Optimization of Traffic Protection Schemes for Utilization in Hybrid Passive Optical Networks

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ABSTRACT

This contribution focuses on the need for traffic protection schemes for utilization in future next-generation passive optical networks. First, basic characteristics of possible hybrid passive optical networks are presented and significance for analyzing of traffic protection schemes in these networks is presented. Following, possibilities for optimization of different considered traffic protection schemes are introduced and analyzed before their implementation in real applied network topologies. Therefore, an extension of the HPON Network Configurator must be realized for obtaining relevant results and source materials to make a decision. Subsequently, an evaluation of HPON traffic protection types for specific hybrid passive optical networks can be executed.

Keywords: hybrid passive optical networks, traffic protection schemes, HPON Network Configurator, evaluation

1. INTRODUCTION

Future passive optical technologies utilized in the access network must be able to provide high sustainable bandwidths on per user basis while keeping capital and operational expenditures as low as possible. Moreover, the large coverage makes possible to reduce the total network costs by merging several optical line terminals into a single one. Furthermore, the growing importance of uninterrupted internet access makes the fault management an important challenge. Therefore, Next-Generation Passive Optical Networks (NG-PON) need to provide survivability schemes in a cost-efficient way. The reliability requirements may depend on user profiles. Thus, NG-PON networks should also support the end-to-end protection for some selected users when requested. Within this context, it is significant to find out an effective way for analyzing of traffic protection schemes for utilization in future passive optical networks.

The evolution of NG-PON networks has processed toward larger coverage of the access areas, higher numbers of users and higher bandwidth per user. Advanced users are requesting reliable connectivity and network operators are expected to provide uninterrupted access to network services. Therefore, it is essential to provide protection mechanisms and efficient fault management in order to meet reliability requirement. Improving a network reliability performance by just a duplication of all the components and optical fibers is expensive and thus, not always suitable for cost-sensitive access networks. Moreover, deployment costs of the fiber infrastructure are the dominating part of capital expenditures and should be minimized by a proper fiber layout.

NG-PON networks present optical access infrastructures for supporting various applications of many service providers. In the near future, we can expect NG-PON technologies with different motivations for developing Hybrid Passive Optical Networks (HPON) [1]. The HPON is a hybrid network in a way that utilizes on a physical layer both Time- (TDM) and Wavelength- Division Multiplexing (WDM) principles together. Moreover, the HPON presents a hybrid network as a necessary phase of the continual transition from actual TDM to prospective WDM passive optical networks. Possible exploitation of hybrid passive optical networks can be meantime divided into following probable scenarios:

- The WDM/TDM-PON network represents a hybrid network based on the combined WDM/TDM approach (Fig. 1). The WDM/TDM-PON architecture associates several smaller TDM networks into one large network, where each TDM network utilizes specific wavelength for communication with the Optical Line Terminal (OLT). A number of subnetworks depends on a number of Power Splitters (PS) or Array Waveguide Gratings (AWG) ports, when every subnetwork can utilize different splitting ratio. More information can be found in [2].

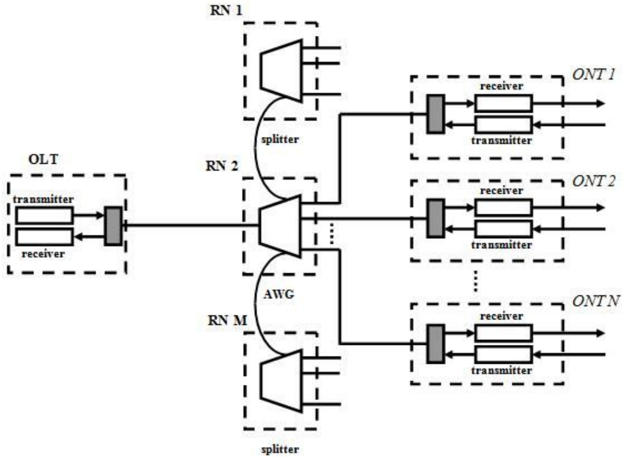

Figure 1 The general WDM/TDM-PON network architecture

- The SUCCESS (Stanford University aCCESS) HPON network [3],[4] introduces a sequential transition to the pure WDM PON network in a compliance with the TDM and WDM technology coexistence (Fig. 2). Its hybrid architecture comprises the ring topology for the WDM transmission. It contains two types of Remote Nodes (RN) for the WDM or TDM star connections. The WDM RN node is created from AWG elements, the TDM RN node from optical power splitters. Changing of OLT and ONU equipment is executed and adding of both (WDM and TDM) Optical Network Unit (ONU) equipment into common network architecture is allowed by using these specialized remote nodes. The OLT terminal generates signals for both WDM and TDM ONU units by means of Dense WDM (DWDM) wavelengths; however the TDM ONU unit transmits signals on Coarse WDM (CWDM) wavelengths. More information can be found in [5].

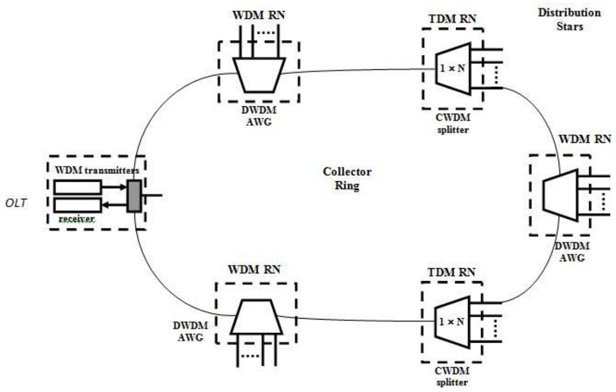

Figure 2 The general SUCCESS HPON network architecture

- The SARDANA (Scalable Advanced Ring-based passive Dense Access Network Architecture) design [4],[6] considers a remote pumped amplification, the backward compatibility with existing 1 GPON networks and a support for standardized 10 GPON networks (Fig. 3). Its scope is to create a modular network and to enable service provisioning for a large number of subscribers either on smaller distance in populous urban areas or in larger geographical areas with small population. The PON fiber topology is creating by two main parts – the WDM ring with the central office and remote nodes, TDM trees connected to particular remote nodes. The WDM ring consists of two optical fibers – one per direction. A key element of the network is the RN. Used ONU units are colourless; they don’t contain any optical source. Transmitting from the ONU is based on the Reflective Semiconductor Optical Amplifier (RSOA) by means of the re-modulation of received signals. More information can be found in [7].

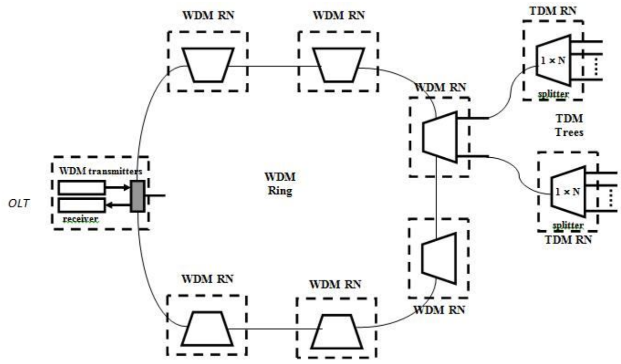

Figure 3 The general SARDANA HPON network architecture

- The Long Reach Passive Optical Network (LR-PON) architecture [8] utilizes active components in an outside plant for network reach enhancement and simultaneously the mutual interconnection of multiple passive optical networks. However, in our design, active components are located in the OLT side to maintain a passive character of the optical access network (Fig. 4). A network attenuation depends on type of optical fiber types, on a selected TDM network, on a number of connected subscribers and on the OLT-ONU distance. More information can be found in [9].

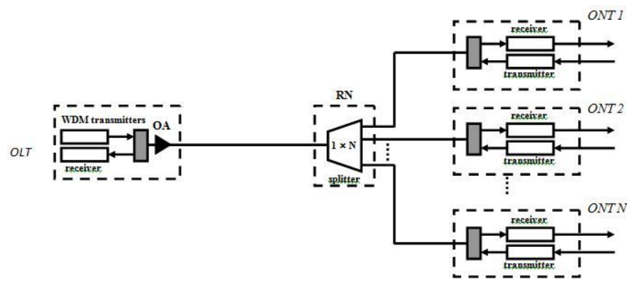

Figure 4 The general LR-PON network architecture

HPON architectures can be proposed with and without protection. They are designed having in mind different possible paths for the network deployment and protection upgrade. The proposed survivable architectures can also be applied to passive optical networks with more than one stage of remote nodes based on power splitters. The hybrid passive optical network can be proposed with different levels of the traffic protection compatible with all the HPON architectures [10].

The benefit of deploying a traffic protection in HPON networking – a significant reduction of the total costs of ownership compared to the unprotected access in all of considered (rural, urban, dense urban) scenarios – at very low increase of infrastructure expenses a large reduction of operational expenditures can be obtained as a consequence of the reliability performance improvement and the service interruption decrement experienced by users. It can be beneficial to either provide protection functionalities at the time of HPON network deployment (approach 1) or at least install a sufficient amount of fibers in advance (approach 2). It can be recommended to provide a traffic protection as early as possible [11].

Also, reasons for the traffic protection are very substantial from a viewpoint of the transmission. Concretely, increasing transmission rates and numbers of subscribers together with enlarging geographical scales and ranges can reach a level where the protection appears to be indispensable. It can be shown a clear benefit when a network planning is done with possible protection upgraded, which leads to a decrease in investment costs. The longer the protection deployment time, the higher the total capital expenditures. This confirms an importance of the right deployment plan for future hybrid passive optical networks [10].

In this contribution, basic characteristics of possible hybrid passive optical networks are presented and a significance for analyzing of traffic protection schemes in these networks is presented. In the section 2, possibilities for optimization of different considered traffic protection schemes and their modifications that can be specifically implemented in future hybrid passive optical networks are introduced and applied to two basic HPON network topologies. For analyzing various possible traffic protection types, the extension of the HPON Network Configurator is realized (section 3) and an evaluation of different traffic protection types available for future HPON networks is executed (section 4).

2. OPTIMIZATION OF TRAFFIC PROTECTION SCHEMES IN PASSIVE OPTICAL NETWORKS

For future hybrid passive optical HPON networks, it is necessary providing a certain level of the traffic protection and restoration [1],[10],[11]. Different protection approaches and/or mechanisms can be proposed, starting from a no-protection scenario toward proposed architectures with the protection:

- First, network providers will deploy an unprotected access network. Then, they can offer a traffic protection to the first remote node. This protection level is necessary in order to prevent a large number of customers being out of service at the same time. Finally, the end-to-end protection is offered on a per-user basis as soon as business customers request a reliability performance improvement.
- Second, a transition from the no-protection scenario in the access network directly to a protection to the first remote node is provided. A possibility for the end-to-end protection for business users is added in the future if required. This approach is more logical if network provider has a dominating position and every user in the region has to be connected to its network eventually.
- Third, it might be more beneficial to deploy a reliable optical access network in a single step, from the no-protection scenario directly toward the end-to-end protection. This approach is realizable, if network operators know in advance a location of all residential and business users in their networks.

In future hybrid passive optical HPON networks [12],[13],[14], the tree topology is one from the most employed where the power signal splitting is executed in one point, called the remote node, which is sensitive for the network failure generating. The traffic protection and restoration can be secured by adding another OLT terminal, by adding a redundant optical fiber between the OLT and the power splitter, or by adding a redundant optical power splitter. Consequently, a role of the Linear Automatic Protection Switching (L-APS) is important. The L-APS can use two control modes. For the centralized control mode, a protection changeover is realized in the OLT after traffic failure detection. For the distributed control mode, each ONU unit includes protection equipment continuously monitoring a status of the optical fiber and passive network components. In this mode, the L-APS is realized and executed individually only for the ONU unit influenced by the traffic failure. Moreover, the ONU price is increased [12]. For this topology, three traffic protection types can be considered – 1+1 (redundant), 1:1 (dedicated) and 1:N (shared).

The ring topology is used above all in optical metropolitan networks, but it is also applicable in future hybrid passive optical HPON networks with the Ring Automatic Protection Switching (R-APS). It can be used in several modifications depending on the ring size, a number of network nodes and supporting service types. For the traffic protection, the R-APS utilizes a dual ring that created from one or two optical fiber pairs. For this topology, these traffic protection types can be considered – Unidirectional Path Switched Ring (UPSR) and Bidirectional Line Switched Ring (BLSR) realized with two or four optical fibers.

3. THE HPON NETWORK CONFIGURATOR

The HPON Network Configurator allows comparing of configuration possibilities for various future hybrid passive optical networks. The created HPON Network Configurator [1],[2],[15],[16] evaluates real possibilities for a consistent transition from TDM-PON to HPON networks based on various specific technical parameters – a network capacity from a viewpoint of the physical layer, a number of TDM and WDM network subscribers, a number of exploited wavelength multiplexing types, a growth of the channel capacity by connecting of new subscribers and other feasibilities.

The HPON Network Configurator is created by using the Microsoft Visual Studio 2010 software in the IDE development environment. There exist possibilities for the graphical interface created by using the MFC (Microsoft Foundation Class) library for the C++ programming language. The simulation model has one main interactive dialogue window (Fig. 5) for inserting and presenting parameters of transitions from TDM-PON to HPON networks. It allows comparing and analyzing four principal approaches for designing and configuring of hybrid passive optical networks. Therefore, additional dialogue windows with the configuration and the relation of basic network infrastructures can be used for the specific HPON configuration setup.

In the HPON Network Configurator, four future hybrid passive optical networks - WDM/TDM-PON, SUCCESS HPON, SARDANA HPON and LR-PON - are reserved. By using CONFIGURE push buttons in the main dialogue window, autonomous dialogue windows for the specific hybrid network configuration are opened. Then, a configuration of specific network parameters and traffic protection types can be proceeding for appropriate options. If necessary, RELATION push buttons are prepared for user with short descriptions of basic features of the selected HPON network.

Finally, a short list of basic characteristics calculated for each option – a total capacity of the hybrid network, a total number of subscribers, an average capacity per one subscriber, the maximum network attenuation – is displayed.

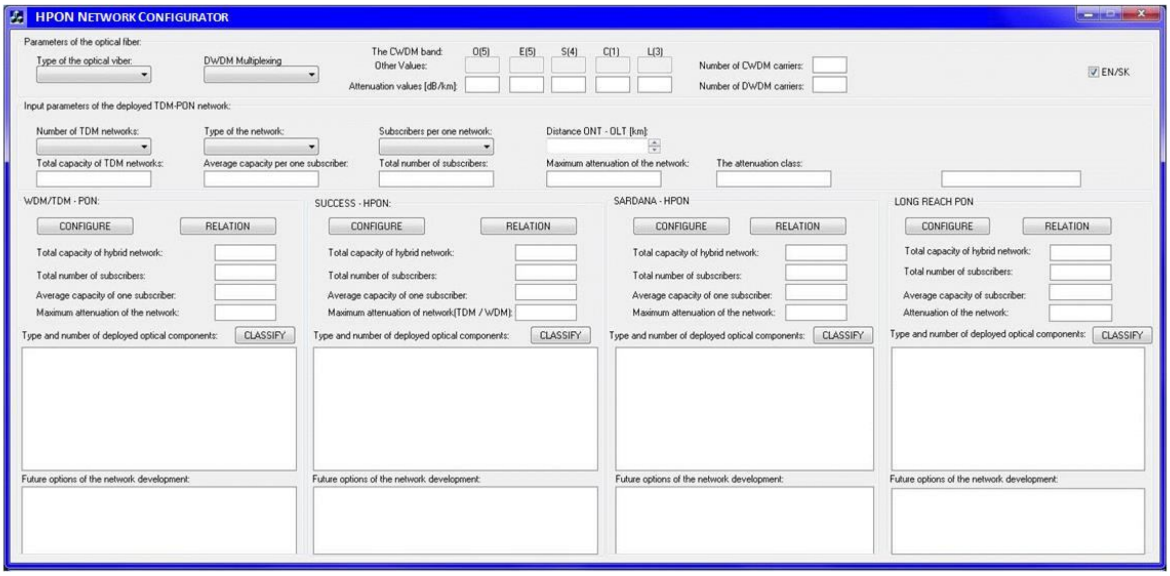

Figure 5 The main interactive window of the HPON Network Configurator

For each HPON option, input parameters can be selected and thereafter particular traffic protection types can be compared. These comparisons together with available financial costs can be used for the conclusive decision about specific traffic protection schemes for the particular hybrid HPON network.

4. EVALUATION OF THE HPON TRAFFIC PROTECTION TYPES

As an advanced extension the HPON Network Configurator, a new functionality is focused on the traffic protection and restoration. There are two basic network topologies of the HPON traffic protection schemes:

- the tree topology,
- the ring topology.

For the selected protection type in the WDM/TDM-PON network [1],[2], there are implemented following specifications:

- a duplicated optical fiber (the 1:2 power switch only at the RN end),
- a duplicated OLT equipment (1:2 power switches at both OLT and the RN ends),
- parallel distribution networks,
- the supplementary circuit included in the RN node.

For all these specifications, short descriptions of their main characteristics are prepared. These traffic protection types can be utilized also in the LR-PON network. For the selected protection type in the SUCCESS HPON network [1],[5], there are implemented following modifications:

- a number of optical fibers,
- a utilization of the transmission capacity,
- an activity at the simple and multiple fiber interruptions or at the node failure,
- installation and deployment costs,
- a complexity.

For all these modifications, descriptions of their main principles are prepared and more so functions in a case of the traffic failure detection are realized. The SARDANA HPON network [1],[7] consists of two main parts – the WDM ring and TDM trees. There are implemented traffic protection types for both tree and ring topologies. If a possibility for the complete traffic protection is selected, then both parts automatically are activated. In consequence, it is necessary to select one specific traffic protection type for the WDM ring. After it, other alternatives remain blocked. The same activity is executed for TDM trees. For each traffic protection type, specifications must be selected. Indeed, it is possible to combine these traffic protection types or to select protection modifications only for one network part.

4.1Traffic protection types in WDM/TDM-PON + LR PON networks

The WDM/TDM-PON configuration window with extended traffic protections is shown on Fig. 6.

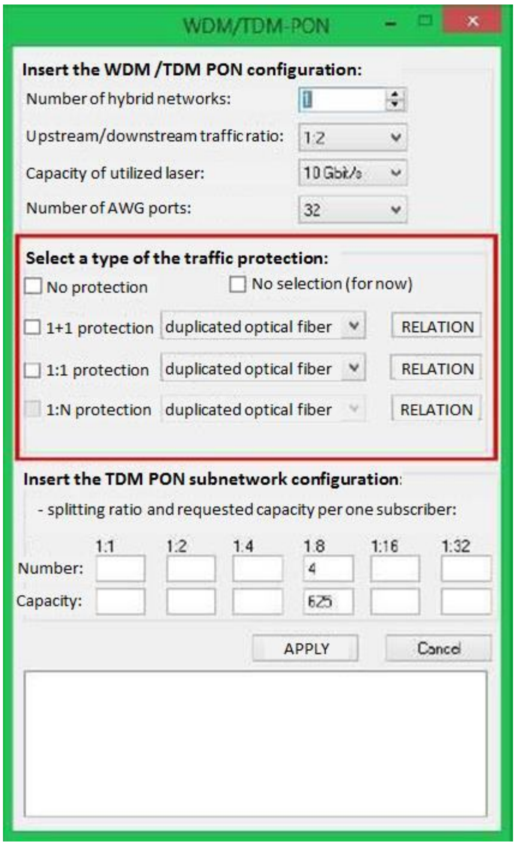

Figure 6 The WDM/TDM-PON configuration window with extended traffic protections

If NO PROTECTION option is selected, then a reasonable notice in an empty bottom panel is displayed. Also, if no protection scheme is required, then the appropriate box must be confirmed and the single WDM/TDM-PON configuration is no influenced. In any type of the traffic protection is selected, then appropriate calculations and notices in the main dialogue window are changing. For 1+1, 1:1 and 1:N protection types, more specifications are available according to corresponding types of the traffic protection.

Simultaneously, a condition for the 1:N traffic protection is implemented. This traffic protection type is active only if a number of WDM/TDM-PON networks is more than 2. The considered condition coordinates a mutual relationship between a number of networks and the selected traffic protection type.

This comparison of traffic protection types in WDM/TDM–PON and LR-PON networks is based on following input parameters:

- in the main window: G.652 D optical fiber, 0,4 nm (50 GHz) DWDM channel spacing, 10G–EPON 10 Gbit/s technology, 2 TDM networks, 16 subscribers per network, 20 km OLT-ONT distance
- in the WDM/TDM-PON configuration window: 2 WDM/TDM-PON networks, 1:2 upstream /downstream traffic ratio, 10 Gbit/s utilized laser rate, 32 AWG ports (a number of subnetworks), 1:8 splitting ratio, 4 TDM subnetworks, 625 Mbit/s channel capacity per subscriber

For particular specifications of traffic protection types, specific parameters and network components are introduced – see Tab. 1 and 2.

For the 1+1 protection type (a duplicated optical fiber), a number of optical components is not increasing excepting a duplication of the optical fiber. However, an increasing of the maximum network attenuation is arising. For other protection types, a number of optical components is increasing and simultaneously network costs are influenced.

For the 1+1 protection type with (duplicated network components), a number of optical components is double increasing when compared to the no-protection scenario. For the 1+1 protection type (the supplementary circuit included in the RN), a number of optical components is double increasing excepting a number of SOA/RSOA amplifiers that can be located in ONU units. For this protection type, 2 power splitters and 2 switches must be located in each RN and therefore network costs are rapidly enhanced.

For the 1:1 protection type (a duplicated optical fiber), a number of optical components is not increasing as it is present for other protection types. Moreover, a maximum network attenuation is not increased. Therefore, a utilization of this protection type has no negative impact on network costs.

For other protection types (with duplicated network components and the supplementary circuit), a number of optical components is increasing and network costs are expressively enhanced. But, more complex traffic protection and restoration is provided.

Table 1 Specifications of the 1+1 traffic protection type in the WDM/TDM-PON network option

WDM/TDM-PON network option 10G-EPON 10 Gbit/s technology			
PARAMETERS	**Duplicated fiber**	**Duplicated network component**	**Supplementary circuit included in the RN**
Total hybrid network capacity	20 Gbit/s	20 Gbit/s	20 Gbit/s
Total number of subscribers	32	32	32
Average capacity per subscriber	625 Mbit/s	625 Mbit/s	625 Mbit/s
Max. network attenuation	41,2 dB	29,2 dB	29,2 dB
UTILIZED COMPONENTS			
Original RN configuration			
10 Gbit/s DWDM lasers	4	8	8
Tunable DWDM receivers	2	4	4
32-port AWG	2	4	4
1:8 passive splitters	4	8	8
ONU units	32	32	32
SOA/RSOA amplifiers	32	64	32-64
Advanced RN configuration			
1:2 splitters in each RN			2
Switches in each RN			2

For the LR-PON network, the same conclusion is valid. A difference is in accessing to optical amplifiers utilization. Each amplifier type has a different maximum amplification level: Raman max. 25 dB, EDFA max. 35 dB and SOA max. 30 dB. Using of these active components, a maximum network attenuation can be accommodated.

For the 1:N protection type (a duplicated optical fiber), optical components are the same. However, it is unavoidable to realize a mutual network interconnection for the 1:N protection provisioning.

Table 2 Specifications of the 1:1 traffic protection type in the WDM/TDM-PON network option

WDM/TDM-PON network option 10G-EPON 10 Gbit/s technology			
PARAMETERS	**Duplicated fiber**	**Duplicated network component**	**Supplementary circuit included in the RN**
Total hybrid network capacity	20 Gbit/s	20 Gbit/s	20 Gbit/s
Total number of subscribers	32	32	32
Average capacity per subscriber	625 Mbit/s	625 Mbit/s	625 Mbit/s
Max. network attenuation	29,2 dB	29,2 dB	29,2 dB
UTILIZED COMPONENTS			
Original RN configuration			
10 Gbit/s DWDM lasers	4	8	8
Tunable DWDM receivers	2	4	4
32-port AWG	2	4	4
1:8 passive splitters	4	8	8
ONU units	32	32	32
SOA/RSOA amplifiers	32	64	32-64
Advanced RN configuration			
1:2 splitters in each RN			2
Switches in each RN			2

4.2 Traffic protection types in the SUCCESS HPON network

The SUCCESS HPON configuration window with extended traffic protections is shown on Fig. 7.

If NO PROTECTION option is selected, then a reasonable notice in an empty bottom panel is displayed. Also, if no protection scheme is required, then the appropriate box must be confirmed and the single SUCCESS HPON configuration is no influenced. In any type of the traffic protection is selected, then appropriate calculations and notices in the main dialogue window are changing. For UPSR, 2F BLSR and 4F BLSR traffic protection types, more specifications are available according to corresponding different levels of the traffic protection.

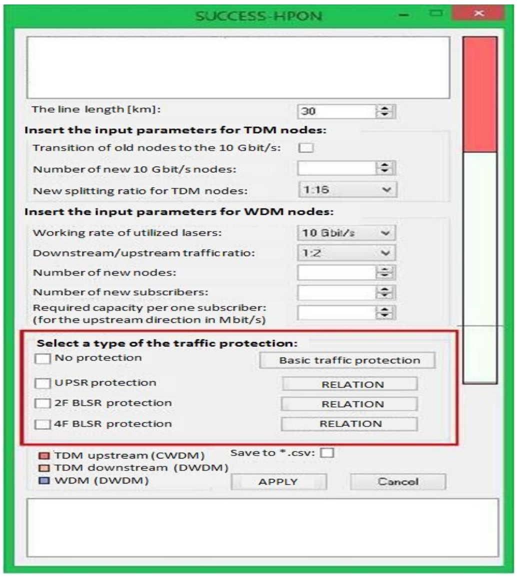

Figure 7 The SUCCESS HPON configuration window with extended traffic protections

As in the previous case, this comparison traffic protection types in the SUCCESS HPON network is based on following input parameters:

- in the main window: G.652 D optical fiber, 0,4 nm (50 GHz) DWDM channel spacing, 10G–EPON 10 Gbit/s technology, 2 TDM networks, 16 subscribers per network, 20 km OLT-ONT distance
- in the SUCCESS HPON configuration window: 60 km ring length, 5 new 10 Gbit/s nodes, 1:16 new splitting ratio for TDM nodes, 1:2 upstream/downstream traffic ratio, 10 Gbit/s utilized laser rate, 8 new WDM nodes, 50 new subscribers, 1000 Mbit/s channel capacity per subscriber

For particular traffic protection types, specific parameters and network components are introduced – see Tab. 3.

5. CONCLUSION

In this contribution, basic characteristics of possible hybrid passive optical networks are presented from a viewpoint of the traffic protection provisioning. Because different protection approaches and/or mechanisms can be proposed, it is significant to find out an effective way for analyzing of traffic protection schemes for utilization in future hybrid passive optical networks. Therefore, possibilities for optimization of different considered traffic protection schemes and their modifications were introduced and applied to two basic HPON network topologies – tree and ring.

For analyzing different HPON networks with available traffic protection types, the advanced extension of the HPON Network Configurator is realized with a new functionality focused on the traffic protection schemes and restoration mechanisms. Based on obtained results from the HPON Network Configurator program, following conclusions can be done. For the tree topology, the 1+1 protection type using duplicated network components is the most advantageous. This protection type is the fastest one because the same information signal is transmitted simultaneously in both working and protection optical fibers. Therefore, an immediate action is possible at the traffic failure detection. However, network costs can be very expressive in this case. For the ring topology, the 4F-BLSR protection type is the most advantageous from a viewpoint of the protection provisioning. This protection type can interact also at the multiple traffic failure detections. However, this network protection type is the most expensive due to the largest number of optical components. Therefore, a recommendation for optimization an appropriate traffic protection scheme provisioned in HPON networks as early as possible is getting more imperative for a large reduction of operational expenditures at very low increase of infrastructure expenses. Just after that, the passive optical network planning done with optimized possible traffic protection schemes can lead to a beneficial decrease in investment costs.

With technological progress, new technologies relevant to future hybrid passive optical networks and related traffic protection and restoration schemes are developing. In future, coming new components and mechanisms is expecting for the higher-level protection safety and for more reliable signal transmission in NG-PON optical networks.

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