FTTB+LAN: a Flexible Access Architecture for Residential and Business Users[1]

Paweł PAROL[a),b)], Michał PAWŁOWSKI[a)]

[a)] Orange Labs,
Wireline Access Division
Obrzeżna 7, 02-691 Warszawa, Poland
[b)] Warsaw University of Technology,
The Faculty of Electronics and Information Technology,
Nowowiejska 15/19, 00-665 Warszawa, Poland
pawel.parol@orange.com, michal.pawlowski1@orange.com

ABSTRACT: In this study 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-implement and cost-effective access solution which can be deployed for both residential and business users. The study provides a wide view on network architecture design and presents methods of how to carry user traffic in effective way within the considered architecture. Thanks to a flexible approach various service profiles cohabitation in one access network is feasible.

KEYWORDS: FTTB+LAN, GPON, VHBB, optical access network, Ethernet, flexible access architecture, residential and business services.

1. Introduction
1.1. 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

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[1] This paper is an extended version of the paper [1] presented at FedCSIS multiconference in September 2012 ([2]).

gaming, video conferences or cloud computing services. Moreover, users tend to upload content to the network more eagerly. Also for business applications reliable high-speed links are required for the purpose of establishing connectivity between branches of company or other company-specific needs. 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 ([8]). In practice only those technologies which utilize an optical fibre (fully or partially) can be considered as VHBB solutions (see Figure 1). The most powerful technology family is FTTH (Fibre To The Home). Two popular FTTH solutions are xPON (Passive Optical Network) based on Point-to-Multipoint 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 built in 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 fibre link acts as a feeder for the considered 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 (Fibre 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.
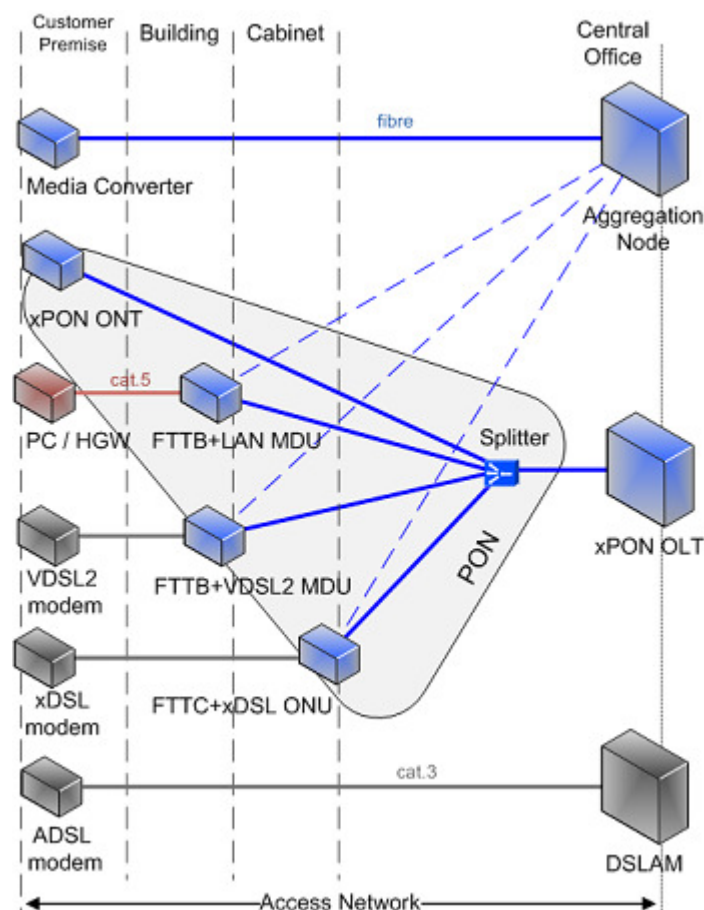
Figure 1. Access Network topologies

1.2. 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: Fibre 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+LAN 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.

2. FTTB+LAN benefits
2.1. Flexible and cost-effective approach for residential users

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 for residential deployment:

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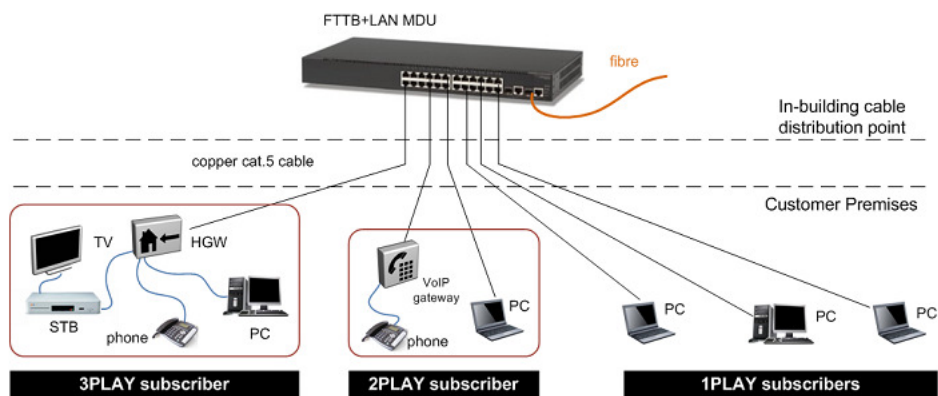- 3Play (Triple-Play): Internet & VoIP & IPTV.

Figure 2. FTTB+LAN for residential users: various service profiles cohabitation

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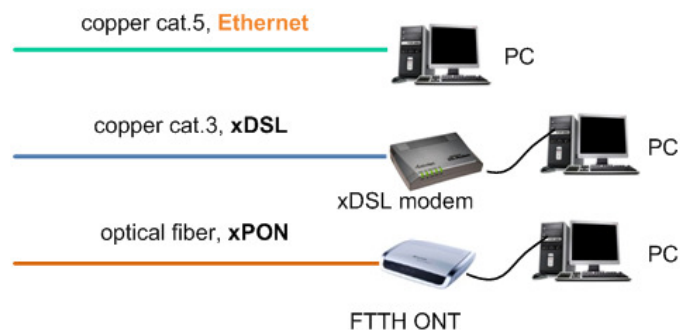

Figure 3. Mono-Play scenario deployment capabilities for different access technologies

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.

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 an 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 1 shows the main additional cost components of considered VHBB architectures in comparison with FTTB+LAN access architecture.

Table 1. 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 fibre infrastructure has to be built; – GPON ONT is required for each service profile;
FTTH P2P optical Ethernet	– In-building fibre infrastructure has to be built; – 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); – VDSL2 modem is required for each service profile.

2.2. FTTB+LAN in area of business services

Additionally to residential offer we propose to use FTTB+LAN solution for business services. This approach might be especially interesting for places like office building where more than one company is located. In traditional business deployment there is a dedicated copper or fibre cable, per customer, reaching offices. Employing FTTB+LAN can give significant CAPEX savings – office buildings usually have good cable infrastructure including copper cables cat. 5. Reusing those cables, instead of installing dedicated copper or fibre line to each customer's office, allow reducing costs. Service provider's infrastructure needs to reach only a distribution point in building (place where in-building

infrastructure concentrates and from where cables to each office exist). What is more single FTTB+LAN MDU can serve several customers making the whole solution even more promising.

Considering business services one should have in mind their specific characteristics. Quality of services, availability, stability, intervention time when failure occurs etc. must meet high requirements. Business offers typically are quite complex and can be composed of several types of services like Internet access, L2 (Layer 2) and L3 (Layer 3) connections (e.g. Point-to-Point or Point-to-Multipoint), voice services, advanced traffic filtering, equipment management and other. Designing flexible and efficient architecture allow FTTB+LAN based access to be used in order to provide such services. In this paper we consider the following business services (this is not exhaustive list, rather examples of business offer and one can create others based on FTTB+LAN access):

- Internet + VoIP (I+V);
- Metro Ethernet + Internet (M+I);
- Metro Ethernet + Internet + VoIP (M+I+V).

Example topology with different business services in one office building is presented in Figure 4. In each case there is OGW (Office Gateway) or switch in customer's premises connected by Ethernet to FTTB+LAN MDU. In VoIP offer an analogue phone is connected to OGW or voice gateway with RJ-11 socket.
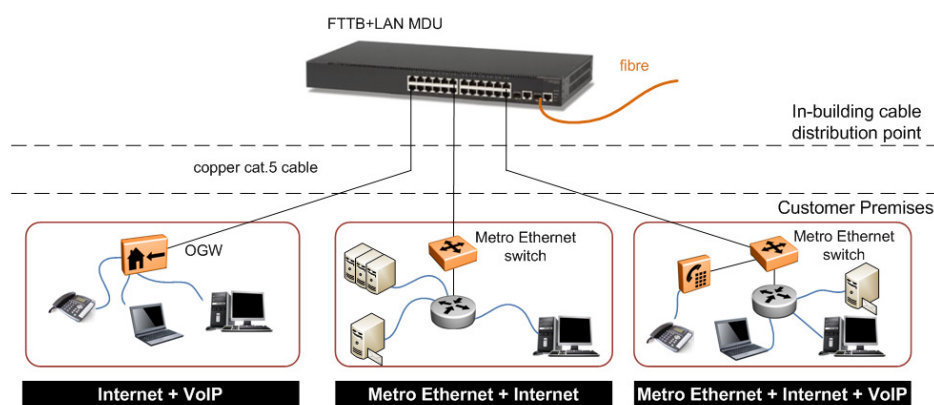

Figure 4. FTTB+LAN in office building – business service cohabitation

In our example Internet + VoIP provides access to Internet and Voice service (by means of VoIP). Metro Ethernet allows establishing L2 connectivity (forwarding of Ethernet frames) between two or more locations (e.g. branches of company). Each customer can have several "connections" on Layer 2 – separated from one another. Internet Access in such configuration means dedicated "service connection" from a switch in customer's premises to the gateway located in operator's network (customer needs to have additional equipment terminating Layer 3 – IP). For VoIP with Metro Ethernet there is additional VoIP Gateway to which analogue phone(s) is connected. VoIP Gateway communicates with VoIP platform located in operator's network.

3. Effective user traffic carrying on GPON layer

In order to ensure various service profiles cohabitation (for both residential and business scenario) 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 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 5).

A 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 ([4]):

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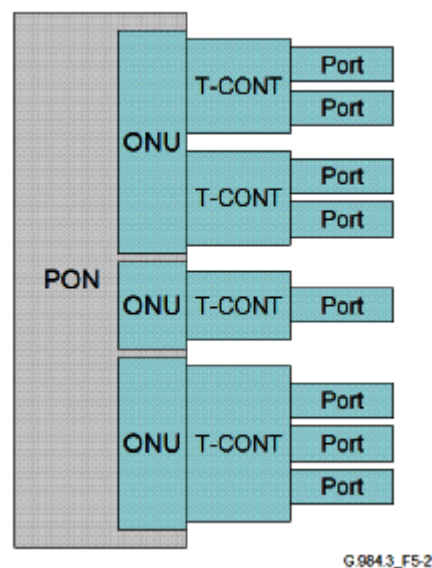– best-effort bandwidth: with lowest priority.

Figure 5. Upstream multiplexing in GPON system ([4])

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 R_F (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 R_A (bandwidth that is available for a given T-CONT on demand; this bandwidth is guaranteed);
- maximum bandwidth R_M (maximum amount of bandwidth, that can be allocated to a given T-CONT on demand; this bandwidth is not guaranteed);
- additional bandwidth eligibility χ_{AB} (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 [4].

Table 2. T-CONT types defined by [4]

Traffic descriptor component	T-CONT type 1	T-CONT type 2	T-CONT type 3	T-CONT type 4	T-CONT type 5
R_F R_A R_M χ_{AB}	$R_F > 0$ $R_A = 0$ $R_M = R_F$ $\chi_{AB} = $ none	$R_F = 0$ $R_A > 0$ $R_M = R_A$ $\chi_{AB} = $ none	$R_F = 0$ $R_A > 0$ $R_M > R_A$ $\chi_{AB} = $ NA	$R_F = 0$ $R_A = 0$ $R_M > 0$ $\chi_{AB} = $ BE	$R_F > 0$ $R_A > 0$ $R_M \geq R_F + R_A$ any χ_{AB}

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 [4].

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. Hence, multi-criteria-based

mapping rules are supposed to be applied for such devices. In this paper we propose an approach of how to map user traffic to GPON-specific entities (GEM Ports & T-CONTs) in effective way for both residential and business deployments. For each case we define:

- a mapping model – principles that have to be followed within mapping process;
- mapping rules – set of criteria (VLAN ID, p-bit, UNI, etc.) that the proposed mapping solution is based on.

3.1. Residential deployments

For residential users the following principles should be taken into account within user traffic to GEM Ports & T-CONTs mapping process:

- *GEM Port per service per user* – each of user traffic streams (corresponding to a particular service) should be transported in a separate GEM Port instance;
- *T-CONT per service* – traffic corresponding to the same service (streams incoming from different users) should be transported in dedicated T-CONT instance which is an appropriate one for the considered service nature.

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 forwarding and multi-VLAN approach (each service has its dedicated VLAN) an appropriate rule is 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. An example of such approach is presented in Figure 6. For 3Play service profile HGW tags traffic streams incoming from various user's devices with an appropriate VLAN ID and p-bit value. For 2Play and 1Play service profiles traffic streams incoming from users are supposed to be, in general, untagged – tagging is performed at MDU UNIs which users' devices are connected to. Next all user streams are mapped to GEM Ports – each stream (like Internet TCP/UDP traffic, VoIP traffic, IGMP signaling for IPTV, etc.) is mapped to its own GEM Port whereas multicast streams relating to IPTV content (those streams are present only within downstream transmission) are assigned a special multicast GEM Port. The entire user traffic encapsulated into GEM Ports is transported in dedicated T-CONT instances which correspond to

physical timeslots within TDMA multiplexing existing in GPON upstream transmission. For VoIP traffic (marked with highest priority, p-bit value equal to 5) a T-CONT instance of type 1 (according to [4]) is utilized that is suitable for carrying fixed-rate delay-sensitive traffic. T-CONT type 1 is characterized by the fixed bandwidth component which represents the reserved portion of the upstream GPON capacity. IGMP signaling messages for IPTV purpose are example of "on-off" type traffic with well-defined rate bound. For such kind of traffic a T-CONT instance of type 2 is used that is characterized by the assured bandwidth component. If the traffic demand is satisfied (or there is no traffic demand in particular time period) this bandwidth portion may be fully or partially reassigned to the other eligible T-CONT instances existing on GPON tree that the considered FTTB+LAN MDU is a part of. Internet traffic (both TCP and UDP-based streams) is assigned a T-CONT instance of type 4. It is suitable for carrying variable-rate bursty traffic. T-CONT type 4 utilizes so called best-effort bandwidth (the lowest one within bandwidth components hierarchy). Such assignment is acceptable for Internet service for residential deployments since Internet traffic is marked with the lowest priority (p-bit value equal to 0).
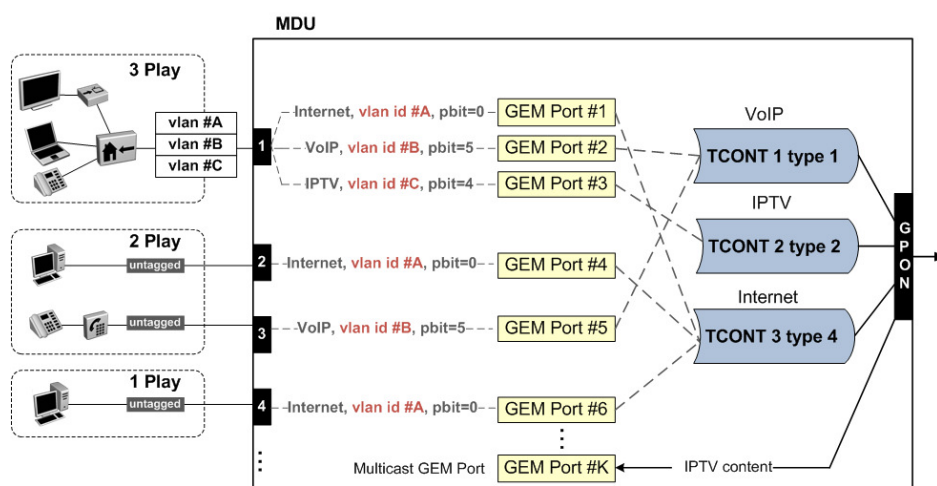

Figure 6. Residential user traffic mapping to GEM Ports and T-CONTs: multi-VLAN approach

For access architectures based on flat-IP L3 forwarding and mono-VLAN approach (all services utilize the same VLAN) the mapping model is the same as for access architectures based on multi-VLAN approach. However, VLAN ID + UNI-based mapping rule is not possible to be applied here since single user streams corresponding to different services are tagged with the same VLAN ID and thus cannot be distinguished correctly while arriving at MDU UNI which

the user is connected to. In consequence those streams cannot be mapped to separate GEM Ports. That is why an adequate mapping rule for access architectures based mono-VLAN approach 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 (see Figure 7).
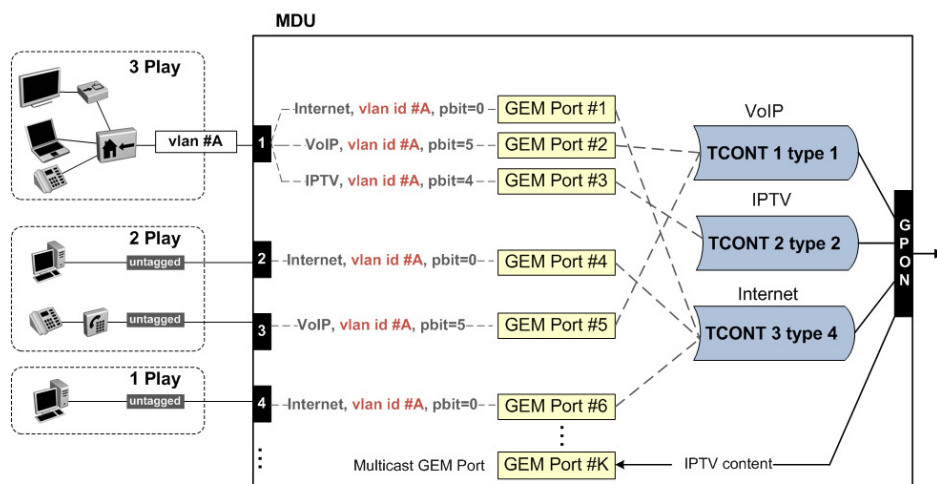

Figure 7. Residential user traffic mapping to GEM Ports and T-CONTs: mono-VLAN approach

3.2. Business deployments

For business users the following principles should be taken into account within user traffic to GEM Ports & T-CONTs mapping process:

– *GEM Port per service per user* – each of user traffic streams (corresponding to a particular service) should be transported in a separate GEM Port instance;
– *T-CONT per service per user* – traffic corresponding to any of user service (Internet, VoIP, Metro Ethernet) should be transported in dedicated T-CONT instance which is an appropriate one for the considered service nature.

In case of business services it is extremely important to ensure an effective traffic forwarding and a very high level of separation between users on the GPON layer. In order to achieve that *T-CONT per service principle* (which is

acceptable for residential applications) have to be turned into *T-CONT per service per user* one. It means that single user traffic is assigned as many number of T-CONT instances as many different services the user is provided with. Similarly to the residential solution, for VoIP streams T-CONT instances of type 1 are utilized which are suitable for carrying delay-sensitive traffic. Internet traffic and Metro Ethernet-related streams are assigned dedicated T-CONT instances of type 2. Unlike Internet for residential users, Internet service for business deployments cannot be considered as best-effort traffic. Hence, an approach based on T-CONT type 4 is not recommended here. In case of Internet for business applications a very high level of service reliability has to be ensured. It implies provisioning an assured bandwidth components for that purpose. In order to meet those requirements T-CONT instances of type 2 have to be assigned to Internet streams. The same approach should be applied for Metro-Ethernet traffic (see Figure 8).
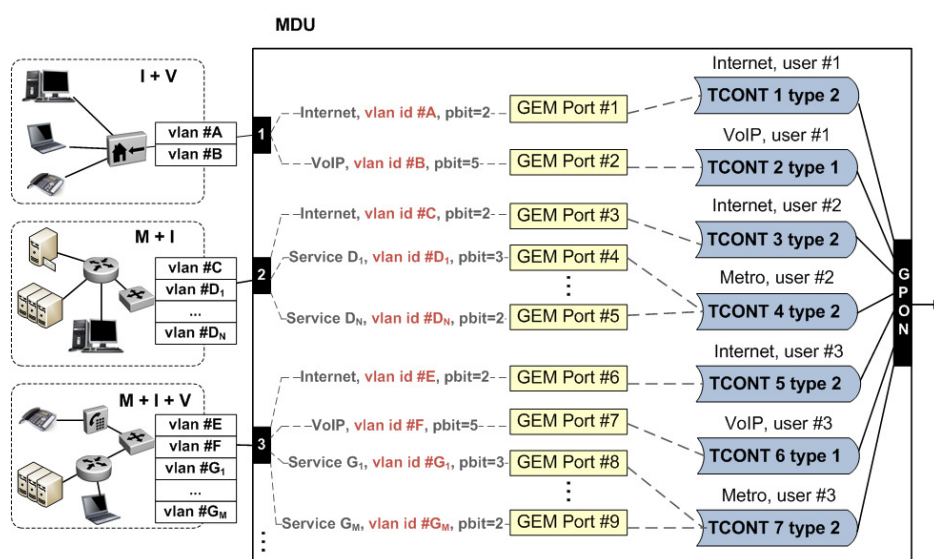

Figure 8. Business user traffic mapping to GEM Ports and T-CONTs

Access architectures for business applications are typically based on multi-VLAN approach. Outgoing traffic is marked with VLAN IDs and p-bits by OGW or switch located in customer's premise. Each service has its dedicated VLAN. That is why in terms of user traffic to GEM Ports mapping process an appropriate rule is the one based on VLAN ID + UNI. In such a case business users are differentiated by UNIs since they are served from different ports on MDU and services are differentiated by VLAN IDs.

4. Access Network architecture

In this paper we propose a flexible architecture allowing to provide different residential and business services in efficient way. Proposed architecture reflects differences in requirements and characteristics of those services. In fact business offer can be very complex, tailored to the needs of companies. Hereafter we describe architecture (with focus on FTTB+LAN access) of business services highlighted in chapter 2.2: Internet + VoIP, Metro Ethernet + Internet, Metro Ethernet + Internet + VoIP. We also include residential services: Internet, VoIP and IPTV in 1Play, 2Play and 3Play configuration. Generic view of services is depicted in Figure 9. Residential and business services do not share the same PON tree so there are also dedicated FTTB+LAN MDUs for residential and business customers.

For residential services we propose network architecture based on IP forwarding and DHCP attachment process. For Internet, VoIP and IPTV services L2 forwarding on FTTB+LAN MDU and L3 forwarding on OLT is considered. This means that end users' devices (HGWs for Triple-Play or PCs for Mono and Dual-Play) are directly connected to OLT on IP level. Those end devices are attached to the network by means of DHCP process: a dedicated DHCP server, located in operator's network needs to be established and assigns IP address.

IP addresses for Mono-Play and Dual-Play customers' equipment are assigned by DHCP server. In that case there is no marking coming from end devices (PCs or VoIP gateways – no additional logic needed on user's devices). FTTB+LAN MDU is configured to add/remove necessary marking for traffic incoming/outgoing from/to such customers. Additionally MDU prevents user-to-user communication (split horizon forwarding, default setting on MDU) and limits the maximum number of MAC addresses per UNI interface (Ethernet port).

For Triple-Play customers HGW works as a gateway for customers' equipment with its WAN IP address being assigned by DHCP server. At the same time HGW assigns private IP addresses to devices on LAN side. OLT works as a default gateway for Home Gateway. HGW tags outgoing traffic with VLAN IDs and p-bits, and removes marking from incoming traffic (from MDU). P-bits are used for traffic prioritization (QoS).
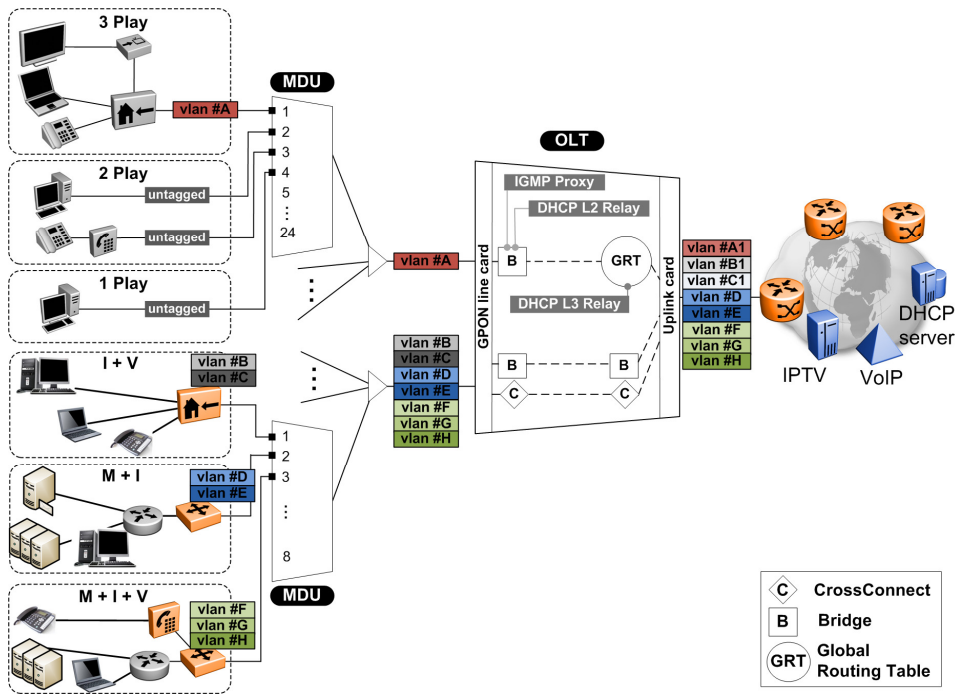
Figure 9. FTTB+LAN high level network architecture

Additional information regarding possible access implementation are given in APPENDIX A: FTTB+LAN access architecture implementation.

First example of business services is Internet Access + VoIP profile (see Figure 10). At customer's premises OGW works as a gateway to Internet. It has built-in VoIP Gateway functionality thus analogues phone can be connected to it. Connection from OGW is terminated on BNG (Broadband Network Gateway [5]),
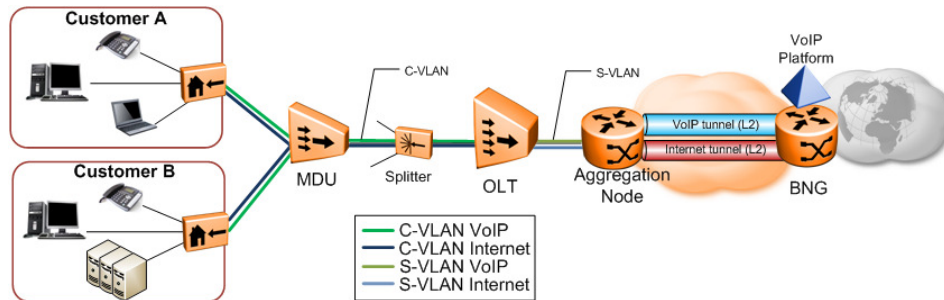

Figure 10. High level architecture: Business Internet + VoIP

which can provide additional function for customer's traffic (filtering, advanced QoS etc.). OGW can be connected to BNG by means of PPP (Point-to-Point Protocol) or simply on IP layer with DHCP based address assignment. In each case, in order to provide BNG functions, OGW and Broadband Network Gateway have connectivity on L2 (no L3-based forwarding in between). OGW tags outgoing traffic with proper C-VLAN – there are 2 VLANs: one for VoIP and one for Internet traffic. All customers of those services use the same C-VLAN numbers which allows simple service provisioning. FTTB+LAN MDU encapsulates traffic in GEM Ports and forwards transparently (no changes in VLAN scheme). On OLT side N:1 traffic mapping ([5]) is used (traffic from all Business Internet customers is forwarded in single S-VLAN towards aggregation). In aggregation traffic is forwarded in L2 and several solution can be used (final solution depends on many factors like network capabilities, volume of traffic etc.) for example MPLS L2 tunnels. Similar approach is used for VoIP. However due to the fact that VoIP traffic is directed to platform located in operator's network, private IP addresses can be used (it can reduce pressure on limited public addresses).

Metro Ethernet services primarily provide L2 connectivity among two or more customer's locations (see Figure 11). Also access to Internet and VoIP might be a part of service (as considered in this paper). At customer's premises Metro switch terminates connection to network and aggregates outgoing traffic from particular location. Each customer can have several independent L2 connections. In this paper such independent L2 connection we call a "service connection". Thanks to such configuration it is possible to separate traffic e.g. of company's services. From one location there might be defined number of service connection, all "going" to the same of different destinations. Traffic mapping to such service connection can be based on criteria such as port (Ethernet port on LAN side) on which traffic is received by switch or VLAN marking (LAN traffic coming to switch tagged with VLAN ID).
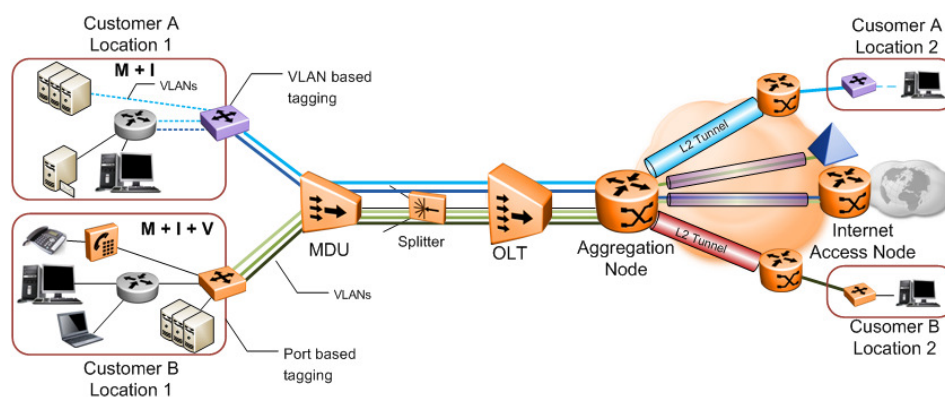

Figure 11. High level architecture: Metro Ethernet (in different configuration)

On WAN side of switch there is dedicated S-VLAN per service connection. On the other side such connections are terminated on other customer's switch(s). Traffic inside S-VLAN is transparently forwarded by FTTB+LAN MDU as well as OLT and then aggregation network (L2 tunnel e.g. VPLS) up to destination. P-bits (set by switch) are used for traffic prioritization in the network.

Thanks to different VLANs traffic of different customers is also separated. For Internet Access there is a dedicated service connection terminated on Internet Access Node (router which acts as a gateway to Internet). For VoIP service there is also a dedicated service connection (VoIP S-VLAN from switch) up to VoIP Service Platform.

In Metro Ethernet service IP addressing of end user equipment is assigned by customer (service provides transport in L2 thus no IP addressing required). Exception is VoIP Gateway which has address assigned by service provider (in order to communicate with VoIP Platform).

In this paper we described example services' architecture for residential and business deployments. Presented generic architecture concept is flexible, easy to implement and cost effective. Similar approach can be used for realization of other services.

APPENDIX A: FTTB+LAN access architecture implementation

In order to verify FTTB+LAN access architecture a field trial was launched targeted to residential users. An opportunity was taken to obtain results, not only from tests performed in laboratory, but also from 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 (see Figure 12) based on main assumption of architectural concept presented in section 4 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.
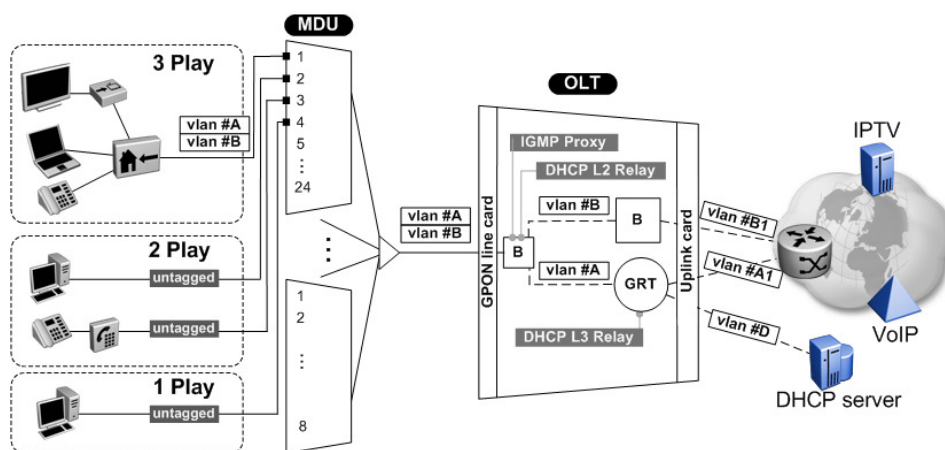
Figure 12. Network architecture used for field trial

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 13).

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.
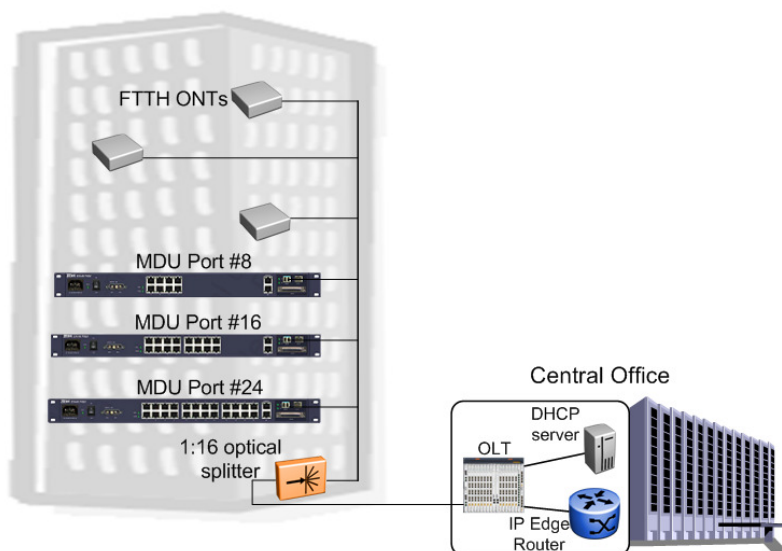
Figure 13. FTTB+LAN field trial network: a generic view

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.

Network architecture used for the field trial purpose followed principles described in chapter 4. Access Network architecture and was based on IP forwarding and DHCP attachment process. However some differences existed. For IPTV the approach was based on BBF TR-101 recommendations ([5]) with L2 forwarding on FTTB+LAN MDU and Access Node (OLT) as well. Additionally IGMP Proxy function was enabled on OLT. Dedicated VLAN (VLAN #B from Figure 12) was used for IPTV traffic between HGW and OLT. Also IPTV traffic was placed in dedicated VLAN from OLT to aggregation node.

Thanks to network architecture design described above installation and service delivery process were simplified in comparison to typical situation (e.g. traditional ADSL access). L3 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).

APPENDIX B: Feedback from a field trial launched for residential users

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 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 3) 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.

Table 3. Example results from tool measuring IPTV packet loss

Test	Successful received packet	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

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 4) proved very good performance of Internet Access service.

Table 4. Measured metric results for internet access service

Metric	Value	Unit
dns_e2e_response_time	9,67	ms
dns_success_rate	100,00	%
download_throughput	100000	kbps
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 14) 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 the field trial) as a commercial service. It allows making a conclusion that Internet service indeed met students' requirements and expectations.
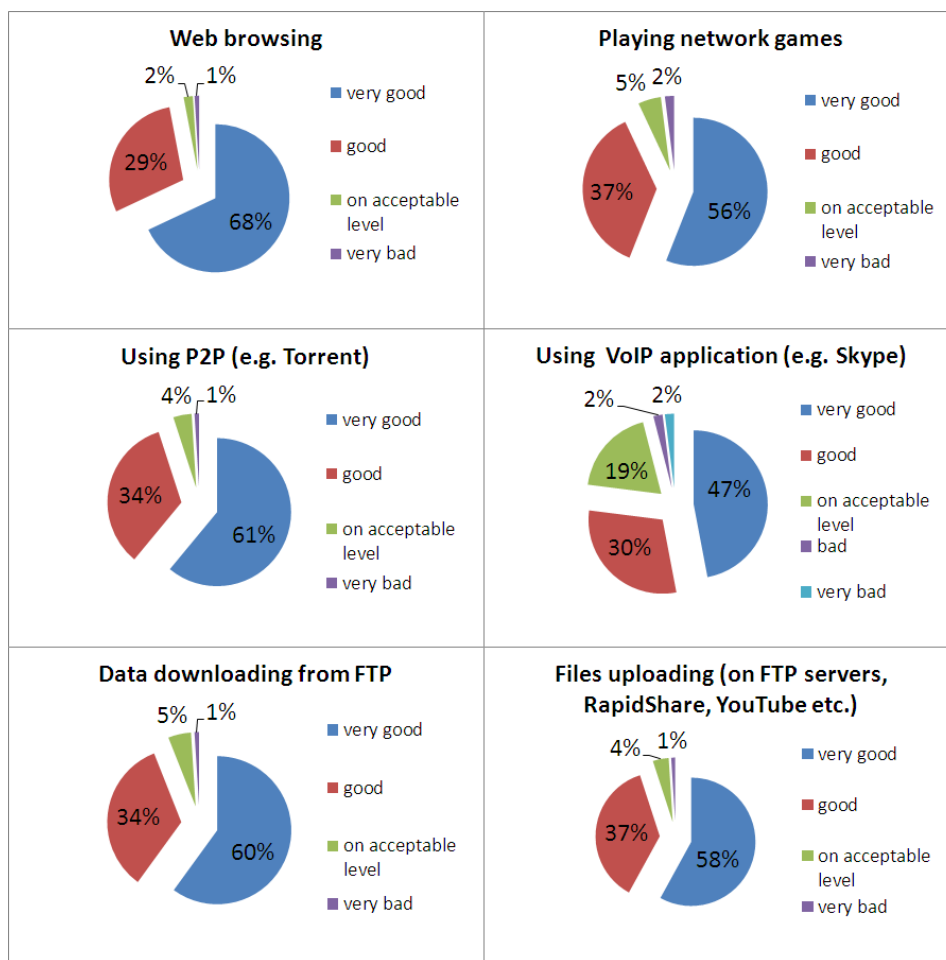
Figure 14. FTTB+LAN field trial Quality of Experience survey results

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FTTB + LAN: elastyczna architektura dostępowa dla użytkowników domowych i biznesowych[2]

STRESZCZENIE: Przedstawiono propozycję podejścia do budowy nowoczesnego, szerokopasmowego punktu dostępowego sieci, bazującego technologii FTTB+LAN, w budynkach wielorodzinnych, w których dostępne jest okablowanie miedziane kategorii 5. Prezentowane podejście pozwala na budowę niedrogich rozwiązań, które łatwo mogą być wdrażane dla użytkowników indywidualnych i biznesowych. W niniejszym opracowaniu szeroko omówiono architektury sieci dostępowych, wraz ze sposobem efektywnego przekazywania ruchu użytkowego. Przedstawiona elastyczna architektura dostępowa umożliwia wykorzystanie jednej sieci dostępowej dla różnych profili usług.

SŁOWA KLUCZOWE: FTTB+LAN, GPON, VHBB, optyczna sieć dostępowa, Ethernet, elastyczna architektura dostępowa, usługi mieszkaniowe i biznesowe.

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[2] Artykuł jest rozszerzoną wersją referatu [1] przedstawionego na multikonferencji FedCSIS we wrześniu 2012 roku ([2]).