International Journal of Engineering & Technology*, 9 (3) (2020) 837-841*

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Emerging network architecture of ultrafast fixed broadband technologies and solutions

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Abstract

This article is introducing the development and emerging network architecture of the newest ultrafast fixed broadband (BB) technologies and solutions in the terrestrial telecommunication industries right across the globe. The modern ultrafast networks and access technologies are known as G.fast, Data Over Cable Service Interface Specification 3.1 (DOCSIS 3.1), and Gigabit Passive Optical Networks (GPON). The basic concepts associated with broadband communication network technologies with emphasis on the provision of multipurpose service focused on the evolution and challenging fields of the broadband communication techniques from the traditional architecture to the incorporation of virtualization services here are also discussed.

Keywords: *Broadband; G.fast; DOCSIS; GPON; XG.fast; STP; UHD; DSLAM; FTTH; FTTP; ADSL/VDSL; ONT; TDMA;*

1. Introduction

Demands for ultrafast broadband bandwidth and access technologies today have largely been driven by the increasing importance of video and TV transmissions, tactile Internet and multimedia. Future applications have to provide not just increased download speeds, but also higher upload speeds and better quality, as measured by characteristics such as low latency, jitter and packet loss, and high availability (uptime) of services.

The global broadband technology markets are using three current access networks of Digital Subscriber Line (DSL) over copper cable, Data Over Cable Service Interface Specification (DOCSIS) over coax cable, and Passive Optical Network (PON) over fibre infrastructures, which have to be upgraded with migration to completely new solutions such as G.fast, DOCSIS 3.1 and Gigabit PON (GPON), respectively. However, the final results of these enhanced technologies are the implementation of the newest generation ultrafast XG.fast, DOCSIS 3.1FD/XG-Cable, and XG/XGS/TWDM GPON broadband technologies, which will be a new alternative to users on the telecommunications market in the coming years.

2. Brief retrospective of networking cables

Since the telephone network solutions advent over 100 years ago, the dominant way to wire the home involved the use of copper cabling. The copper phone wire is perfectly adequate for a voice signal, which is what it was intended for. All things considered, however, it offers very limited bandwidth. Still, so many are familiar with copper that they doubted any other medium would ever supplant it.

Copper does offer advantages for those in rural areas. It already exists (it has been used, as noted, to wire telephones, so copper already found its place in the household) and is less expensive when used to connect network devices. Those in rural areas where no fibre optics have been run may find copper the most cost-effective, because they don't have to pay to run new cabling.

The modern solutions of ordinary copper wire are the twisted pair that connects home and many business computers to the network of telephone telecommunication companies, which sample is illustrated in Figure 1 (Left). However, to reduce crosstalk or electromagnetic induction between pairs of wires, two insulated copper wires are twisted around each other, known as a Shielded Twisted Pair (STP).

Coaxial cable was invented by English engineer and mathematician Oliver Heaviside, who patented the design in 1880. Coaxial cable or coax is a type of electrical cable that has an inner conductor surrounded by a tubular insulating layer, surrounded by a tubular conducting shield. Many coaxial cables also have an insulating outer sheath or jacket. Thus, the term coaxial comes from the inner conductor and the outer shield sharing a geometric axis. Coaxial cable is used as a transmission line for radio frequency signals and for feedlines radio transmitters and receivers to antennas, computer network and Internet connections, digital audio, and distributing cable television signals.

Fig. 1: Twisted Copper Pair, Coaxial and Fibre Cable Solutions.

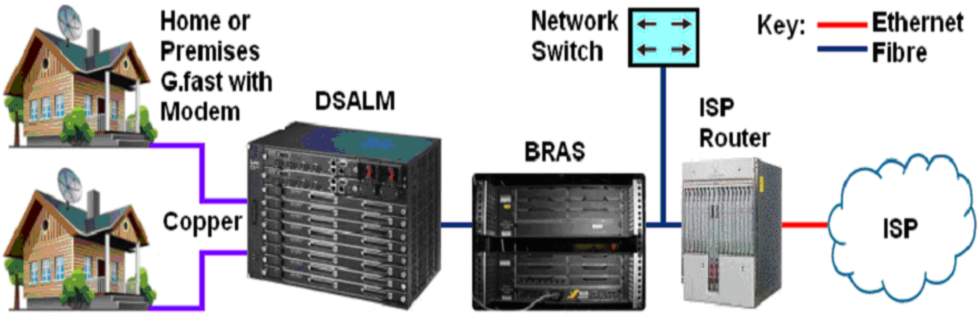

Fig. 2: Solutions for G. fast Network.

Coaxial cable conducts electrical signal using an inner conductor, usually, a solid copper, stranded copper or copper plated steel wire, surrounded by an insulating layer and all enclosed by a shield, typically one to four layers of woven metallic braid and metallic tape, which configurations is shown in Figure 1 (Middle).
Fibre optics refers to technology that transmits data through thin strands of a highly transparent material that usually is either glass or plastic. Fibre optic communications were launched in the 1970s, though the first fibre optic telecommunications networks were not installed until the early 1980s. By the mid-1980s, the bandwidth and distance of fibre capabilities made it significantly less expensive than other communication mediums, so it has replaced them. In the mid-1990s, cable television discovered fibre could enhance performance reliability, as well as enable the offering of both phone and Internet service on the same fibre, which solution is illustrated in Figure 1 (Right).
Fibre optic versus copper wire transmission is faster and can be boiled down to the speed of photons versus the speed of electrons, which travel at the speed of light of 299,792 km/s in the vacuum. Its transmission results in less attenuation when traveling over a long distance, thus fibre optic cables experience less signal loss than copper cabling, known as low attenuation.
Fibre optic cables are impervious to electromagnetic interference, namely which loses are only 3% signal strength going over 100 meters (approximately 320 feet) in distance. By contrast, copper loses 94% over the same distance. Finally, fibre optic cables do not break as easily, which means that you will not have to worry about replacing them as frequently as copper wires.

3. G. Fast network

The direct predecessor of G.fast is G.now full duplex broadband technology. Thus, G.now is an extension of G.hn (home networking) for the broadband access that enlarges the scope of the ITU-T G.hn to meet the fastest market requirements up to 500 Mb/s, with no truck roll job supporting Ultra High Definition (UHD) and latest IEEE 802.11ac standard as short Backhaul Evolution Program (BEP). The IEEE 802.11ac spec will allow wireless speeds in excess of a gigabit per second in the actual payload. Before that it was used Very-high-bit-rate Digital Subscriber Line (VDSL) solution, 20 years old technology, supporting 100 Mb/s maximum limited in HD/UHD.
The G.fast solution is the latest in copper technology and is intended for deep fibre applications called Fibre-to-the distribution point (FTTdp) where the distribution point is about 200 meters or less away from the home. This is an extended frequency approach using 106 MHz and 212 MHz profiles unlike the 30 MHz spectrum limit of VDSL2. Thus, G.fast is not intended to replace VDSL2 copper links greater than 250 meters and it speeds promise up to 1 Gb/s, but typical speeds maybe 150 Mb/s for 250 meters, 200 Mbps for 200 meters, and 500 Mbps for 100 Meters, which capacity will vary on spectrum used and distance.
In general, the G.fast solution aims to provide ultrahigh speeds over copper twisted pairs, up to and sometimes even exceeding speeds of 1 Gb/s. The planned loop lengths for G.fast are from 50 to 250 meters (150 to 750 feet) between DSL Access Multiplexer (DSLAM) and FTTH or FTTP with G.fast modem.
The G.fast network is shown in Figure 2, which is expected to be deployed in the FTTdp (distribution point) architecture, where the Internet Service Provider (ISP) is connected to the ISP Router via an Ethernet cabling, and then the broadband signal is fed to the Broadband Remote Access Server (BRAS), Network Switch and DSALM terminal throughout fibre lines. From there, very short copper cables and drops of about 250 meters serve subscriber G.fast modem in-home or premises.
The main advantage of G.fast network is that it's much cheaper to install modem than FTTP, so the ITU reckons customers will be able to install it themselves in homes. The main disadvantages are that it's not as fast as FTTP, and that, as with Asymmetric Digital Subscriber Line ADSL/VDSL, speed falls off with distance. It is meant to "bridge the gap", namely is enabling operators to offer FTTH-like speeds where fibre is not currently available or time to market is of high importance in a competitive environment. Its key features such as support for 212 MHz and coaxial cable have proven to be attractive characteristics and allowing it to be a viable option for their broadband services but also opening up potential deployment opportunities for a variety of operators.
Traditionally, copper network operators complement an FTTH strategy with a hybrid fibre copper deployment in which fibre is gradually brought closer to the consumer, and DSL technology is used for the remaining copper network. The evolution aspect of G.fast is new system concepts of XG.fast, a 5th generation broadband technology capable of delivering up to 10 Gb/s bandwidth connection speeds over two twisted short copper pairs bonded at 30 metres distance.

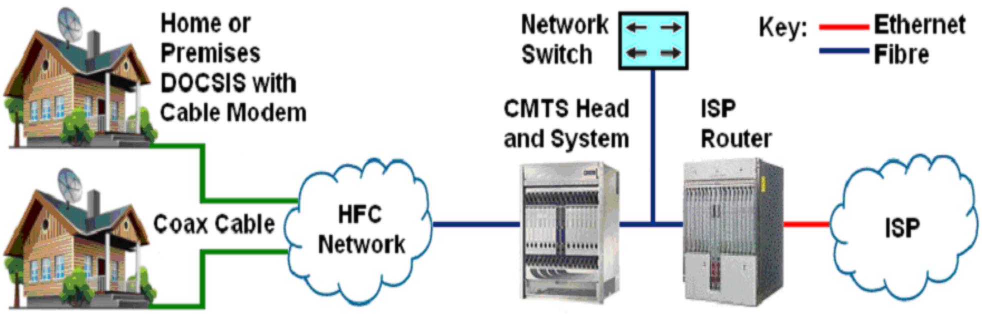

Fig. 3: Solutions for DOCSIS 3.1 Network.

4. DOCSIS 3.1 network

The Data Over Cable Service Interface Specification 3.1 (DOCSIS 3.1) standard enables the cable to readily deliver 1Gb/s downstream. Full duplex further extends its capabilities and enables symmetric bandwidth at 10 Gb/s. However, full-duplex may require fibre to the last amplifier, and the shared nature of cable networks and the involvement of active equipment in the access network may limit quality, especially compared with point-to-point FTTP.

The DOCSIS 3.1 network is depicted in Figure 3 with its main components. It is deployed in Fibre Node architecture in which ISP and ISP Router are connected through Ethernet cable. Then, fibre lines are connecting Network Switch and Cable Modem Termination System (CMTS) Head and System with HCF Network and DOCSIS modems in customer homes or premises.

The DOCSIS 3.1 system has its predecessors such as DOCSIS 1.0 developed in March 1997, DOCSIS 1.1 in March 1999, DOCSIS 2.0 in December 2001, DOCSIS 3.0 in August 2006 and DOCSIS 3.1 October 2013. DOCSIS 3.1 is incompatible with DOCSIS 3.0, and migration to it is not an evolutionary upgrade. Thus, it requires new CMTS terminals, new modems, re-segmentation of the network, as well as repetitively licensable frequencies, making the transition a perpetual investment. In the near future, migration from DOCSIS 3.1 requires many steps and will improve impact on customer satisfaction.

The first DOCSIS 1.0 version achieves a full-duplex downstream capacity of 40 Mb/s and an upstream capacity of 10 Mb/s with only data applications, while DOCSIS 1.1 has the same capacity of both transmissions with added Voice over IP (VoIP) capabilities and standardized the DOCSIS 1.0 QoS mechanisms. The DOCSIS 2.0 version provides the same downstream capacity and an upstream capacity of 30 Mb/s with enhanced upstream data rates. The DOCSIS 3.0 provides a downstream capacity of 1.2 Gb/s and an upstream capacity of 200 Mb/s with a significantly increased transmission data rates, introduced support for IPv6 and introduced channel bonding.

Announced in February 2016 DOCSIS 3.1 Full-Duplex (FD) XG Cable system is an evolution project developed to improve DOCSIS 3.1 and to use the full spectrum of the cable plant (0 MHz to ~1.2 GHz) at the same time in both upstream and downstream directions. In fact, this technology is proposed to enable multi-gigabit symmetrical services while remaining backward compatible with DOCSIS 3.1.

The DOCSIS 3.1 full-duplex broadband technology significantly increased downstream and upstream data rates, restructured channel specifications, with a maximum downstream capacity of 10 Gb/s and maximum upstream capacity of 1 – 2 Gb/s, while the new DOCSIS 3.1 FD technology introduces support for fully symmetrical speeds with same downstream and maximum upstream capacity of 10 Gb/s.

The Netgear DOCSIS 3.1 CM1000 Ultra-High Speed Cable Modem provides a connection to high-speed cable Internet with speeds up to 1 Gb/s for customer PC or Wireless Router, which network architecture of Netgear producer is depicted in Figure 4.

Therefore, this is a new case of the first designed sample of DOCSIS 3.1 CableLabs certified cable modem that supports Internet service providers DOCSIS 3.0 and 3.1. In addition, the ultra-high-speed modem cable is ready for today's service plans and future upgrades.

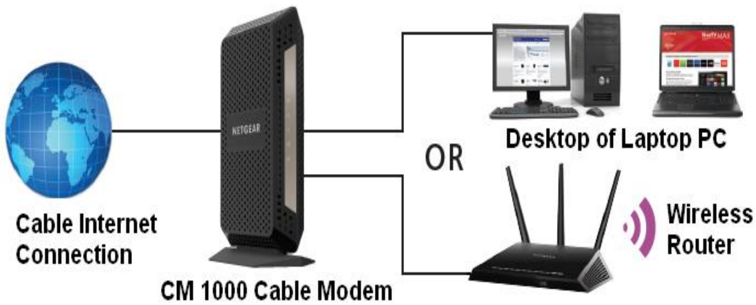

Fig. 4: DOCSIS 3.1 Ultra-High-Speed Cable Modem of Netgear Producer.

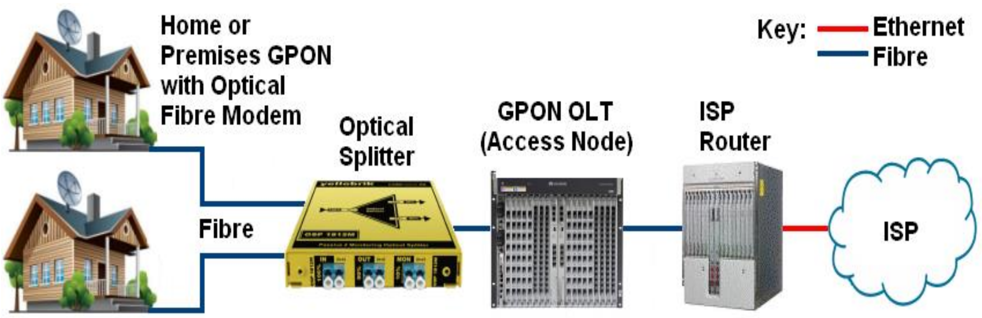

Fig. 5: Solutions for GPON Network.

One of the key advantages of DOCSIS 3.1 over Fibre applications is that it uses the same "last mile" technology, the coax cable, to support the higher Gigabit speeds. The DOCSIS 3.1 provides speeds up to 50% faster than existing DOCSIS 3.0 to the home or business premises and its standard offers significant benefits to cable network operators. However, the primary disadvantage of cable Internet lies in the coaxial end of the connection, especially if customers are essentially on a network loop with the other residences in their area and share bandwidth. Most of the time this may not be a problem, but during hours of peak Internet usage, customers might notice network speed slow considerably.

5. GPON network

The Gigabit Passive Optical Networks (GPON) access network is a point-to-multipoint, fibre to the premises network architecture in which unpowered optical splitters are used to enable a single optical fibre to serve 32-128 premises. The GPON FTTH network exploits the low attenuation and high bandwidth of single-mode fibre to provide many times more bandwidth than currently available with existing broadband technologies.

This broadband standard extends fibre all the way to the home or premises, and uses an entirely passive Outside Plant (OSP), with the exception of Optical Network Terminals (ONT), that are sometimes located outside of the home or premises. While the point-to-point links of Vectored VDSL, G.now, or G.fast are entirely separate until they are aggregated by Ethernet switching at a DSLAM or DPU, GPON shares the fibre medium among multiple subscribers. This sharing is performed with Time-Division Multiple Access (TDMA) under the scheduling control of the Optical Line Terminal (OLT). In this way, multiple (typically 32) subscriber lines are combined into a single fibre running into an exchange and terminating on an OLT. Thus, there are relatively few ports on the network-end active equipment. This system is standardized by the ITU-T G.984 series of Recommendations and typically supports aggregate line rates of 2,488 Mb/s in the downstream direction and 1,244 Mb/s in the upstream direction on two separate wavelengths.

The advantage of the GPON standard is that it uses the GigaPON Transmission Convergence sub-layer (GTC). The GTC solution defines several different types of containers for scheduling Time Division-Multiplexing (TDM) services with guaranteed QoS. Under this scheme, portions of each time frame are dedicated to services, and the OLT allocates downstream transmission opportunities.

The OLT infrastructure also performs Dynamic Bandwidth Allocation (DBA) to control the allocation of upstream transmission modes, which is assisted by a feedback mechanism from the ONT devices to the OLT cable for reporting buffer-fill. DBA can be further assisted by inputs from policy management systems. The GTC protocol allows fragmentation and is efficient, losing only a little of line rate to overhead, unless there is an unusually high number of service streams. While the speeds of GPON may seem ample, they are shared across many users and may at some times be exhausted, particularly for high-bandwidth services that are not amenable to a concentration such as unicast video streaming during prime-time. The GPON system can be upgraded by splitting nodes, e.g., serving 32 users per OLT port instead of 64, or it can be upgraded to new, higher-speed systems with no change to the fibre components of the OSP. XG-PON supports 10 Gb/s down and 2.5 Gb/s up using TDMA similar to GPON, but at faster line speed. XG-PON has been standardized and equipment is now becoming available.

The GPON network is illustrated in Figure 5, where ISP and ISP router are connected with an Ethernet line. From there, the GPON OLT access node via Optical Splitter is connecting home or premises GPON with optical fibre modem throughout fibre lines. The GPON network does not include electrically powered switching equipment and instead uses optical splitters to separate and collect optical signals as they move through the network. Thus, powered equipment is required only at the source and receiving ends of the signal. Additional advantages of GPON include their efficiency when in that each fibre optic strand can serve up to 32 to 128 customers. Finally, GPON has a low building cost relative to active optical networks along with lower maintenance costs.

The main disadvantage of GPON is the installation cost of fibre all the way to the home or apartment; the fibre-drop and ONT installation are particularly costly. Thus, Greenfield deployments are clear winners for GPON, however they represent roughly only 1% of subscribers per year. In Brownfield deployments, the aerial plant is easier to upgrade to fibre than the buried plant.

Generally speaking, only a subset of locations is cost-effective for GPON installation based purely on return-on-investment criteria.

Finally, an alternative model for deployment is to rely on "pull" demand from subscribers, whereby GPON installation takes place only after a certain number of customers have committed to purchasing the service.

6. Comparison of broadband access technologies

In comparison to current copper technologies it is possible to realize that the speed rate of ADSL is 24 Mb/s, VDSL provides 100 Mb/s, and the rate of G.fast is up to 1 Gb/s at 100 metres.

Coax cable is providing a speed rate from 1,2 to 10 Gb/s and full fibre FTTP is getting rate from 2.5 to 10 Gb/s.

An overview and comparison of the current above described and new designed broadband access technologies are shown in Table 1.

The basic access technologies for comparing the provision of broadband access are:

1) Copper Pairs – This broadband access technology is upgraded with FTTC/VDSL2, which future upgrades will rely on the replacement of the active VDSL equipment with G.fast and newest XG.fast alongside deployment of fibre closer to the customers by 10 times higher speed of transmission.
2) Coax Cable – Upcoming upgrades of DOCSIS 3.0 involve the deployment of DOCSIS 3.1 technology. Thus, a potential further enhancement to Full Duplex (FD) will allow symmetric connectivity, but require additional fibre deployment to the last amplifier close to the homes. Bandwidths on coax cable networks are 2 times higher than copper pair and can also be increased by node splitting and adjustments in spectrum use.
3) Full-fibre (FTTP) – Full-fibre can be deployed as a dedicated point-to-point or in a Point to multipoint architecture by 2025, in conjunction with PON technology. Upgrade paths for PON broadband technology include XG.PON and XGS.PON with further splits each fibre into wavelengths, enabling 4 times higher capacity of speed. The TWDM-PON system is still under standardization and development and will further split each fibre into wavelengths, enabling additional capacity, which up and down bandwidth can be from 4 to 8 x 10 Gb/s. The newest Ethernet point-to-point (P2P) based optical access system is an alternative to EPON for the access network. It provides very high bandwidth and Quality of service (QoS), low-latency direct fibre connections linking sites that are less than 28 miles apart with speed and its up and down bandwidth can be n (1, 2, 3, …) x 10 Gb/s.

Table 1: Overview of Broadband Access Network Technologies

Transmission Technology	FTTx	Bandwidth Down	Bandwidth Up	Individual/ Shared	QoS	Ultrafast BB 0.3G	Ultrafast BB Up-grade 1G
Copper Pair		[Gb/s]	[Gb/s]				
VDSL2 Supper Pair	FTTC	0.25	0.1	I	1	n	n
G.fast	FTTC/S/dp	0.5	0.5	I	1	y	n
XG.Fast	FTTB	5	5	I	1	y	y
Coax							
DOCSIS 3.0	Fibre Node	1.2	0.12	S	2	y	n
DOCSIS 3.1	Fibre Node	10	1	S	2	y	y
DOCSIS 3.1 FD/XG-Cable	Deep Fibre	10	10	S	2	y	y
Fibre							
GPON (PMP)	FTTP	2.5	1.25	S	2	y	n
XG.PON	FTTP	10	2.5	S	2	y	y
XGS.PON	FTTP	10	10	S	2	y	y
TWDM GPON	FTTP	4 - 8 x 10	4 - 8 x 10	S	2	y	y
Ethernet P2P	FTTP	n x 10	n x 10	I	3	y	y

7. Conclusion

The new fixed broadband market is dominated by three ultrafast access technologies, such as G.fast, DOCSIS 3.1 and GPON standards. The G.fast standard enables service providers to capitalize on existing infrastructure, achieving fibre-like speeds without rewiring urban areas already equipped with copper. It is the 4th generation DSL technology for local loops shorter than 250 metres, with performance targets between 150 Mb/s and 1 Gb/s, depending on loop length. High speeds are only achieved over very short loops less than 100 metres. However, while current G.fast technology covers up to 250 metres with reasonable bandwidth, under prevailing conditions, new XG.fast is typically used only for much shorter copper cable lengths of below 50 metres. It is likely that the needs of the most demanding users including for 1Gb/s download and significant up-stream capacity could be achieved only through XG.fast deployments.

Cable operators have a clear benefit of offering higher bandwidth peak rates compared to telecom operators and will continue with DOCSIS 3.1 rollouts. Thus far the DOCSIS structure foresees an asymmetry whereby 10% of the bandwidth is used for upstream traffic. If, as expected, traffic demand becomes more symmetric, this degree of asymmetry may result in a bottleneck. In order to overcome this, DOCSIS 3.1 will be amended by Full Duplex (FD) capability, which is announced with availability not planned before 2020.

The full-fibre GPON FTTP networks are capable of very high and symmetric transmission and therefore can in principle meet the requirements of high and top-level users in the medium term. However, there are also already higher performance systems of the GPON family market available, so additional network planning and upgrades with new generations of GPON standards should ensure that it is suitable at least for residential and most small business needs for the foreseeable future.

References

[1] Gul S. & Gutierrez J., (2017), "Evolution of Broadband Communication Networks: Architecture and Applications", IntechOpen Limited, London, 16. https://doi.org/10.5772/intechopen.73590.

[2] ASSIA, (2014) “Delivering Ultra-Fast Broadband)”, Adaptive Spectrum and Signal Alignment, Inc., Redwood City, CA, 17.

[3] ATM, (2017), “G.fast Modem – ARRIS”, Advanced Media Technology, Deerfield Beach, FL, USA, 5.

[4] Ilcev D. S., (2018), “Presentation of Mobile Broadcasting Networks", DUT, Durban, South Africa, 144.

[5] CTC, (2104), “The State of the Art and Evolution of Cable Television and Broadband Technology”, CTC - Columbia Telecommunications Corporation, Kensington, MD, 55.

[6] Zhao R. at all, (2012), “Broadband Access Technologies”, Fibre to the Home Council Europe, Brussels, Belgium, 18.

[7] Godlovitch L. at all, (2018), “The Benefits of Ultrafast Broadband Deployment”, WIK, Bad Honnef, Germany, 98.

[8] Mastrangelo T., (2018), “G.fast and furious in 2018”, Technically Speaking, ADVA Optical Networking, 3.

[9] Kelly T. & Rossotto C.M., (2012), "Broadband Strategies Handbook", International Bank for Reconstruction and Development, Washington DC, 404.

[10] Werbach K., (2014), "The Development of Fixed Broadband Networks", OECD Publishing, Paris, France, 50.

[11] Frontier Economics, (2016), Ultrafast network developments, competition and the EU Telecoms Regulatory Framework, Frontier Economics Ltd for Telenor, London, UK, 73. ital

[12] Machuca C.M. et all., (2013) “Migration from GPON to Hybrid PON: Complete Cost Evaluation”, Photonische Netze, Leipzig, Germany, 5.