Proceedings of the Federated Conference on
Computer Science and Information Systems pp. 655–662

ISBN 978-83-60810-51-4

# How to build a flexible and cost-effective high-speed access network based on FTTB+LAN architecture

Paweł Parol
Orange Labs
Obrzezna 7, 02-691 Warszawa, Poland
Warsaw University of Technology
The Faculty of Electronics and Information Technology
Nowowiejska 15/19, 00-665 Warsaw, Poland
Email: Pawel.Parol@orange.com

Michał Pawłowski
Orange Labs
Obrzezna 7, 02-691 Warszawa, Poland
Email: Michal.Pawlowski1@orange.com

***Abstract*—In this paper we propose an approach of building a modern high-speed access network based on FTTB+LAN architecture in multi-dwelling buildings where cat.5 copper infrastructure is available and can be used. Presented approach allows building easy-to-deploy and cost-effective access network as compared to another FTTH and FTTB-based topologies. Thanks to flexible network design various service profiles cohabitation in one access network is possible. The study presents also methods of how to carry user traffic in effective way within the considered architecture. The proposed approach was verified during a field trial, which results are discussed in the paper.**

## I. INTRODUCTION

### A. VHBB solutions

NOWADAYS one can observe increasing demand for bandwidth which is driven mostly by video related services (HD TV, 3D HDTV, Ultra HDTV, VOD, Youtube etc.) being the most bandwidth-hungry applications. Apart from that there is a need for effective web browsing and files downloading, online gaming, video conferences or cloud computing services. Moreover, users tend to upload content to the network more eagerly. It is getting even more important issue for network operators to provide high-speed access links in cost-effective way.

The first bottleneck alongside an end-to-end path between end-user and service content is an access network. Most of currently deployed access networks, which utilize copper infrastructure like ADSL-based systems, are not capable of meeting high bandwidth requirements due to technology-specific limitations concerning maximum transmission speed. Today only VHBB (very high-speed broadband) solutions (sometimes called super-fast broadband solutions) provide users with possibility to consume as much bandwidth as they need. Typically a broadband technology qualifies as VHBB when it offers download speed of at least 50 Mbit/s, and has the potential for 100 Mbit/s or more ([6]). In practice only those technologies which utilize an optical fibre (fully or partially) can be considered as VHBB solutions (see Figure 1).

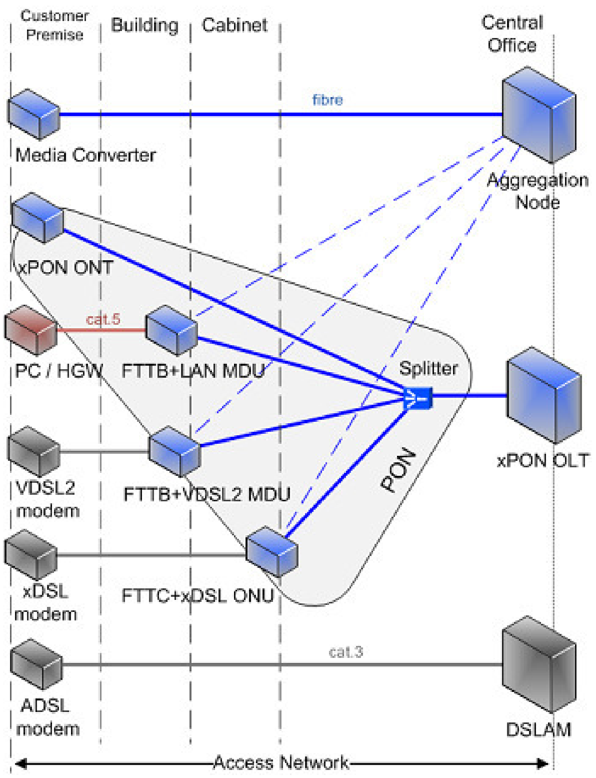


Fig. 1. Access network topologies

The most powerful technology family is FTTH (Fibre To The Home). Two popular FTTH solutions are xPON (Passive Optical Network) based on Point-to-MuliPoint topology, e.g. GPON ([1]), and P2P optical Ethernet based on Point-to-Point topology. Both assume that an optical fibre is provided up to customer premises and therefore it is possible to offer very high transmission speeds. However, FTTH networks are expensive ones since complete fibre infrastructure has to be

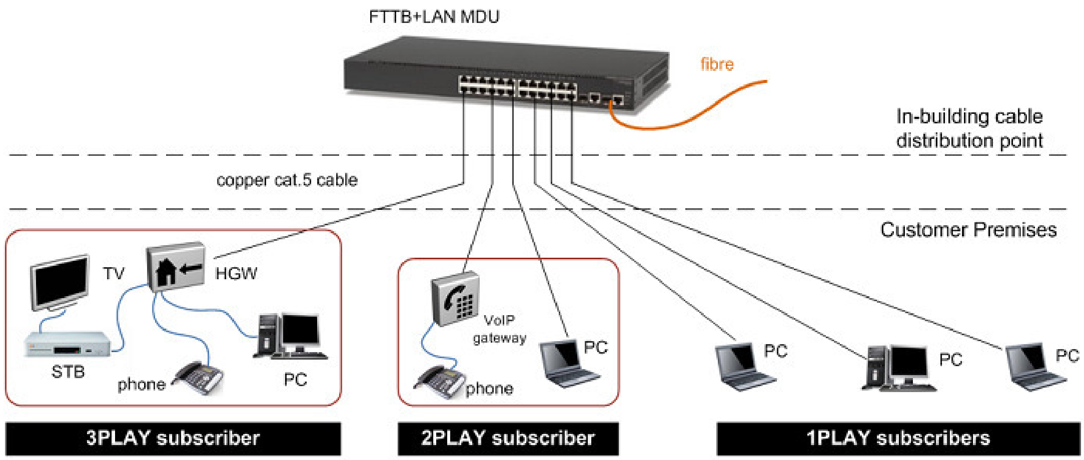


Fig. 2. Various service profiles cohabitation

built in the order to connect customer premises. It leads to significant network cost increase, thus a great challenge for network operators is to find an acceptable trade-off between total network cost and network capabilities according to a business model they follow. Another technology that meets VHBB requirement is FTTB+VDSL2 (Fibre To The Building + Very High Speed Digital Subscriber Line 2). In such topology fibre is provided to a building where access node equipped with VDSL2 interfaces is located. P2P or xPON-based fiber link acts as a feeder for the access node. Inside a multi-dwelling building cat.3 copper infrastructure is used in order to connect customer premises with VDSL2 access node, so called MDU (Multi Dwelling Unit). In some cases also FTTC+VDSL2 (Fiber To The Cabinet/Curb) can be considered as VHBB solution but only when the copper part of the network is short enough, because transmission capabilities of VDSL2 technology deteriorate together with longer distance between customer premise and VDSL2-based access node. For buildings with existing cat.5 copper infrastructure which can be reused an effective VHBB access technology seem to be so called FTTB+LAN.

### B. What is FTTB+LAN?

The acronym FTTB+LAN can be not clear enough at first glance, hence an explanation of this term is given below.

A term LAN (Local Area Network) originally refers to computer network that connects computers and devices in a limited geographical area such as home, school, computer laboratory or office building. There are several LAN technology standards but the most popular is Ethernet (IEEE 802.3) with its various working modes: Ethernet (10 Mbps), Fast Ethernet (100 Mbps), Gigabit Ethernet (1 Gbps), etc. That is why FTTB+LAN means in fact: Fiber to the Building + Ethernet inside a building.

Depending on optical access technology provided to a building (xPON link, P2P GbE link) the following devices can be installed in the building:

- xPON MDU device (xPON uplink & Ethernet copper interfaces towards users)
- switch (GbE optical uplink & Ethernet copper interfaces towards users)

One of the most popular solutions available on the market is GPON-based FTTB+MDU with K * FE ports, which refers to a device equipped with GPON uplink interface and K * Fast Ethernet (100 Mbps max. rate) interfaces (typically K = 8,16,24,32) on LAN side. Such kind of device we consider for the purpose of the network architecture we propose in this paper.

Inside a multi-dwelling building an in-building copper cat.5 infrastructure is available with Ethernet (RJ-45) sockets installed in customer premises in order to connect those premises (i.e. users devices located there) with FTTB+LAN MDU typically located in in-building cable distribution point (for instance located in a basement of a multi-dwelling building).

*Remark:* A configuration with different users sharing one FTTB+LAN MDU may create an impression that all of them are in the same LAN segment. It is not the case, because an important feature of FTTB+LAN MDU is that, as opposed to a standard L2 (Layer 2) Ethernet switch, it blocks direct communication between users by default, mainly due to security reasons.

## II. Access network architecture

### A. Flexible and cost-effective approach

One of the main assumptions of network architecture design we propose in this paper is to support various service profiles cohabitation within FTTB+LAN access network (see Figure 2) allowing to make flexible and cost-effective solution. The following service profiles are considered:

- 1Play (Mono-Play): Internet
- 2Play (Dual-Play): Internet & VoIP
- 3Play (Triple-Play): Internet & VoIP & IPTV

1Play (Internet) service profile uses Ethernet connections which are considered as mature, well-known and common

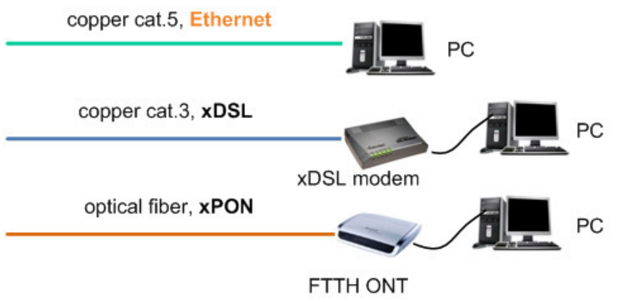


Fig. 3. Mono-Play scenario deployment capabilities for different access technologies

technology and almost each PC (notebook or desktop) is equipped with network card providing Ethernet-based (for instance Fast Ethernet: 100 Mbps) interface. That is why no additional intermediate device is required to connect user's PC to the network. In order to access Internet user needs only to connect his or her PC to Ethernet (RJ-45) socket installed in customer premise using popular Ethernet cable. In case of other VHBB access architectures like FTTB+VDSL2, FTTH GPON or FTTH P2P optical Ethernet an intermediate device: VDSL2 modem, GPON ONT (Optical Network Termination) or Media Converter respectively is always required to be installed in customer premise even for Mono-Play service scenario (see Figure 3). The reason for that is obvious: since PCs are not equipped with any DSL-based or optical interfaces an external module is necessary to act as technology-specific termination unit. It leads to higher total cost of the network because additional device always means additional cost from network operator perspective. Moreover, the total cost of all CPE (Customer Premise Equipment) has a great impact on the total cost of the network. Thanks to using FTTB+LAN access architecture that cost can be reduced. Thus, an important advantage of considered solution (for 1Play scenario) can be noticed, especially in case of deployments with high percentage of 1Play subscribers amongst all users.

In order to serve Dual-Play (Internet & VoIP) two Ethernet ports on FTTB+LAN MDU are required to be used for each user. Internet is provided in the same way as in Mono-Play scenario. In order to serve VoIP an appropriate VoIP gateway (a device which enables VoIP session initiation/termination) needs to be used. An analogue phone is connected to VoIP gateway (using RJ-11 telephone cable) and VoIP gateway is then connected to the Ethernet socket (using Ethernet RJ-45 cable). Two Ethernet (RJ-45) sockets are used in customer premise to connect user's devices (one socket for PC, another one for VoIP gateway).

If only one Ethernet socket is available in customer premise it is still possible to offer 2Play - if transmission rate not higher than 100 Mbps is assumed. For such transmission rate only 2 of 4 pairs are used in Ethernet 100BASE-TX standard (commonly used nowadays). Using special cables (with transmission pair splitting) it is possible to serve 2Play having only one Ethernet socket in customer premise (VoIP & Internet signals are transmitted in one cable). Using dedicated VoIP gateway for 2Play service profile purpose is still less expensive than using GPON ONT or VDSL2 modem with integrated VoIP gateway functions in case of FTTH GPON and FTTB+VDSL2 architectures respectively.

TABLE I
COST RELATED DRAWBACKS OF CONSIDERED VHBB SCENARIOS IN COMPARISON WITH FTTB+LAN ARCHITECTURE

| **VHBB architecture type** | **Additional cost components in comparison with FTTB+LAN access architecture** |
|---|---|
| FTTH GPON | - In-building fiber infrastructure has to be built<br>- GPON ONT is required for each service profile |
| FTTH P2P optical Ethernet | - In-building fiber infrastructure has to be built<br>- Media Converter is required for each service profile |
| FTTB+VDSL2 | - FTTB+VDSL2 MDU is more expensive than similar FTTB+LAN MDU (VDSL2 interfaces are more expensive than FE ones since VDSL2 is more sophisticated technology than Ethernet)<br>- VDSL2 modem is required for each service profile |

For 3Play (Internet & VoIP & TV) scenario HGW (Home Gateway) is required, which aggregates traffic from various user's devices. In FTTB+LAN architecture 3Play is provided in similar way as in FTTH GPON or FTTB+VDSL2 architectures. User's devices: STB (Set-Top-Box), PC and analogue phone are connected to HGW which is connected to Ethernet socket (RJ-45) in customer premise. HGW with Ethernet WAN port is the only CPE required for FTTB+LAN access architecture. In case of other architectures like FTTH GPON or FTTB+VDSL2, GPON ONT and VDSL2 modem respectively are required additionally what of course makes those solutions more expensive than FTTB+LAN.

*Remark:* In case of FTTH GPON and FTTB+VDSL2 architectures there is also alternative configuration using single equipment which integrates functions of HGW and GPON ONT/VDSL2 modem instead of using two independent devices (GPON ONT + HGW or VDSL2 modem + HGW). However, it is easy to notice that because of its complexity (extra hardware plus more features implemented) such all-in-one device is still much more expensive than HGW with Ethernet WAN port used for FTTB+LAN access architecture purpose.

Table I shows the main additional cost components of considered VHBB architectures in comparison with FTTB+LAN access architecture.

### B. Various service profiles cohabitation

In order to ensure various service profiles cohabitation within the same FTTB+LAN MDU an appropriate network architecture design has to be made. Since FTTB+LAN MDU is equipped with GPON uplink interface it acts as ONU (Optical

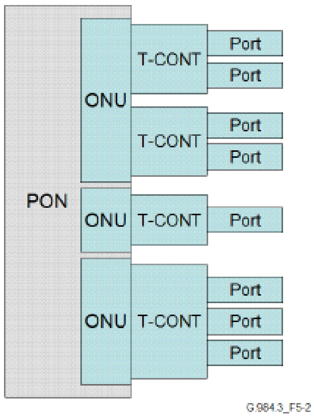


Fig. 4. Upstream multiplexing in GPON system (source: [2])

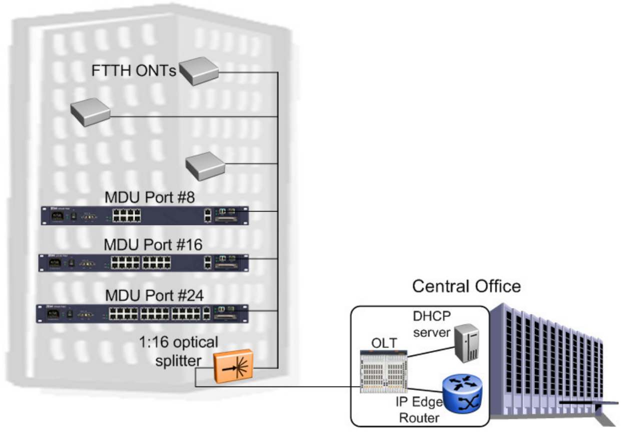


Fig. 5. FTTB+LAN field trial network: a generic view

Network Unit) from GPON system perspective (like ONT does in FTTH topology). That is why an important issue is to carry user traffic in downstream and upstream directions on the GPON layer (using GPON-specific traffic entities) in effective way.

GPON system encapsulates transported Ethernet frames into GEM (GPON Encapsulation Method) frames. A single logical connection within the GPON system is called GEM Port and it is identified by GEM Port ID. In the upstream direction GPON system also utilizes T-CONTs (Transmission Containers) corresponding to timeslots within TDMA multiplexing existing in GPON. Each T-CONT represents a group of logical connections (GEM Ports) that appear as a single entity for the purpose of upstream bandwidth assignment on the PON (see Figure 4).

Each T-CONT can be seen as an instance of upstream queue with a certain bandwidth profile (a set of bandwidth parameters). The bandwidth assignment model applied in GPON system effectively introduces a strict priority hierarchy of the assigned bandwidth components ([2]):

- fixed bandwidth: with highest priority
- assured bandwidth
- non-assured bandwidth
- best-effort bandwidth: with lowest priority

Each T-CONT instance is associated with a bandwidth profile. Bandwidth profile is described using the traffic descriptor, which has the following components:

- fixed bandwidth (bandwidth that is reserved exclusively for a given T-CONT and no other T-CONTs can use it; this bandwidth is statically allocated to a T-CONT)
- assured bandwidth (bandwidth that is available for a given T-CONT on demand; this bandwidth is guaranteed)
- maximum bandwidth (maximum amount of bandwidth, that can be allocated to a given T-CONT on demand; this bandwidth is not guaranteed)
- additional bandwidth eligibility (type of additional bandwidth that a given T-CONT is eligible to get, can have the following values: none –no additional bandwidth, NA –non-assured bandwidth, BE –best-effort bandwidth)

Depending on the used set of those parameters, five T-CONT types are defined by [2]. Depending on the traffic type (latency-sensitive traffic, data transmission, etc.) the most appropriate T-CONT type should be selected to carry considered traffic.

Upstream user traffic (Ethernet frames) is encapsulated into GEM ports and then into T-CONTs. Each FTTB+LAN MDU, which acts as ONU from GPON system perspective, uses its own set of T-CONTs and GEM ports, unique within a PON tree, which MDU belongs to. A single GEM port can be encapsulated into only one T-CONT, however a single T-CONT may encapsulate multiple GEM ports. For a more detailed explanation please refer to [2].

For those access architectures which assume using access devices shared between many users (like FTTB+LAN MDU) it is important to define appropriate rules (consistent and unambiguous ones) allowing to forward data streams incoming from users to appropriate GEM Ports. Users traffic to GEM Ports mapping rules can be mono-criterion-based i.e. mapping is based on only one of the following criteria like:

- VLAN ID (Virtual LAN - IEEE 802.1Q)
- p-bit (IEEE 802.1p)
- UNI (user port number on MDU)

or multi-criteria-based i.e. more than one criterion is used in that case:

- VLAN ID + p-bit
- VLAN ID + UNI
- UNI + p-bit
- UNI + VLAN + p-bit

Mono-criterion-based mapping rules are in most cases not sufficient to ensure effective traffic forwarding and separation between users on acceptable level if GPON-based access devices shared between many users (like FTTB+LAN MDU) are assumed to be used. *GEM Port per service per user* and *T-CONT per service* principles are difficult or even impossible to be followed when a mono-criterion-based mapping rule is

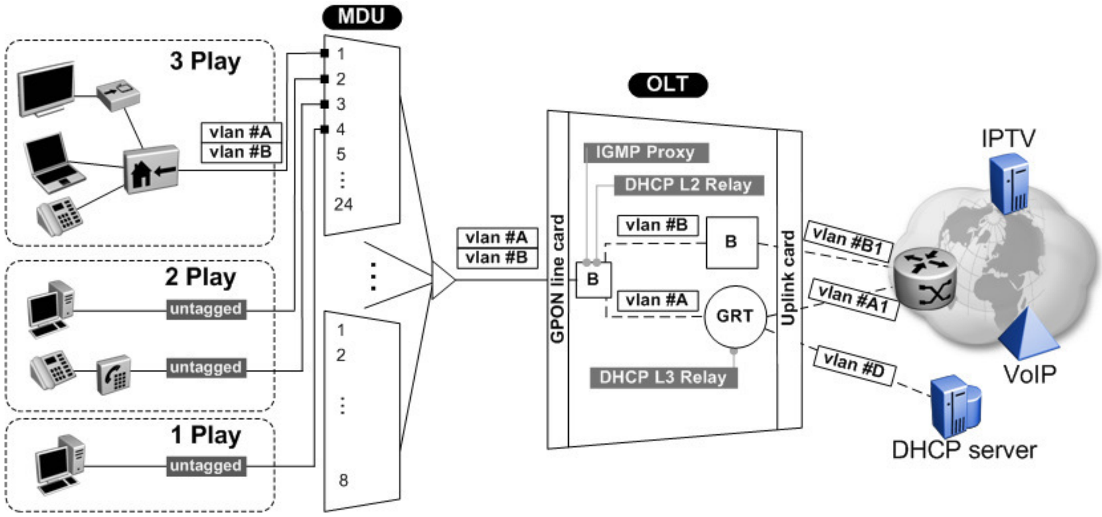


Fig. 6. Network architecture of FTTB+LAN solution used in the field trial

applied. That is why for FTTB+LAN MDU multi-criteria-based mapping rules are supposed to be used. Depending on so called VLAN plan defining VLAN IDs and p-bits corresponding to services an optimal user traffic to GEM Port mapping rule has to be chosen. For access architectures based on L2 (Layer 2) forwarding and multi-VLAN approach (each service has its dedicated VLAN) an appropriate rule would be the one based on VLAN ID + UNI. In such a case users are differentiated by UNIs since they are served from different ports on MDU and services are differentiated by VLAN IDs. For access architectures based on flat-IP L3 (Layer 3) forwarding and mono-VLAN approach (all services utilize the same VLAN) an adequate rule is the p-bit + UNI-based one. In such a case users are differentiated by UNIs since they are served from different ports on MDU and services are differentiated by p-bits.

## III. Implementation

In order to verify presented access network architecture the field trial was launched. Thus, an opportunity was taken to obtain results, not only from tests performed in laboratory, but also in a real network environment. Orange Labs Poland launched FTTB+LAN field trial in Orange Poland network in 2011. The trial took place in one of student dormitories in Warsaw associated with Warsaw University of Technology. About 50 students decided to act as testers.

For the field trial purpose FTTB+LAN network was built based on an architectural concept presented in section II (see Figure 2) i.e. a possibility of providing various service profiles within the same access network was ensured. The following profiles were deployed: Mono-Play Internet, Dual-Play (Internet and VoIP), Triple-Play (Internet, VoIP and IPTV). Over half of users were Mono-Play users. Additionally using the same optical Access Node (GPON OLT: Optical Line Termination) services were offered in FTTH technology for some students. The aim of such configuration was to verify a cohabitation of FTTB+LAN users and FTTH users in one PON. Inside a student dormitory (a multi-dwelling building) a copper cat.5 infrastructure was available with Ethernet (RJ-45) sockets installed in customer premises (in order to connect those premises with FTTB+LAN MDUs installed in cable distribution point i.e. server room). MDUs were connected via GPON to OLT located in nearby Central Office (see Figure 5). For each service profile a specific way of connection to the network was defined. Mono-Play (Internet) users' PCs have been connected directly to RJ-45 Ethernet sockets installed in customer premises using common Ethernet cables. For Dual-Play scenario two parallel links were used between users' end devices (PC and phone) and FTTB+LAN MDU. It implied using two LAN (Fast Ethernet) ports on MDU for each Dual-Play user. Internet in Dual-Play scenario was realized exactly in the same manner as in case of Mono-Play service profile. For VoIP service an additional device was required since analogue phones were not capable to adapt to any kind of digital transmission. Due to that fact dedicated VoIP gateway initiating/terminating VoIP session was used. User's analogue phone was connected to FXS port of VoIP gateway using standard RJ-11 based cable with VoIP gateway connected to Ethernet RJ-45 socket. For Triple-Play scenario HGW was used, which aggregated traffic incoming from various users' devices. HGW was equipped with different "user interfaces": Ethernet-based (FE), FXS, WiFi. HGW's uplink port (WAN port) was connected to Ethernet RJ-45 socket installed in customer premise. That configuration proved high flexibility as well as eased the process of service delivery. Moreover, for Mono-Play there was no additional device like modem or router. Such solution allowed lowering the costs. Installation process for customers was simple and practically the same as when connecting PC to a local network thus allowing self-installation and plug-and-play experience.

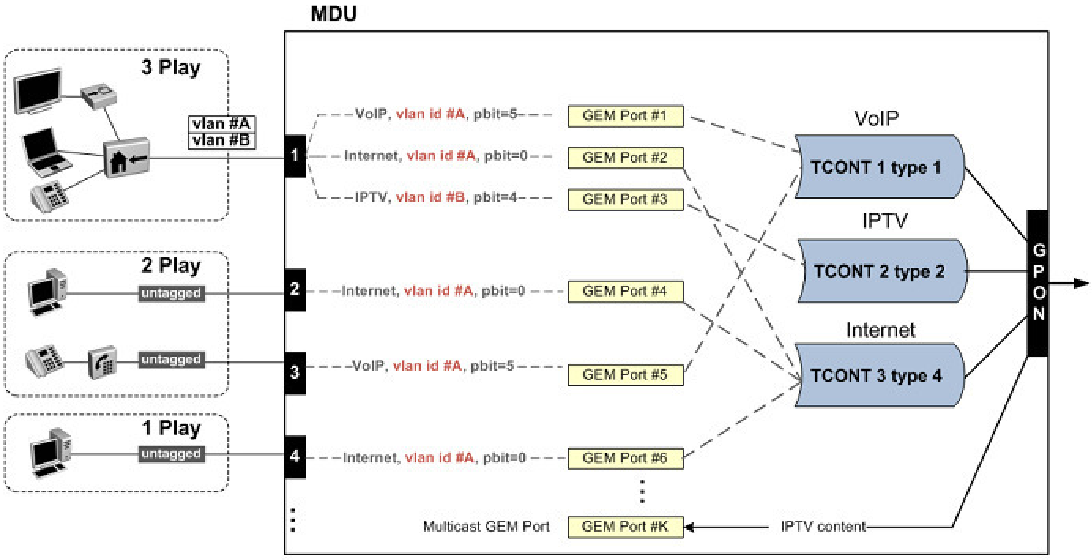


Fig. 7. User traffic mapping to GEM Ports and T-CONTs

### A. Network architecture

Network architecture used for the field trial purpose was based on IP forwarding and DHCP attachment process. However some differences existed depending on the service type. For IPTV the approach was based on BBF TR-101 recommendations ([3]) with L2 forwarding on FTTB+LAN MDU and Access Node (OLT) as well. Additionally IGMP Proxy function was enabled on OLT. For Internet and VoIP services L2 forwarding on FTTB+LAN MDU and L3 forwarding on OLT were used. This meant that end users' devices (HGWs for Triple-Play or PCs for Mono and Dual-Play) were directly connected to OLT on IP level. Those end devices were attached to the network by means of DHCP process: a dedicated DHCP server, serving field trial users, was established and it assigned IP address. OLT was connected to Internet through Orange Poland network. A generic view of architectural solution used in FTTB+LAN field trial is depicted in Figure 6.

For Triple-Play customers HGW worked as a gateway for customers' equipment with its WAN IP address being assigned by DHCP server. At the same time HGW assigned private IP addresses to devices on LAN side. OLT worked as a default gateway for Home Gateway. HGW tagged outgoing traffic with VLAN IDs and p-bits and removed marking from incoming traffic (from MDU). P-bits were used for traffic prioritization (QoS). IP addresses for Mono-Play and Dual-Play customers' equipment were assigned by DHCP server. In that case there was no marking coming from end devices (PCs or VoIP gateways). FTTB+LAN MDU was configured to add/remove necessary marking for traffic incoming/outgoing from/to such customers. Additionally MDU prevented user-to-user communication (split horizon forwarding, default setting on MDU) and limited maximum number of MAC addresses per UNI interface (Ethernet port).

In order to ensure an effective traffic forwarding and separation between users on acceptable level on the GPON layer *GEM Port per service per user* and *T-CONT per service* principles were followed within user traffic to GEM Ports mapping process. According to so called VLAN plan designed for the field trial purpose Internet and VoIP traffic was transmitted in VLAN ID#A and IPTV traffic was transmitted using VLAN ID#B (see Figure 6). For the considered FTTB+LAN solution a hybrid L2/L3 forwarding model was used and more than one VLAN was utilized to carry user traffic in access network. Hence, p-bit + UNI-based mapping rule was applied as an optimal one in terms of considered VLAN plan (see Figure 7).

Thanks to network architecture design described above installation and service delivery process were simplified in comparison to typical situation (e.g. traditional ADSL access). Layer 3 forwarding and attachment based on DHCP allowed reusing other parts of the network without changes (aggregation and core network). FTTB+LAN-based access network introduction required only to connect OLT to Orange Poland network and to configure appropriate routing (only dedicated DHCP server was added on the network side).

### B. Results

During the field trial an opportunity was taken to perform service tests using dedicated tools (applications). The aim of the tests was to verify performance of FTTB+LAN access network in real network conditions, under traffic generated by real users. Tests performed not only in laboratory but also in the real network environment allowed a much better assessment of the solution and led to trustworthy predictions about how such systems would perform in case of future deployment.

For that purpose a tool for traffic and miscellaneous optical parameters monitoring was used. The tool allowed continuous

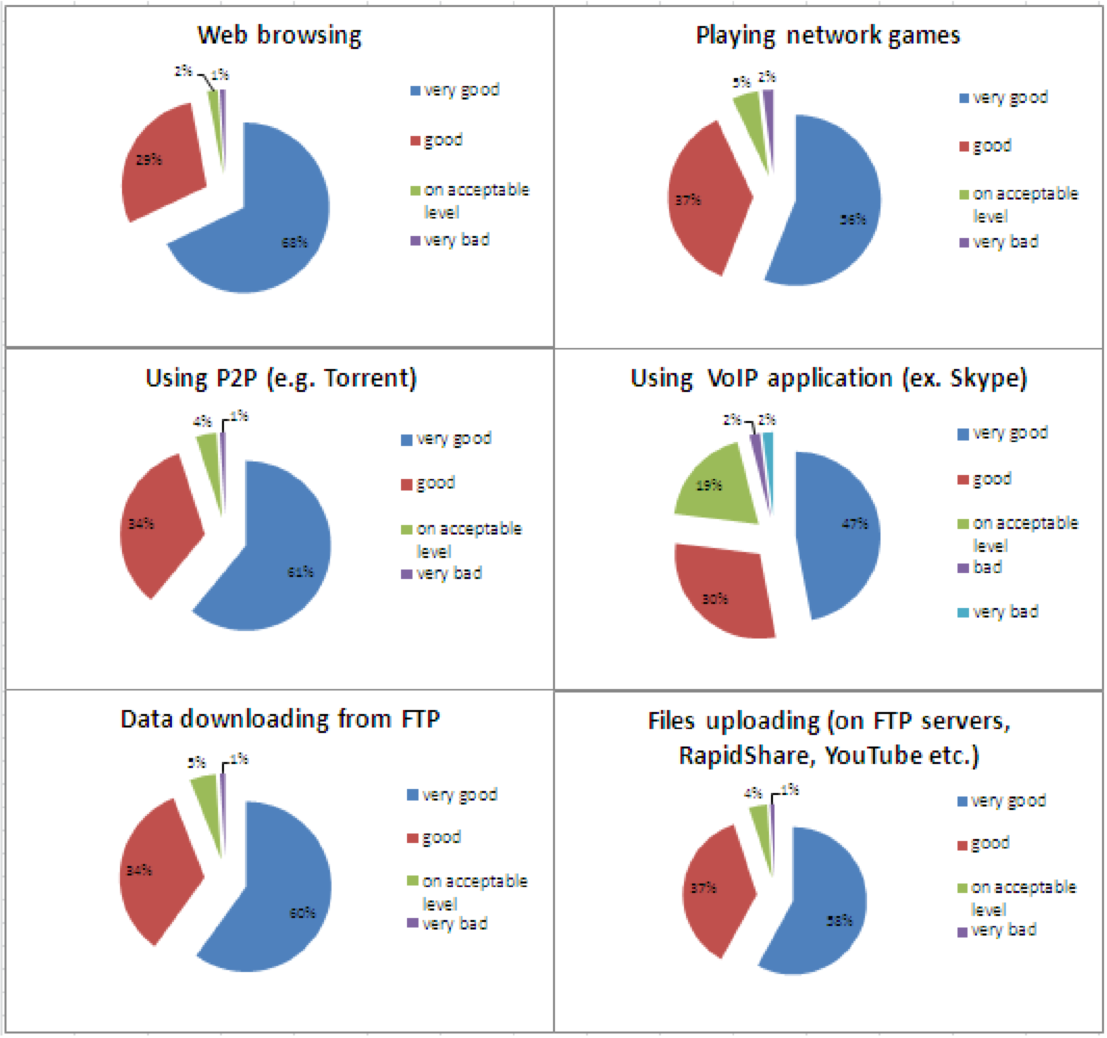


Fig. 8. FTTB+LAN field trial Quality of Experience survey results

retrieving of requested parameters. Data retrieving process was based on SNMP messages exchange between application server and FTTB+LAN MDUs and optical Access Node (OLT). The main conclusion based on received results analysis is that the FTTB+LAN solution had sufficient bandwidth for handling high number of users and offer them proper QoS.

Another application was employed to monitor the quality of IPTV by connecting to multicast streams and performing RTP (Real-time Transport Protocol) header analysis. The tool was able to measure packet loss and to check continuity of the streams.

Results (see Table II) show very small number of errors that occurred during tests and thus a very good performance of IPTV on tested FTTB+LAN configuration. Also important is that there were small numbers of lost packets while transmitting a long burst of packets.

Many test items were focused on Internet service quality since 1Play profile was the most common service profile deployed during FTTB+LAN field trial. For that purpose an application for Internet service performance measurement was used. Following metrics were measured using the tool:

- Internet DNS E2E response time
- Internet DNS success rate
- available IP bit rate (download throughput)
- Internet delay variation
- Internet round trip delay
- Internet web-page download time

Obtained results (see Table III) proved very good performance of Internet Access service.

TABLE II
EXAMPLE RESULTS FROM TOOL MEASSURING IPTV PACKET LOSS

| Test # | Successful received packets | Packet lost | Duration of measurement | Packet loss ratio |
|---|---|---|---|---|
| 1 | 493124816 | 25655 | 11 days | 5,20e-5 |
| 2 | 1961718298 | 15382 | 26 days | 7,84e-6 |
| 3 | 3085972984 | 26557 | 11 days | 8,61e-6 |

TABLE III
MEASSURED METRIC RESULTS FOR INTERNET ACCESS SERVICE

| Metric | Value | Unit |
|---|---|---|
| dns_e2e_response_time | 9,67 | ms |
| dns_success_rate | 100,00 | % |
| download_throughput | 100000 | kb/s |
| delay_variation | 0,56 | ms |
| rtt | 3,86 | ms |
| web_page_download_time | 1633,42 | ms |

Overall results received from all tools proved very good performance of the services and high level of quality. Based on those results a conclusion can be made that considered FTTB+LAN solution provides high bandwidth and also assures high quality of delivered services with small number of errors. Moreover, it offers flexibility and simplicity in terms of service delivery and usage by customers.

An important objective of FTTB+LAN field trial was to receive feedback from users. Students were supposed to perform do-it-yourself tests and to fill dedicated questionnaires in. Based on Quality of Experience survey results students' impressions and opinions regarding services provided during FTTB+LAN field trial were gathered.

According to received feedback (see Figure 8) it can be noticed that users were very satisfied with Internet Access service - achieved download and upload speeds were much higher than speeds which are offered normally in academic campus network. Moreover, several users declared they would have paid for Internet Access service if Orange Poland decided to launch such service (with the same performance as observed during field trial) as a commercial service. It allows to make a conclusion that Internet service indeed met students' requirements and expectations.

## ACKNOWLEDGMENT

This study was done in the scope of R&D project conducted between Orange Labs Poland and France Telecom R&D. The FTTB+LAN field trial was launched by Orange Labs Poland in cooperation with Warsaw University of Technology.

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