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Upgrade of a hybrid fiber/coax broadband access based on a techno-economic analysis and prediction of the traffic growth

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Abstract. This paper presents and compares different access-network technologies and their market shares, both globally and in the Republic of Kosovo. We mainly focus on the hybrid fiber/coax (HFC) access-network technology for being most widely used in Kosovo today. The purpose of this study is to select a technology approach, as well as to design the performance of the access-network operator for the next five years. Based on a literature review, we first present the trends in the internet-traffic growth. A thorough analysis identifies the traffic and network status for the example town of Vitia in Kosovo. We propose and discuss different upgrade approaches from a techno-economic perspective. In the conclusion we propose, schedule and comment on the evolutionary migration approach as the most promising option for upgrading to a next-generation access network.

Keywords: hybrid fiber/coax network, fiber to the home, access network, traffic-growth prediction

Nadgradnja hibridnega vlakensko/koaksialnega širokopasovnega dostopa na podlagi tehnološko-ekonomske analize in predvidevanja rasti prometa

Prispevek predstavi in primerja tehnologije sodobnih dostopovnih omrežij in njihovo razširjenost na svetovni ravni in v Republiki Kosovo. Osredotočimo se na hibridno omrežje iz optičnih vlaken in koaksialnih kablov (hibridno vlakensko/koaksialno omrežje, ki ima na Kosovu prevladujoč delež. Namen študije je izbor tehnologije in pristopa ter načrtovanje zmogljivosti operaterja dostopovnega omrežja za prihodnjih pet let. Na podlagi zbranih izsledkov iz literature najprej predstavimo napovedi glede trendov rasti prometa. S podrobno analizo v nadaljevanju ugotovimo promet in delovanje omrežja za vzorčni primer mesta Vitia na Kosovu. Razdelamo in komentiramo več možnih pristopov za nadgradnjo omrežja ter jih primerjamo z vidika tehnologije in ekonomike. V sklepu predlagamo, časovno umestimo in komentiramo uporabo evolucijskega migracijskega pristopa kot najobetavnejše možnosti za nadgradnjo v dostopovno omrežje prihodnje generacije.

Ključne besede: hibridno vlakensko/koaksialno omrežje, vlakno do doma, dostopovno omrežje, napoved prometne rasti

1 INTRODUCTION

The exponential growth in the capacity demand for telecommunication services and the technological and economic development have been the main driver in keeping service providers in a constant search for the best ways to leverage the existing networks and capacities, but at the same time to find the best technological solutions as a future-proof choice. The Nielsen's law predicts that bandwidth requirements for the top tier offered by multi service providers (MSPs) will increase by 50% every year, and the accuracy of this prediction has been very consistent over 30 years [1]. Lately, this increase is driven by cloud computing, IPTV and augmented-reality games [2]. In the European market of today, broadband internet services offered by service providers achieve rates of 100/10 Mbps in the downstream/upstream directions.

Kosovo is the youngest country in Europe with a population under 2 million [2]. Based on the statistics of the Regulatory Authority of Electrical and Post Communications (RAEPC), 73% of the households use internet services, compared to the beginning of 2011 when this number was 45% [3]. The market leader in Kosovo for the broadband services is IPKO Telecommunication, with a 47.84% market share, followed by Kujtesa, with 24.37%. Telekomi i Kosoves (Telecom of Kosovo) is the third with a 15.46% market share. The rest of the market is distributed among local internet-service providers (ISPs) that operate in Kosovo [3].

2 OVERVIEW OF FIXED BROADBAND SERVICES AND TRAFFIC-GROWTH ESTIMATES

The impact of internet services on society has been the subject of analysis in several research works. Broadband internet has an impact in many areas of our life and sees a constant growth of internet users and capacity usage. Today, over 3.4 billion people are using some kind of the internet service [4].

The number of internet users is increasing annually by 2-3%, independently of the technology that it utilized and this trend is clear from 2000 (Fig. 1). However, even though we are living in an era of high-speed

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wireless communication and fiber to the home (FTTH) solutions, only 45% of the world's population is currently having access to internet services [4]. Worldwide cable broadband subscriptions and their projection from 2012 to 2020 are presented in Fig. 2 [5].

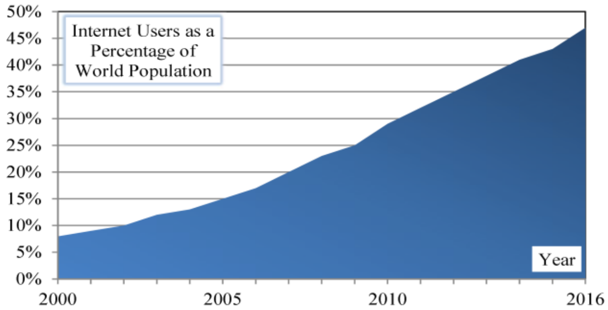

Figure 1. Global internet penetration.

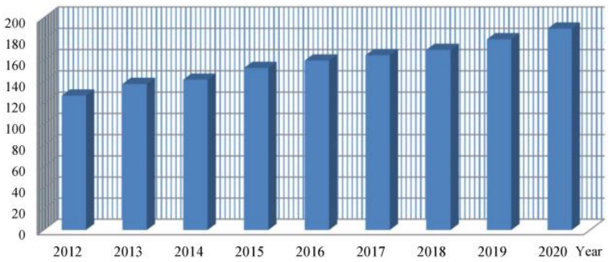

Figure 2. Worldwide cable-broadband subscribers (million).

The client base in the cable technology is expected to increase by 25% for the period 2015-2020. This means that by 2020 we expect to have more than 190 million subscribers. However, this growth must be followed by a constant upgrade of the existing technologies such as hybrid fiber/coax (HFC) and digital subscriber line (DSL), but a significant role in answering the trends presented in Fig. 2, will be played by the expansion of the fiber-based technology [6].

In the today's market, fixed broadband internet services are being offered via different technologies. In Asia, the main fixed access technology is FTTH, with a high rate of increase in recent years, but with the same trends DSL is losing its users. Over 230 million users are connected via FTTH. HFC in Asia has a small portion of the fixed client base. In North America, HFC is the leading technology with the largest client base (over 70 million or 56% of users). A small increase in the number of the FTTH clients has been noticed, but the numbers are still not comparable with HFC. In Latin America, the dominant platform is DSL, followed by HFC [5].

In the telecommunication industry it is very common to share resources, mostly the infrastructure that is needed to implement the network, such as underground infrastructure or areal infrastructure. This has direct impacts on lowering the overall capital expenditure (CAPEX) for a project. For the Kosovo case, most of the service providers use an aerial electric network that is owned by KESCO (Kosovo Electricity Supply Company) as a base to build their networks.

Besides sharing the infrastructure, the capacities in cable networks (such as HFC) are shared among the same client base. With shared capacities it may be that due to the high demand of one subscriber the other subscribers' resources can be affected during peak hours.

Due to the property of the shared capacity, cable-service providers offer different broadband services. The broadband market can be seen as a pyramid with different service tiers. Usually, the majority of the subscribers choose between a basic or economic service tier, which represents the bottom and medium tiers. The premium service tier is intended for business clients. The shared infrastructure makes it possible to offer basic, medium and premium services in a very effective way [7].

The global average internet speed for Q1 of 2017 [8] is 7.2 Mbps. The country with the highest average internet speed is S. Korea, with 28.6 Mbps. In Europe, the highest ranked country is Norway, ranked as the second in the world, with an average internet speed of 23.5 Mbps. Singapore recorded the largest annual internet-speed increase (24%). The USA is also in the top ten with a 22% speed increase. Slovenia is ranked 29th in the world, having an average internet speed of 14 Mbps with an annual increase of 13%, but FTTH is making progress [9].

Broadband demands are dependent on the variety of users and their needs. The future growth is still uncertain to some extent, so the future requirements are unknown. There are different assumptions, starting from those who assume that the gigabit speeds will soon be required and others who claim that the requirements will be far less. Ultimately, the internet services offered by cable-service provides will reach the limits of HFC with Data Over Cable Service Interface Specification (DOCSIS) 3.0.

Predicting the internet-data usage for the coming years is a complex process, there are lots of factors to be taken into account and it is not easy to make a proper prediction. It is predicted that the main factor that will drive us toward the gigabit usage will be Augmented Reality (AR), Virtual Reality (VR) and Holographic Video [4]. Besides the bandwidth increase, latency will also be an important factor for future applications. In Fig. 3 we present the future applications and their needs in terms of the bandwidth and latency [10].

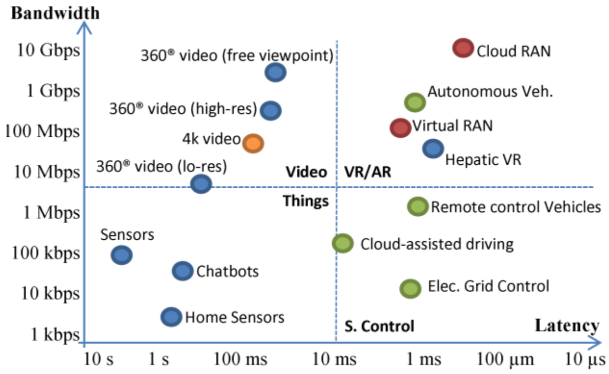

Figure 3. Future applications and requirements.

Besides the well-known Nielsen's law that predicts a 50% increase in the maximum speed, CISCO foresees that global average fixed speeds will double by 2020 [11], as shown in Fig. 4. The same trend is expected for Kosovo case.

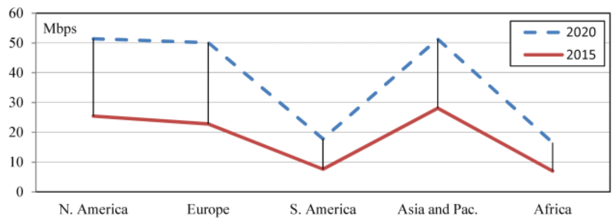

Figure 4. Global average fixed broadband-speed prediction.

3 IPKO's HFC TOPOLOGY AND THE AVERAGE INTERNET SPEED IN KOSOVO

In Kosovo, IPKO and Kujtesa offer their broadband services through the HFC access network and Telekom of Kosovo is using xDSL technology [2]. The leading technology is HFC, with standard DOCSIS 3.0. Over 74% of the subscribers are connected through HFC (DOCSIS), followed by DSL (18%) and FTTX (2%). The IPKO's main access network is the HFC network, with the Euro DOCSIS 3.0 standard being applied.

3.1 HFC network

One of the most promising technologies in the wireline access network is the cable technology. In telecommunication industry, the cable technology is commonly known as hybrid fiber/coax (HFC). As the name indicates, the HFC network comprises an optical fiber and coaxial cable part. The optical fiber is used as the primary distribution medium to carry the signal from the headend, where the cable modem termination system (CMTS) is located, up to the point in the network known as the optical node (ON), located in the center of the neighborhood, as presented in Fig. 5. ONs have optical/electrical signal converters. From ON, the coaxial network is used to propagate the radiofrequency (RF) downstream signal to the client premises, where a cable modem (CM) for internet services is installed. The same path is used for the upstream communication from CM to ON. After the electrical/optical conversion at ON, a separate fiber is used to send the signal back to the headend.

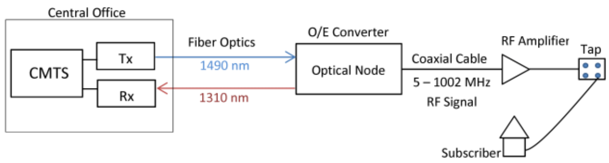

Figure 5. HFC network topology.

Over the years, service providers have progressively extended the optical part of the network closer to the customer in order to improve the quality of service and increase the capacity. Usually, the coaxial part of the network is called the last kilometer or last mile.

3.2 DOCSIS

The DOCSIS standard is developed by Cable Labs and regulates the use of the HFC network for broadband communication. To meet the continuous demands for higher broadband capacities and better quality of services, DOCSIS has evolved accordingly. The first version of DOCSIS was introduced in 1997 with a maximum of 40 Mbps capacity in the downstream and 10 Mbps in the upstream. The table below presents the DOCSIS evolution [4].

Table 1. DOCSIS versions

Broadband Generation	Highlights	Downstream Capacity	Upstream Capacity	Production Date
DOCSIS 1.0	Initial cable broadband technology	40 Mbps	10 Mbps	1997
DOCSIS 1.1	Added voice over IP service	40 Mbps	10 Mbps	2001
DOCSIS 2.0	Higher upstream speed	40 Mbps	30 Mbps	2002
DOCSIS 3.0	Greatly enhanced capacity	1 Gbps	100 Mbps	2008
DOCSIS 3.1	Capacity and efficiency progression	10 Gbps	1-2 Gbps	2016

The first gigabit-capable version of DOCIS is version 3.0. It is the most widely used version of DOCSIS today, mainly used in cable networks in North America and Europe [4]. DOCSIS 3.1 is the newest version, released in 2016, that defines support for the downstream capacities of 10 Gbps. Some of the most notable performance enhancements for 3.1 versions are [12], [13]:

- 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 QAM with options up to 16,384 QAM
- OFDM channels bandwidth can extend from 24 to 192 MHz in the downstream direction and 6.4 to 96 MHz for upstream direction leveraging 25 kHz or 50 kHz sub-carriers.

The cable industry has been very consistent in keeping pace with customers' demands for high internet speeds and other services. Even in the age of FTTH, the cable industry has been offering broadband speeds comparable with the FTTH solutions.

The bandwidth capacity carried today by the HFC access network is far away from the real potential that HFC offers. With smaller investments and upgrades in the existing HFC networks it is possible to increase the broadband capacities, which decreases the need to take a more revolutionary path, such as deployment of an FTTH solution. This is also a more cost-effective solution from the economic perspective.

DOCSIS 3.1 enables data rates of 10 Gbps in the downstream capacity and 1 Gbps in the upstream capacity. It supports the DOCSIS legacy and enables the extension of the upstream spectrum up to 200 MHz and downstream spectrum to 1.2 GHz or 1.7 GHz. For the future, it is predicted to develop full duplex DOCSIS, which would enable symmetric 10 Gbps capacities [4, 14].

To be able to support rates of 1G/10G in DOCSIS 3.1, the existing frequency spectrum of 5–869 MHz is not sufficient, even with a higher spectral efficiency. Compatibility with DOCSIS 3.0 is guaranteed through the same HFC frequency spectrum. As shown in Table 2, the migration to DOCSIS 3.1 requires some of the elements to be replaced or upgraded, while others can be used in their unchanged form.

Table 2. The compatible network elements for DOCSIS 3.0 and 3.1.

	DOCSIS	
Equipment	**3.0**	**3.1**
CMTS	X	
Optical Eq. in HE	X	
Optical Nodes	X	
Amplifiers	X	
Optical Cable	X	X
Coaxial Cables	X	X
Cable Modems	X	

3.3 Current configuration for the Vitia network

To be able to provide Gigabit broadband capacities in the Kosovo case, we have to analyze the current capacity usage, technical possibilities for future network upgrades and techno-economic aspects of HFC network upgrades. This study uses the Vitia HFC network as the subject of the analysis. The data from the HFC network is collected at the IPKO’s platform.

Vitia is a town in the south of Kosovo with a population of around 10,000. The implementation of the HFC access network was completed in 2010, with EuroDOCSIS 2.0 being the standard at that time. In 2013 EuroDOCSIS was upgraded to 3.0.

The HFC network of Vitia is aggregating in 16 segments, where each of them has one ON assigned, as graphically presented in Fig. 6. To have a manageable noise level in the network, the maximum number of RF amplifiers in a cascade is five, although only three amplifiers in the cascade and twelve amplifiers per ON, on average are used in practice in the Vitia network. The HFC topology used in Vitia is known as tree and branch.

Fig. 7 presents the spectrum allocation in the Vitia network. With DOCSIS 3.0, it is possible to expand the frequency band above 1 GHz, but in the IPKO case due to the fact that existing passive equipment installed in the network supports a frequency band up to 860 MHz, it is not possible to use a higher frequency band without upgrading the network.

The frequency band from 40 to 65 MHz with four QPSK channels of 6.4 MHz is used for upstream communication. Each of the two ONs share four channels of the total of 40 Mbps capacity. For the downstream communication the frequency band from 498 MHz to 554 MHz with eight QAM channels of 8 MHz is used. EuroDOCSIS 3.0 provides channel bounding to enable better optimization of the capacity usage, since one service group with eight ONs shares the capacity offered by eight downstream channels. The modulation type for downstream communication is 256 QAM and the capacity per downstream channel is around 50 Mbps. In total, 400 Mbps are available for an eight channel bounding.

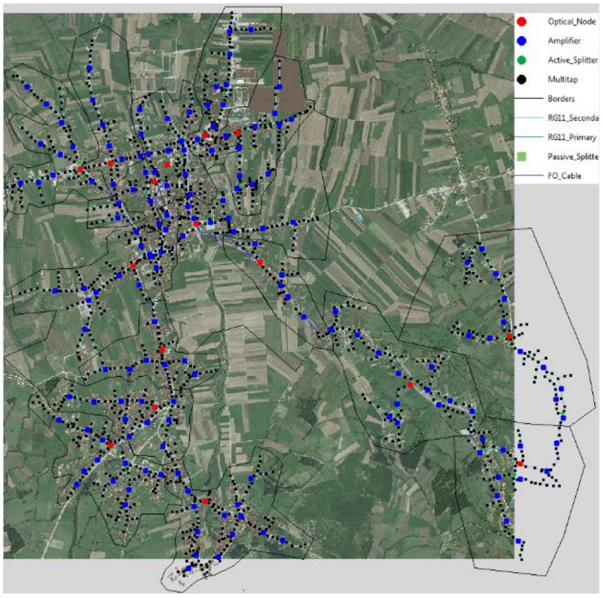

Figure 6. HFC coverage of the Vitia network.

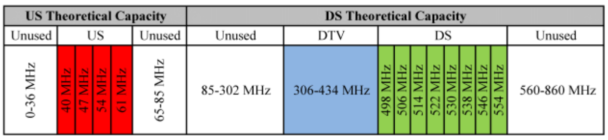

Figure 7. Spectrum allocation in Vitia

The current setup for the downstream and upstream communication with the number of modems, channel width, and modulations used is presented in Table 3.

Table 3. Channel bonding and capacities per ON.

Nr	Project name	Total CM	Total Shared Cap. (Downstream)	DS ch. Per Sevice Gropu	Channel Width in MHz	DS Mod.	Total Shared Cap. (Upstream)	US ch. Per Sevice Gropu	Channel Width MHz	US Mod.
1	Vitia 01	186	400 Mbps	8 Channle	8 MHz per channel	256 QAM	40 Mbps	4 Channels	6.4 MHz per channel	QPSK
2	Begunca 01									
3	Vitia 02	113					40 Mbps	4 Channels		
4	Vitia 03									
5	Vitia 04	103					40 Mbps	4 Channels	6.4 MHz per channel	QPSK
6	Vitia 05									
7	Vitia 06	140					40 Mbps	4 Channels		
8	Vitia 07									
9	Vitia 08	160	400 Mbps	8 Channels	8 MHz per channel	256 QAM	40 Mbps	4 Channels	6.4 MHz per channel	QPSK
10	Vitia 09									
11	Vitia 10	132					40 Mbps	4 Channels		
12	Begunca 01									
13	Kabashi 01	132					40 Mbps	4 Channels	6.4 MHz per channel	QPSK
14	Kabashi 02									
15	Begunca 03	154					40 Mbps	4 Channels		
16	Binça									

With the current frequency allocation and the capacities offered in Figs. 8 and 9, it presents the current average usage of the existing capacities, maximum (peak hours) usage and the capacities that are available with the current configurations for both downstream and upstream communication.

For the Vitia network, the downstream communication set-up is organized to have two service groups (SG) with eight ONs assigned per each SG. The number of households per each SG is approximately 800 and they share 400 Mbps of the broadband capacity. Currently, the average capacity usage is around 200 Mbps or 50% of the total capacity in disposal. In the peak hour, which is at around 8 pm, the capacity usage is 366 Mbps.

In the upstream direction, two ONs are assigned to SG with a 40 Mbps capacity. The average speed varies from 3 to 10 Mbps, while the peak hour speed varies from 10 to 20 Mbps, depending on the number of cable modes assigned to each ON.

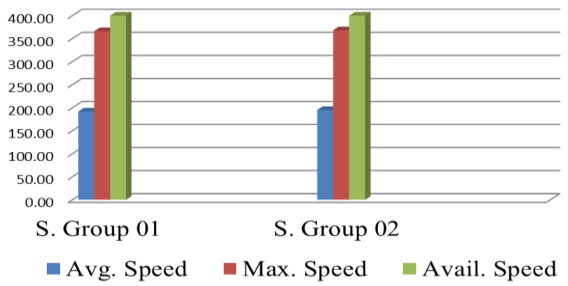

Figure 8. Downstream internet speeds for the Vitia network (Mbps).

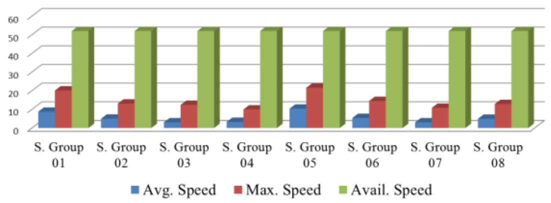

Figure 9. Upstream internet speeds for the Vitia network (Mbps)

In total there are 48 channels for the downstream communication, offering up to 2.4 Gbps. MSPs should note that there are additional costs for channel licenses and modems to enable the clients to use these capacities. These capacities are comparable to the gigabit-capable passive optical networks (GPON).

3.4 IPKO broadband-service tiers

Mainly for the economic reasons, most of the today's service providers in the cable industry design their network as a shared infrastructure. This has a direct impact on lowering the costs per user and per service delivered. However, this should not come to the limit of risk for the quality of services and therefore requires a careful technical measurement to manage the traffic properly, especially in the time of congestions.

In the case of DSL, a dedicated capacity is assigned to each connection, and the capacity cannot be transferred to another customer when it is not used by the first customer.

By benefiting from the fact that not all users are active all the time and the fixed dedicated capacities are not needed at the same time, application of the shared capacity is made possible. The overbooking factor represents the ratio between the maximum bitrate and the average during ten minutes of the service peak hours. Overbooking allows the cable operators to calculate the shared capacities based on this factor. The today's value of overbooking is around 20, which means that they can provide broadband services with bitrates 20-times larger than the capacity per customer [15]. The Vitia network has approximately 550 subscribers with 400 Mbps available, which requires a 15 Mbps basic broadband service. Using the capacity of 100 Mbps, for example, 2.5 Gbps can be offered for the same service group.

Due to the property of the shared medium in most of the broadband industry, all three service providers in Kosovo have organized their broadband-service tiers in the upper (top), medium (common) and lower (basic) tier. The upper tier represents the premium service with few customers receiving this service. The majority of the customers receive the basic and common tiers. Table 4 presents the broadband services for the Kosovo market.

Table 4. Service tiers in Kosovo market.

	IPKO (HFC)		Kujtesa (HFC)		Telekomi i Kosoves (xDSL)	
Service tier	Service name	Content	Service name	Content	Service name	Content
Basic tier	DUO Familjare	10 Mbps	HDMAX Spring	10 Mbps	TiKtv&on &Tel A	2 Mbps
		100 SD Channels		125 SD Channels		93SD Channels
		NA		16 HD Channels		7 HD Channels
Medium tier	DUO Familjare HD	10 Mbps	HDMAX Bonus+	20 Mbps	TiKtv&on &Tel B	5 Mbps
		100 SD Channels		125 SD Channels		93SD Channels
		16 HD Channels		16 HD Channels		7 HD Channels
Premium tier	Super DUO Premium	25 Mbps	HDMAX Smart+	60 Mbps	TiKtv&on &Tel C	10Mbps
		110 SD Channels		125 SD Channels		93SD Channels
		33 HD Channels		16 HD Channels		7 HD Channels

All the service tiers are a triple-play, which means they offer internet, television and fixed-telephony services.

The table does not include the business clients that use dedicated capacities. In IPKO, over 95% of the clients belong to the basic and medium tiers.

3.5 Prediction

One of most consistent predictions over the past 30 years is the Nielsen's law. It predicts that the user's required maximum speed doubles every 21 months, which means an annual increase of 50% [1], [7]. Using the measurements from the IPKO network and taking into account the Nielsen's law for our study case, we have predicted the possible capacity increase up to 2023.

Based on this prediction, the same number of customers (as today) will require a gigabit capacity in 2019 and almost 5 Gbps capacities by 2023. This prediction is made for the downstream-communication speeds, but the same increasing trend is expected in the upstream communication.

What we should have in mind is that the Compounded Annual Growth Rate (CARG) of 50% according to the Nielsen's Law is applicable for the top tier, which in the Vitia case represents less than 5% of the total clients. Other services that represent over 95% of the client base belong to the basic and medium service tiers, and CARG for these service tiers is from 25% to 30% [7], [16]. For this reason another prediction is made for 25% CARG, as presented in Fig. 10. This shows that in 2021 lower tiers will require gigabit capacities.

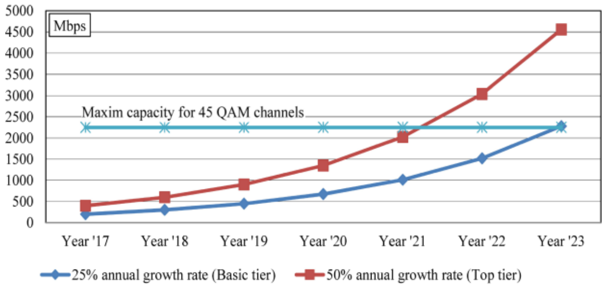

Figure 10. Maximum capacity (in Mbps) increase projection based on a 50% annual growth rate.

Based on this prediction, we suggest the IPKO approach for the capacity upgrade by choosing a selective subscriber-migration strategy and migration of the top service tier to FTTH. This also offers the possibility to recalculate the capacity for the re-use for other service tiers [7].

4 APPROACHES SUPPORTING THE FUTURE CAPACITY NEEDS

In order to be able to support the subscriber's needs for higher broadband speeds in the cable industry, plans for upgrades in the network should be made. There are two common approaches that can be followed to find the future proof solutions for the gigabit capacities. The first (evolutionary) approach tends to increase the bandwidth through the HFC technology by using advantages of new available technologies. In this scenario, the last mile of the access-network infrastructure is kept unchanged as long as possible. In the second (revolutionary) approach, service providers usually build a parallel network. There are several options to choose from, mainly relying on the FTTH architecture [14]. Both approaches have pros and cons from the technical and economic perspective.

4.1 Technical perspective

In this section we discuss the Vitia network upgrade based on the evolutionary and revolutionary approache.

In all media (copper, coax or fiber), the technologies are expanding their capacities. For the brownfield case of Vitia, having in mind that IPKO has already started pilot projects with GPON, the two logical paths that can be taken are investing in DOCSIS and upgrading the exiting network, or taking a more radical step such as switching to the GPON technology. To have a clearer idea about the capacities offered now and in the near future by HFC (DOCSIS) and passive optical network (PON), the data is collected in Fig. 11 [17]. These values represent the capacities after encoding and using FEC.

Although there is a slight advantage for PON, these results are comparable (xG-PON2 and Full Duplex DOCSIS offer a symmetric 10G capacity). From this perspective, continuing with HFC (DOCIS) is very favorable for the Vitia network.

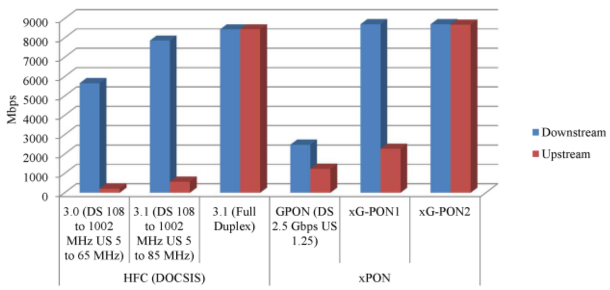

Figure 11. HFC and GPON capacities used for the analysis.

XG-PON is a more revolutionary step, but offers some advantages over DOCSIS 3.1. Having a passive distribution network offers great advantages for its maintenance. Fiber optic cables do not pose a problem with the capacity limits in an access network, which makes PON a more future-proof technology [18].

4.2 Economic perspective

Both the evolution and revolution path have their financial implications. Greenfield investments are moving towards FTTH, butwith a frequency-spectrum extension, node splitting, DOCSIS 3.1 and full duplex DOCSIS. As shown in previous sections, the cable networks still offer a great potential for gigabit capacities, especially in the brownfield cases as is the case with the Vitia network.

In the Vitia brownfield case, the coverage with the HFC network is near 100%, the migration options are several and the path to be chosen is not so straightforward.

To evaluate the economic evolution for HFC and FTTH, we have used data from IPKO, as IPKO has already started with a GPON pilot project and can gain valuable results regarding the possibility of network migration for Vitia. As the existing HFC network in Vitia is an aerial network, the same conditions are assumed for the GPON case. (Fig. 12)

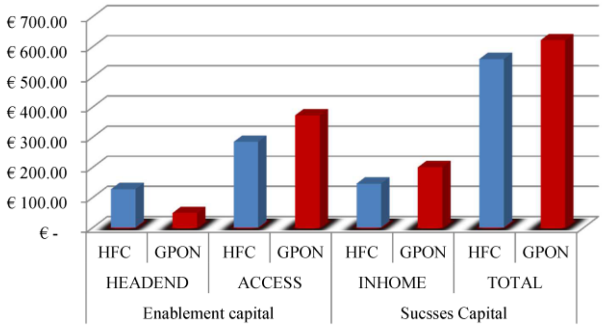

Figure 12. HFC vs FTTH comparison.

Our analysis is conducted for a 35% take rate, which is currently the take rate in the HFC network. Fig. 13 presents the HFC and GPON architectures used in this economic analysis. The analysis shows that the overall prices for DOCSIS 3.0 and GPON are comparable. As adopting the FTTH solution over the top of HFC for the Vitia network is a very expensive, a evolutional road is proposed.

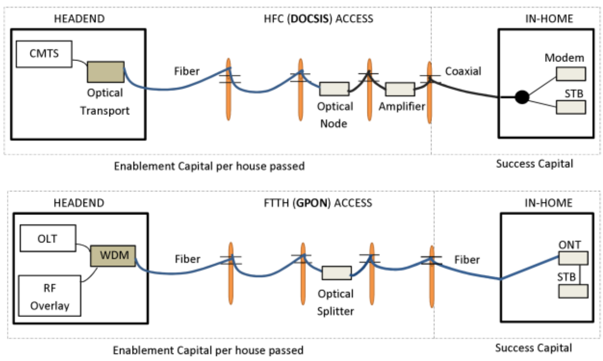

Figure 13. HFC and GPON networks used for the analysis.

4.3 Brownfield migration for the Vitia network

The pillars of the future cable access network will be a deeper fiber penetration and higher capacities, through node splitting, deep fiber, spectrum expansion and spectral efficiency by the DOCSIS evolution. With smaller nodes, additional spectra and higher spectral efficiency, gigabit capacities will be offered to the Vitia customers.

As seen from the capacity prediction given in Fig. 11 using a 25% CARG, the gigabit capacities will not be needed before 2021, and by 2019 the capacity at the top tier it is expected to reach a 1 Gbps. The most logical path to be taken is a deep fiber and higher capacities to be achieved by the node-size reduction, higher modulation and spectrum expansion [19]. An evolution scenario suitable for the Vitia network is presented in Fig. 14, where the roadmap of the HFC access-network evolution is presented.

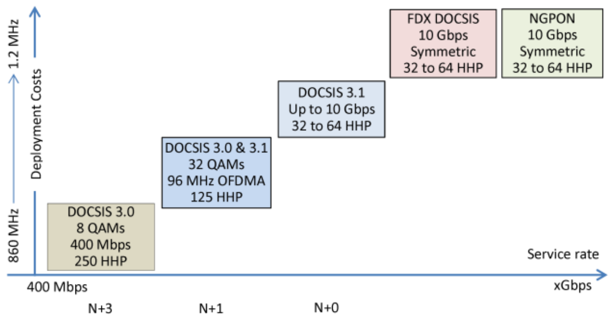

Figure 14. Roadmap of the Vitia network evolution.

The future demand for a higher capacity in the Vitia network can be resolved by a gradual migration. An additional spatial reuse can be achieved by a node-size reduction. The node-size reduction from *N*+3 to *N*+0 means that the number of pasted households will gradually decrease from 300 to 64 or even 32. With each ON split, the capacities offered for SG are doubled. The node splitting of the current 16 Vitia ONs would double the capacity per SG. With the first node split, SG will be reduced on average from 550 to 250 subscribers, but the SG capacities will remain the same. This means that the capacity per SG will be doubled. The financial implications are related to installation of additional fibers, new ONs and new optical transmitters and receivers in the headend.

With migration to DOSIS 3.1, more spectral efficiency is achieved by increasing the modulation up to 4096 QAM and using full duplex DOCSIS, with a 10 Gbps capacity for the downstream and upstream direction. With the possibility of migration to 3.1 and spectrum expanded to 1.2 MHz, the capacities can reach 10G/1G, which is comparable to XGPON. By switching to a remote, physically distributed access architecture, where the full physical layer, including FEC, symbol generation, modulation and digital-to-analog and analog-to-digital conversion are moved from the headend to ON, the signal-to-noise ratio will improve and decrease the headend power and rack space [20]. With the possibility of an additional expansion to 1.7, followed by full duplex DOCSIS, symmetric 10G/10G capacities in both directions are also achievable for the future Vitia customers.

5 CONCLUSION

Our paper presents the HFC technology, statistical data on its users and its market share compared to other access technologies, together with the current trends.

The current internet-speeds and traffic-growth estimations in the world are discussed. Our analysis is based on the current HFC network configuration in the Kosovo town of Vitia, with the data of the current internet speeds for the upstream and downstream communication. Based on 50% CARG for the top tier and 25% CARG for the basic tier capacity prediction up to 2023, we propose, compare and comment different upgrade options to follow these trends. We analyze two possible migration solutions, namely DOCSIS 3.1 and GPON. Based on the technical and economic analyses, we propose an evolutionary migration approach compliable with the speed-growth predictions. Such migration approach can also be used for other similar brownfield scenarios.

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