

# Visualization Tool for Control Signalling in NG-PON2

Michal Jurcik, and Tomas Horvath

**Abstract**—The requirements of end users on the quality of Internet connection and services is forcing the Internet providers and technical community to propose and introduce new technologies which may react to this demand. The most promising solution in this regard seems to be a passive optical network. There are many standards and recommendations provided by the organizations IEEE and ITU-T, such as EPON, GEAPON, G-PON, XG-PON, and newly added NG-PON2 described in the ITU-T G.989 recommendation. Due to the implementation of TWDM mechanism the recommendation describes additional control messages to manage the whole network. This leads us to a need for a visualization tool which clearly shows control message flows and events between ONU and OLT units for each state. The application, designed by the authors and developed in C# programming language, is mainly focused on education purposes, but could be also useful to skilled industry professionals and in general those who have read the standard but are not fully familiar with the sequence of data flow in NG-PON2.

**Index Terms**—NG-PON2, visualization, PLOAM, C#.

## I. INTRODUCTION

**D**UE to increasing requirements of end users on the quality of Internet services and offered transmission speeds, the ISPs (Internet Services Providers) and technical community are motivated to propose and introduce new technologies which react to this demand. According to [1], the Internet video applications will experience an annual growth rate of 47% in the near future. Optical networks have become a standard for both transport and access networks. Passive optical networks are widely considered as a promising solution for the future Internet connection due to higher bandwidth capacity and transmission stability [2], [3].

PONs are being built according to standards and recommendations defined by the organizations IEEE (Institute of Electrical and Electronics Engineers) and ITU-T (International Telecommunication Union, Telecommunication division). In general, the IEEE standards dominate in Asia and ITU-T standards dominate in Europe. This article deals mainly with the ITU-T standard NG-PON2 (Next Generation PON) described in the ITU-T G.989 standard [4]. The first standard for passive optical networks was APON (ATM Passive Optical

Network) followed by BPON (Broadband PON). Both of them used ATM (Asynchronous Transfer Mode) cells at the network layer. Then the first standard with transmission speed in the range of Gbit/s, GPON (Gigabit PON), was approved in 2005. The main difference between GPON and the previous standards was the used transmission unit as in GPON both Ethernet frames and/or ATM cells can be used. Evolution of passive optical network technologies is aimed at offering higher transmission rates with communication model converging to the Ethernet technology. The ITU-T standards use a proprietary encapsulation method - effectively the Ethernet frame is mapped into GTC (Gigabit PON Transmission Convergence) model by GEM (Gigabit Encapsulation Method). Customer's demand of even higher bandwidth for multimedia services (Netflix, 4K video etc.) resulted in development of another standard with 10 Gbit/s transmission speed: XG-PON (Next Generation PON). Current research of ITU-T is concentrated on NG-PON2 (Next Generation PON Stage 2) standard. This optical network specification, based on XG-PON modification with extensive TC (Transmission Convergence) layer optimization. A new proposal of NG-PON2 shares majority of key properties with XG-PON network. The main differences are the transmission rate (up to 40 Gbit/s in comparison of 10 Gbit/s), the geographic range of the passive part of the network (up to 40 km, an extension from 20 km), and also higher split ratio (up to 1:256 instead of maximum of 1:128). Data transmission in this network uses a combination of multiplexing methods: TDM (Time Division Multiplexing) and WDM (Wavelength Division Multiplexing) known as TWDM (Time Wavelength Division Multiplexing).

The main innovation in the ITU-T draft recommendation for NG-PON2 (ITU-T G.989) is the implementation of TWDM. Since the OLT (Optical Line Termination) and ONU (Optical Network Unit) must negotiate the use of specific wavelength channels, the draft had to be extended to include new algorithms and control messages. The recommendation also describes, inter alia, all the principles of connection establishment, negotiation and liaising in these networks. Communication conditions and allocation structures sent between the units are described as well. Every manufacturer of the network equipment for NG-PON2 network has to accurately implement this functionalities.

This article describes control messages and data which are exchanged between ONU and OLT units during the operation states. Due to the complexity of communication in NG-PON2 network we have decided to create an application software in C# programming language to demonstrate this issue. The

Manuscript received February 14, 2016; revised June 8, 2016.

Research described in this paper was financed by the National Sustainability Program under grant LO1401, SIX CZ.1.05/2.1.00/03.0072 and the European Centre of Excellence CEITEC CZ.1.05/1.1.00/02.0068. For the research, infrastructure of the SIX Center was used.

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application is able to simulate all the states including security options, which are clearly sorted in the listbox according to ITU-T G.989.3 recommendation. The user may choose any operation state and follow the exact content of the individual reports and timers or use buttons for control of communication model and simulate network faults. The main benefit of this solution is that the person who operates the application does not need a complete overview of all events which take place during connection and data transfer phases. The application is primarily used by students in the course "Optical Networks", but could be also useful to skilled industry professionals as a reference and in general to those who have read the standard but are not fully familiar with the sequence of data flow in NG-PON2.

The outline of this paper is organized as follows. In Section II, we give an overview of the related works. The handshake algorithm between OLT and ONU and service PLOAM (Physical Layer Operations, Administration and Maintenance) messages and operational states are described in Section III. A description of the development of the software for network visualization is provided in Section IV. Finally, we conclude this paper in Section V.

II. RELATED WORKS

In recent years, many works dealing with passive optical networks have been published. Several different publications and papers from public sector and commerce focused on the NG-PON2 standard are available. Unfortunately, most of them deal only with the physical layer. For example, in the paper [5] the authors describe influence of cross-talk on the upgradability of TWDM-PON. The work [6] deals with transmission line redundancy in NG-PON2 networks. The authors also present Markov chain models for the service failure during reconnection process. The papers [7], [8] introduce the design of the new network in greenfield scenario. The article [7] deals with the physical layer parameters, especially split ratio, distribution networks, wavelength plan, Raman fiber non-linearity related degradation, and interchannel cross-talk tolerance. In [8], wavelength control, technology feasibility, management and control channel design, and potential future standardization directions of such a multi-wavelength PON system are discussed. Authors of [9] analyze the issue how the XG-PON and NG-PON2 systems will compete, coexist, or cooperate. No relevant publications dealing with simulations and detailed description of higher layers (than the physical layer) in the NG-PON 2 standard can be found. There are only some simulations of the older standard XG-PON presented by Xiuchao et al. [10]. The authors have also presented a paper focused on the TC layer in the XG-PON standard, [11].

III. HANDSHAKE ALGORITHM

The process of connection establishment is known as the ONU activation cycle. It consists of nine operating states between OLT and ONU, described below in detail. The state diagram is displayed in Fig. 1.

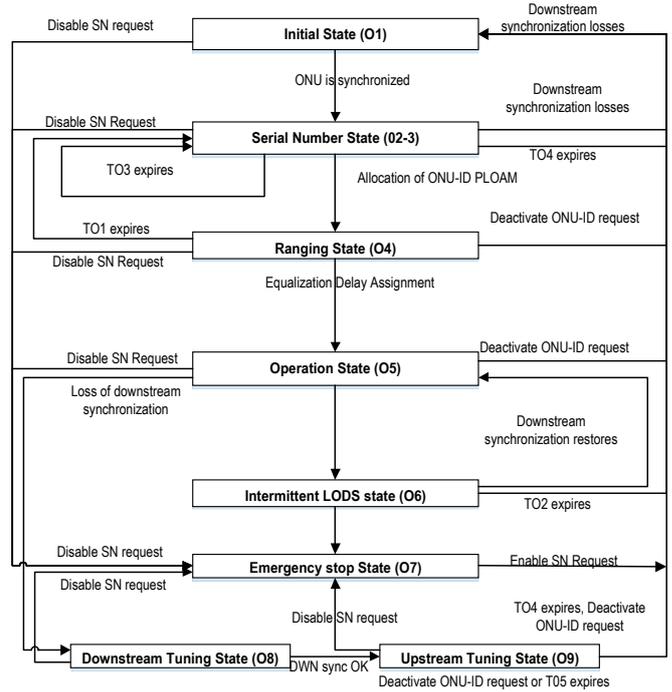


Fig. 1. The states diagram for NG-PON2 [4].

A. Service PLOAM messages

The control signalling between OLT and ONU is based on PLOAM message exchange. The PLOAM message length is 48 octets and they have a well-defined format, see Tab. I. Messages are transmitted using the so-called PLOAM channel and allow for full management of the NG-PON2 network.

TABLE I  
PLOAM MESSAGE CONTENT.

Octet	Field
1-2	Specification of ONU-ID
3	Message type ID
4	Sequence number
5-40	Message content
41-48	Message integrity check

The number of distinct PLOAM messages is finite in NG-PON2 recommendation and they are divided between downstream and upstream directions. Further, the messages are divided according to their destination on a unicast and broadcast. PLOAM channel carries the following instructions [4]:

- Arranging of communication profiles.
- Activation, deactivation and registration of ONU units.
- Transmission of information to secure communication.
- Information for tuning the wavelength.
- Instructions to control system power management of devices.

These messages have a prominent role in the NG-PON2 protocol, and are included in the visualization software.

### B. State O1 – Initial state

This is the default state when ONU is switched on, transmission is disabled. In this state the ONU tries to synchronize with the OLT unit. ONU receives all downstream PHY frames and looks for a PSync (Physical Synchronization) field which contains a 64-bit fixed sequence  $0 \times C5E51840FD59BB49$ . The sequence appears in all PHY frames (in both the downstream and the upstream directions) and determines the start of the frame. Next the ONU obtains PHY frame boundary (due to fixed frame length) and starts parsing of all incoming PLOAM messages. The ONU collects all settings from the OLT to allow for transmission - system (ID  $0 \times 17$ ), channel (ID  $0 \times 18$ ) and burst (ID  $0 \times 01$ ) profiles. As soon as all this information is received the ONU moves to state O2-3 [4].

### C. State O2-3 – Serial Number State

The ONU starts the discovery timer TOZ, activates its transmitter, and makes best effort to tune it to the upstream wavelength channel corresponding to the host downstream wavelength channel used. The OLT periodically sends broadcast in-band serial number grant with Alloc-ID 1021 (10G + 2.5G lines), 1022 (10G line) or 1023 (2.5G line). If the OLT supports both 10G and 2.5G upstream rates it should use Alloc-ID 1021 to reduce the time required for connection establishment. The ONU waits for in-band serial number grant from OLT and once the ONU receives it, it responds with an in-band Serial\_Number\_ONU PLOAM message with the Random\_delay field set. The ONU waits for response from the OLT until the timer TOZ expires. Possible incoming messages regarding to transmission wavelength negotiation are Calibration\_Request message ( $0 \times 13$ ) that forces the ONU to calibrate and tune up the receiver or the transmitter while remaining in the state O2–3, or Adjust\_Tx\_Wavelength message ( $0 \times 14$ ) that commands the ONU to modify the transmitter wavelength and return to the state O1. When the ONU receives the Assign\_ONU-ID message with unique ID, it advances to the state O4. Otherwise the ONU returns to the state O1 and begins the search for an alternative downstream wavelength channel [4].

### D. State O4 – Ranging state

The ONU starts the ranging timer TO1. The ONU waits for the Ranging\_Time message ( $0 \times 04$ ) from the OLT. During the waiting the OLT may send a Request\_Registration message ( $0 \times 09$ ) to request an ONU registration ID. The ONU responds with Registration message ( $0 \times 02$ ). Once the ONU receives a Ranging\_Time PLOAM message with updated equalization delay it sends the Registration message and advances to the state O5. When the timer TO1 expires, the ONU ignores the assigned ONU ID value along with default Alloc-ID and default OMCI XGEM port-ID and returns back to state O2–3. All the profile information collected in the chronologically previous states is preserved [4].

### E. State O5 – Operation state

The ONU processes downstream frames and transmits upstream bursts, as directed by the OLT. In this state the ONU

is fully operational and should send or receive data [4].

### F. State O6 – Intermittent LODS state

The ONU shall enter this state from the state O5 when the downstream synchronization is lost. After that the ONU starts TO2 and TO3 timers to support the wavelength channel protection (WLCP), namely maintaining wavelength stability and clock synchronization. If synchronization is restored before the timers TO2 and TO3 expire, the ONU returns back to Operation state (O5). When the timer TO2 expires, the ONU switches to the Initial state (O1) whereas when the TO3 timer expires the ONU switches to the Tuning state (O8) [4].

### G. State O7 – Emergency stop state

This state may be entered from any state described before. If ONU receives Disable\_Serial\_Number message with the fifth octet set to  $0 \times FF$ , it is denied from upstream transmission and has to shut off its laser. If the value of fifth octet is  $0 \times 00$  the ONU is allowed for upstream transmission but has to discard all acquired parameters and return to Initial state (O1). Note that using the Disable\_Serial\_Number message it is possible to deny or allow upstream access for all ONUs at once by setting the disable option to  $0 \times 0F$  or  $0 \times F0$  [4].

### H. State O8 and O9

These states are used for downstream and upstream wavelength tuning of the TWDM channel. The ONU starts the TO4 timer and when the timer expires, what means a failure, the ONU switches to the Initial state (O1) and discards any agreed upon TC layer configuration [4].

## IV. VISUALIZATION SOFTWARE

The visualization software is a tool developed to help the interested parties learn about the features and technical specifications of the NG-PON2 network. For the implementation of the application, the C# programming language was used. It also offers some useful features, such as the OOP (Object-Oriented Programming) paradigm and the possibility to easily modify the application when following specifications arise [12][13].

The latest version of the ITU-T G.989 available at the time of application design was the fourth revision (published in 2016). It is expected that the principle of communication establishment is already finalized in this revision, and that further changes will only affect formal details such as the names of control messages and their descriptions, and clarify the specification.

The user interface is designed with an emphasis on ease of use for people who are interested in learning about the operational states in NG-PON2 networks. The user interface contains several elements:

- Communication states selector.
- Selection of frames generated in modes where the number of messages is variable.
- Space for displaying data structures.
- Overview of events occurring in the network.

- Buttons for controlling the communication model and generating extraordinary events.

The actual visualization occurs when the user selects a communication state in the application. There are several objects in each state which are always displayed with their descendants. The number of objects can vary due to other contingencies such as the number of data structures. Objects can also be dynamically added, for example, in the case of encryption selection. The **FrameConstructor** class handles the communication state selector and builds an array of objects for rendering. This class contains two static methods. These methods return the newly created frame **TreelItem**, which is then added to the visualization view. There are two methods: *DownstreamFrameConstruct* and *UpstreamFrameConstruct*. The *DownstreamFrameConstruct* input parameters are:

- PLOAM count.
- Array of MessageID identifiers.
- ONU-ID identifier.
- Number of ByteArray fields which represents a the content of PLOAM messages (depends on number of PLOAM messages).
- Sequence number.

The *DownstreamFrameConstruct* input parameters:

- A bit which determines whether the frame contains a PLOAM message.
- MessageID identifier.
- ONU-ID identifier.
- Array of type ByteArray which represents the content of a PLOAM message .
- Sequence number.

In order to be visualized, objects have to implement the interface **IStructureItem** that requires the definition of the method responsible for displaying the object by the tree visualizer. It is expected to display class attributes in the tree structure of the main window. This interface also implements method *toItem* that returns a data structure of the **TreelItem** type. To avoid unimplemented method *toItem* from the **IStructureItem** interface in other classes, an abstract class **PonStructure** containing the default implementation was added. This could prove useful in case of future extensions of the application as the default behaviour alerts the programmer that the method is not overridden. The abstract class **PonStructure** also implements an operator for implicit conversion to data type **TreelItem**. The resulting structure is illustrated in class diagram in Fig. 2.

The visualisation tool presumes reliable delivery of all messages and default flow of operation of all processes. In practice there could arise some problems such as LOS (Loss of Signal) and the deactivation of ONU unit, which are not currently modelled. Right-clicking on a visual element allows the user to summon a special dialog box. The box displays the data in the selected data structure graphically. Objects supportive this graphical view have a delegate method which creates an instance of the class **StructDetail**. This class is responsible for rendering the auxiliary dialog box and paste the text content of the class into the picture. Additional pictures of

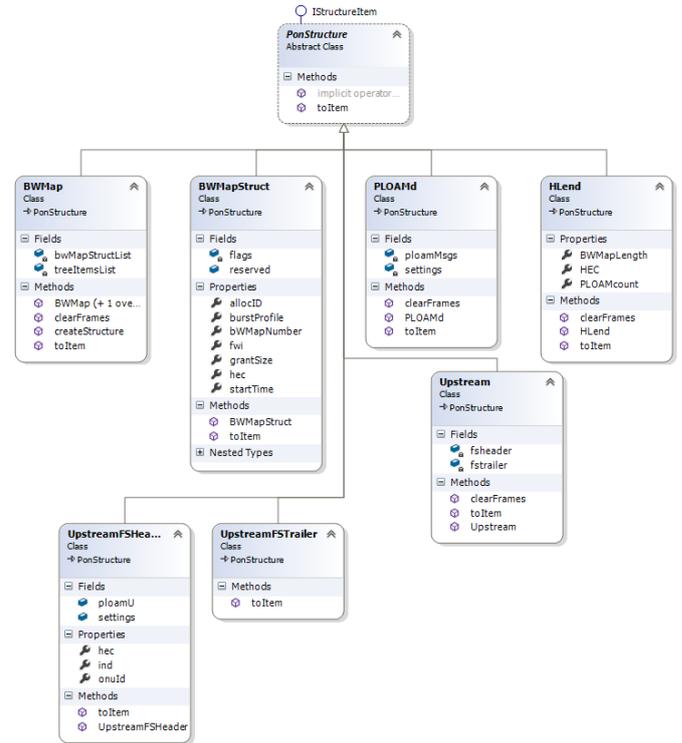


Fig. 2. Class PonStructure and its Descendants.

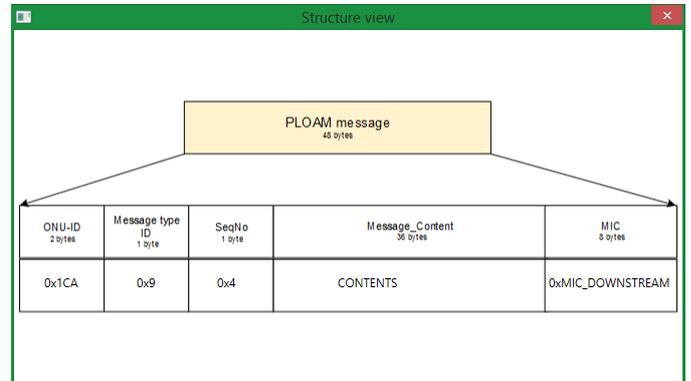


Fig. 3. PLOAM Message Structure.

data structures are stored in the application package as raster images. The demonstration of the preview of PLOAM message is shown in Fig. 3

The resulting GUI (Graphical User Interface) application was created to help users understand the communication. The controls are intuitive and unified for any communication state. The form of the main window is shown in Fig. 4.

### V. CONCLUSION

In this article the parameters of the transmission convergence layer of NG-PON2 network were analysed and an intuitive visualization method for its signalling flow was developed. The main aim is to describe the state diagram of the NG-PON2 transmission convergence layer, where each state is represented by a set of PLOAM messages and events organized into an entity called process. Next an application was designed

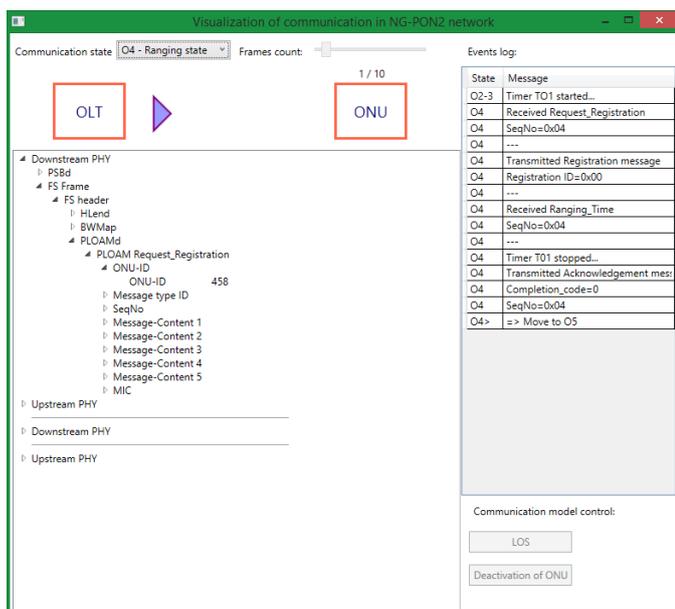


Fig. 4. Main Window of Application.

and implemented, which allows the user to visualize the most important messages for each state. The state diagram had to be generalized for efficient implementation in the programming language of choice, C#. Primarily, the visualization tool was developed for educational purposes in undergraduate course regarding Optical Networks.

As a future work, the authors plan on extending the visualization tool to support the display of detailed message frame structure for all PLOAM messages, implementing a flow diagram display and mainly to model the loss of signal situation, which would interrupt the communication.

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