is not new to the ISPs. This approach is known as "business-as-usual" and has been present among ISPs for decades. In terms of the potential of HFC, if we compare current capacities and the potential of the HFC network, we can say that the current capacity provided by the ISP is just the tip of the iceberg and although DOCSIS will not last forever, there is still time before we see the end of DOCSIS. The same question arose in the mid-1990s regarding the twisted-pair-based fixed network, where there were suggestions among ISPs that the lifespan of the

Table 1. Fixed average speeds in different regions.

	Mb/s	
Regions	2017	2022
Global	39	75.4
Asia Pacific	46.2	98.8
Latin America	11.7	28.1
North America	43.2	94.2
Western Europe	37.9	76
Central and Eastern Europe	32.8	46.7
Middle East and Africa	7.8	20.2

network had come to an end. Some of the ISPs began to deploy FTTH in some areas; however, most of the ISPs found more cost-effective ways to drastically enhance the performance of the network with DSL and G.Fast technologies. The more comprehensive explanation of the DOCSIS solution upgrade is provided under Appendix B as the HFC roadmap.

Since Kosovo is a relatively small country, it is very suitable for conducting a field test of future telecommunications network equipment that was recently tested under controlled conditions in a laboratory. Multi-core optical fiber in an optical access network [20], a wavelength-division-multiplexing passive optical network (WDM-PON) with an injection-locked Fabry–Pérot laser [21, 22] or a fiber-based radio access network for 5 G [23] are just some of the technology candidates waiting for such field experiments.

5. Conclusions

The turbulent political times that Kosovo has gone through in the past three decades have had an inevitable impact on the development of the telecoms sector. After the 1999 war, Kosovo started its rebuilding process with an unclear political status. The political uncertainties in Kosovo kept away investments from abroad and this had an impact on economic development. After 2007, when Kosovo declared its independence, things started to move in the right direction. However, even today, Kosovo finds it difficult, at some international levels, to find financial support, because of political issues.

The real expansion of the wireline network started after 2005, and great credit for this expansion can be attributed to TS, which acquired IPKO Net, at the time just a local ISP. This fueled the Kosovo market, and had an impact in starting the deployment of a HFC network at the national level by IPKO and Kujtesa, and soon we had three operators, i.e., IPKO, Kujtesa, and TK with national coverage. Today, Kosovo has over 55 ISPs, although over 80% of the market share is in the hands of four operators.

The leading technology through which broadband services are offered to residential users is HFC, followed by xDSL and FTTH. Until 2014, FTTH (P2P) was seen as a solution to offer dedicated capacities to business users, with high security. The data traffic in the P2P solution is designed in two configurations. In the first configuration, two dedicated fibers are assigned for upstream and downstream communications, where the 1310-nm wavelength is used for both directions of communication. In the second configuration, a single fiber is used for both directions of the communication, which forced operators to use two different wavelengths, 1310 nm for the upstream direction and 1550 nm for the downstream direction.

From 2014, most of the operators with national coverage have started deploying a FTTH network, in the form of a P2MP solution, for residential users. Although the P2P solution can provide a larger bandwidth per customer than P2MP, it has already been realized that a mixture of P2P and P2MP solutions will be the right, future-proof solution to fulfil the different needs of the different types of users. While P2P will serve for the more-demanding and sensitive users, which require more security in providing the service and in this category are government and local institutions, embassies, banks and other business users, P2MP will be employed for residential users, with lower requirements, but will still be in line with the European digital agenda. Both presented solutions, P2P and P2MP, are passive without expensive electronics in the outside plant

and are far less costly to operate and maintain. A video signal can be delivered either as IP traffic using the IPTV solution or via RF video broadcasting over a PON. For RF video broadcasting, the use of APC connectors is mandatory. The RF video signal carried by a dedicated wavelength is first split into multiple, identical streams by an optical splitter and then fed into the distribution network, which can be P2P or P2MP.

A great contributor to the expansion of FTTH technology, especially in rural areas with an extreme configuration, is expected to be the projects of the government of Kosovo in cooperation with the World Bank. In this project, the government will co-invest with the telecoms sector to make sure that all the inhabited areas of Kosovo are covered by a fiber-based fixed-access network, capable of providing broadband services.

The ultimate goal of Kosovo's main operators is installing a fiber infrastructure all the way between the CO and the business or residential customer locations. This full optical solution has numerous advantages and is also the final solution in broadband access technologies.

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Appendix A

Roadmap of PON

GPON and EPON are the world's most-deployed FTTH solutions among ISPs that chose the optical access network solution. PON solutions come with several advantages: a passive distribution network, the possibility of sharing the same single-fiber optics among tens of users, low-cost implementation, and maintenance, to name just a few.

Most ISPs are constantly searching to improve their networks in terms of reliability and capacity, targeting gigabit-per-second levels. As a response to these needs, both standardizing bodies, the IEEE and Full Service Access Network (FSAN), have provided 10-Gbit/s-capable platforms and today ISPs have available XG-PON (ITU-T G.987), offering 10/2.5 Gbit/s in the down- and upstream directions, respectively, and XG-PON2, offering symmetrical 10/10 Gbit/s capacities for communications.

Compared to the above-mentioned TDM-PON solutions, which are not seen as a favorable platforms to fulfill the future needs of multiple tens of Gbit/s in access networks, WDM-PON (ITU-T G.698.3), which involves the wavelength multiplexing technique, and offers bandwidth scalability, long reach, higher security and dedicated traffic for each user through the assignment of a dedicated wavelength [9].

One of the main challenges of the WDM-PON is to provide "colorless" features to WDM-PON ONTs. The best-known techniques that enable this feature are injection-locking, tunable lasers,

solutions with wavelength re-use, and coherent detection [24]. However, current developments of the WDM-PON are not at the mature level, and for ISPs, it is too big a step forward. The needs of industry are not yet compatible with the WDM-PON potential and the current industrial solutions have very high prices for the broad deployment of a WDM-PON.

Due to the challenges that WDM-PON faces for wide deployment, as a primary solution for the NG-PON2, the TWDM-PON (ITU-T G.989 series) was chosen. This standardized solution represents a mixed TDM and WDM, which enables the ISP to leverage some features of WDM and at the same time provides compatibilities with existing TDM-PON solutions (GPON and XGPON) [9], as presented in Figure A1.

Appendix B

Roadmap of HFC

Parallel to PON developments, the newest versions of DOCSIS (3.1 and 4.0) are able to match the PON standards, offering capacities of 10/1-2 Gbit/s (DOCSIS 3.1) and 10/10 Gbit/s (DOCSIS 4.0), which provide a trusted platform to fulfill future-capacity needs. Some noticeable performance enhancements offered by the newest versions of DOCSIS (3.1 and 4.0) are [19]:

- Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Access (OFDMA)
- Low-Density Parity Check (LDPC) Forward Error Correction (FEC)
- High-efficiency modulation with mandatory support up to 4096 quadrature amplitude modulation (QAM) with options up to 16,384 QAM
- The OFDM channel bandwidth can extend from 24 to 192 MHz in the downstream direction and from 6.4 to 96 MHz for the upstream direction, leveraging 25 kHz or 50 kHz sub-carriers.

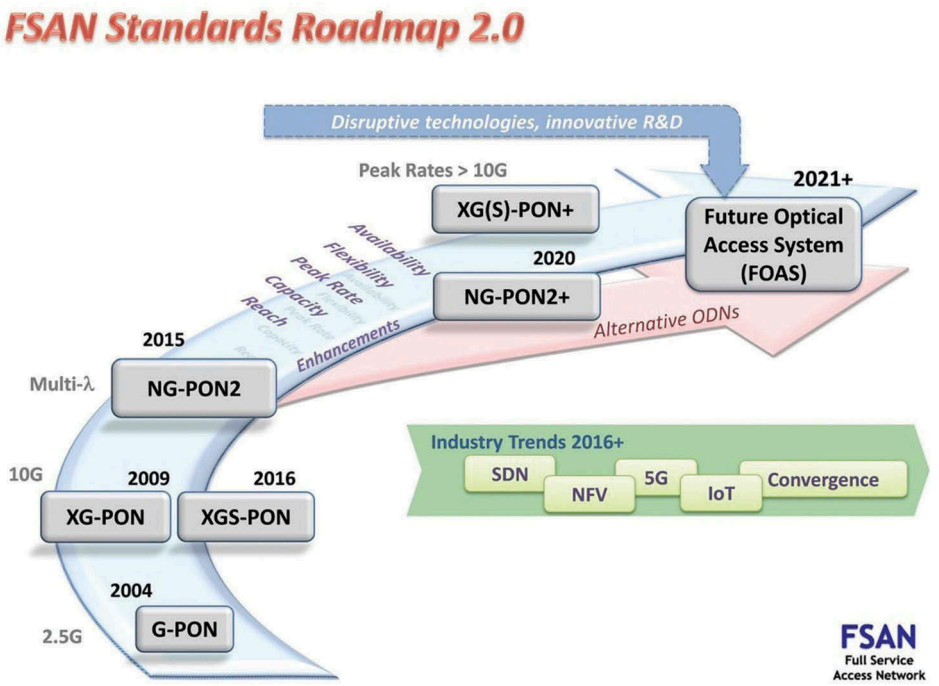

Figure A1. Roadmap of HFC network evolution in Kosovo.

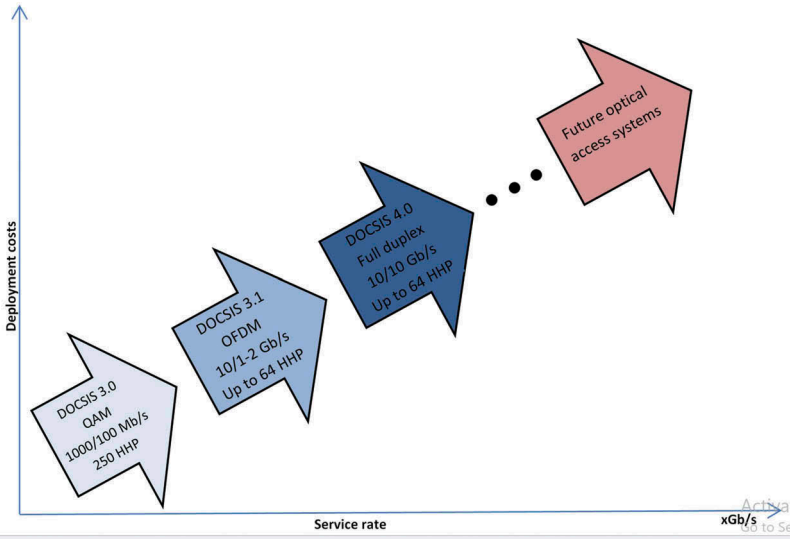

Figure B1. Roadmap FTTH network [25].

This migration path has enabled ISPs to have options to leverage the benefits of the existing HFC network. A roadmap of HFC, which can be applicable for the case of Kosovo's HFC access and also for other regions where HFC network is deployed, is presented in Figure B1.

The DOCSIC 4.0 version will include Full Duplex (FDX), which makes it possible to use the same spectrum simultaneously for down- and upstream communications. The DOCSIS 4.0 standard is yet to be finalized; however, what is known is that the low-latency requirement for sub-1-millisecond latency and an additional security feature are being addressed. In the DOCIS 4.0 standard, besides low latency and security enhancements, an extended spectrum up to 1.8 GHz is set to be supported. These network upgrades will support internet speeds of 10/10 Gbit/s in the downstream/upstream directions.

HFC and DOCSIS 4.0 offer different upgrade solutions for the access network. On the one hand, it supports the Full Duplex DOCSIS, distributed access architecture (remote PHY) and network segmentation that supports configurations where signal amplifiers between the optical node and the user are eliminated (NODE + 0), and, on the other hand, the extended spectrum DOCSIS and network architecture that still support signal amplifiers in configurations such as "node + 1", "node +2", etc [26].

As presented in Figure B1, although probably still too early to predict, in the future the HFC upgrade will terminate in one of the versions of the future optical access system (FOAS). The evolution provides the means for an upgrade that can be less problematic for ISPs in terms of cost and technical challenges.