Time and Memory Complexity of Next-Generation Passive Optical Networks in NS-3

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***Abstract*—Passive optical networks (PONs) offer a high network capacity and densified coverage at the cost of high capital expenditure. That fact is why operators use a shared infrastructure with one fiber for more customers in a split ratio. Deploying a passive optical network requires capital, but the operators can use a simulation tool to verify the physical layer parameters. The higher layers are less relevant for operators than for researchers. In this paper, we provide a basic simulation topology with downstream and upstream services. In real networks, the services control optical line termination (OLT), but in a simulation, it requires a router after optical line termination. We demonstrate a comparison of the time and memory complexity for low-rate services in 10G passive optical networks with different split ratios in Network Simulator 3 (NS-3).**

***Index Terms*—complexity, NS-3, simulation, transmission convergence layer, XG-PON**

I. Introduction

The last few decades have shown us the success of Internet connections around the world [1]. The number of end points (cell-phones, etc.) is massively increasing year by year, and this trend is expected to continue. These facts have an impact on power consumption worldwide [2]. With the sharing of optical fiber in the distribution network, the operator can save capital investments.

The European Union deploys a gigabit passive optical network (GPON), as can be expected according to its price [3], [4]. Next-generation PON (XG-PON) has a much higher cost of optical network unit (ONU) in comparison with GPON. The photonic services such as stable frequency transmission or accurate time do not require a high bandwidth, but do require a stable delay, in the photonic path [5]. Access networks focus on high bandwidth for customers because the total bandwidth is shared due to point-to-multipoint (P2MP) topology. Eventually, 4k will replace full high definition (HD) video transmission, and the streaming services will become very popular.

The transmission convergence layer of PONs does not have dedicated simulation tools in comparison with the physical layer. This layer can be implemented by authors in the OPNET Modeler, Network Simulator 3 (NS-3), or another tool [6], [7]. Our implementation of the transmission convergence layer requires hardware resources, and it is not possible to simulate the real transmission speed, for example, 10 Gbit/s bidirectionally.

The rest of this paper is structured as follows. Section II gives an overview of the NS-3 simulation tool with parameters. Section III introduces our simulation model with one service for the downstream and one for the upstream direction time and memory complexity investigation, respectively. Section IV concludes this paper.

II. Network Simulator 3

Network Simulator 3, which is also known as NS-3, is an open-source discrete network simulator that was developed primarily for research and education purposes. This simulator supports the research of both IP-based and non-IP-based networks. However, most of the research is focused on wireless or IP simulation using models such as wireless fidelity (Wi-Fi) and long term evolution (LTE). One of the simulation models

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is also the XG-PON module, which is defined according to [8].

While working, users can take advantage of the possibility of generating or receiving communication from real network elements. NS-3 can also serve as a link between multiple virtual workplaces.

Because NS-3 is an open-source development environment, its development is also being made available to the public (the scientific community, students, etc.). To make working with NS-3 more user-friendly, there is extensive documentation available at [9].

The XG-PON module that is used by NS-3 was designed to simulate the behavior of a network as accurately as possible and to solve any problems with the simulation so that it can be immediately integrated into a real network [10], [11]. The XG-PON standard is very extensive; therefore, the proposed module contains some simplifications. However, simplified processes can be added/redesigned using C++ in the future. The proposed module focuses primarily on the next-generation transmission convergence (XGTC) layer (can serve as a physical layer).

Individual parts of the standard (function) and their different implementations in the XG-PON module. Physical layer:

- Optical distribution network (ODN) – in real networks, the transmission route is often complicated. Therefore, in the proposed module, the overall ODN is implemented using a *XgponChannel* channel that simulates a complete optical path. Depending on the direction of transmission, this channel passes the transmitted frames to the end units with a one-way delay d_{max} (attribute of the system; in simulation/s (ns)). Within the channel, it is assumed that the power of the lasers and the total route damping have values that ensure reliable transmission. The channel parameters that can be set are delay and throughput.
- ONU management and control interface (OMCI) – static definition of next-generation encapsulation method (XGEM) ports and transmission container (T-CONT) before running simulation via *XgponHelper* (it enables ASCII, pcap tracing, and XgponNetDevice on nodes and attaches them to XgponChannel) instead of dynamic allocation through OMCI.
- Forward error correction (FEC) – not performed by an algorithm, even though it is present.
- Scrambling – not performed.
- Frames creation – cyclic redundancy check (CRC) and hybrid error correction (HEC) fields are not used. The reason is to reduce the load of a processor during simulation/s.
- Physical layer operations, administration and maintenance (PLOAM) – the logic and interface for the transmission of messages are implemented; the activation procedure is not implemented; the addition of ONU is done only before the simulation is started. The project itself does not deal with the activation process, so its implementation is unnecessary. Moreover, the immediate state of the unit O5 during the activation process is considered to be sufficient [12].
- Descending planner and quality of services (QoS) – Round-robin algorithm is implemented in *XgponOltDbaEngineRoundRobin* class that serves each T-CONT with a fixed number of bytes. There is also *XgponOltDbaEngineGiant* class supporting different T-CONT variables with variable QoS parameters. DBA at OLT is responsible for allocation upstream bandwidth to T-CONT. In general, DBA algorithms may significantly improve or worsen throughput and delay in whole networks [13]–[15].
- Ascending planner and QoS – Round-robin algorithm is implemented in *XgponOnuUsSchedulerRoundRobin* class, which serves to operate the individual XGEM ports of a given T-CONT (a single ONU).
- XGEM frame creation – fragmentation and reassembly of SDU is implemented.
- Encryption/decryption – only logical implementation is present due to the reduction in computational requirements.
- Multiplexing – packet classification, data flow management, and mapping allocation identifier (Alloc-ID) and XGEM port to Internet protocol (IP) address are implemented.
- SDU – in the XG-PON standard, SDU IP packets or second layer-frames of different network technologies (Ethernet) can be found. The proposed module supposes the presence of IP packets whereby the IP address is used to map the XGEM port to T-CONT.
- XGEM ports – only one XGEM port can be assigned to an ONU (reason is 1:1 mapping, i. e., XGEM port: IP address); to assign multiple XGEM ports to a single ONU, multiple nodes need to be used.
- Queues – a first in first out (FIFO) queue is implemented, which sends the units in the order in which they were received.
- XgponXgtcBwmap – broadcasts BWmap (Bandwidth map) to all ONUs in the header of the XGTC downstream frame.

During simulations, it is not entirely clear that a module simulating the behavior of an optical network is present, since the most obvious observation that can be obtained from the results is the fact that some IP-related work is present. Due to the complexity, the model itself was not reworked completely. However, the IP addresses are used to map the communication to individual identifiers such as ONU identifier (ONU-ID) and Alloc-ID.

III. Demonstration of Memory and Time Consumption of Simulations

To demonstrate the complexity of the simulations, a topology that is shown in Fig. 1 was created. In this figure, it is possible to see that the topology consists of OLT and ONU units that form an optical network, and a router connected to OLT is connected to public stations (5, 6, 7). Likewise, client stations (8, 9, 10) are connected to the individual ONUs. In corresponding stations, there is a communication of 150 kB/s and 37.5 kB/s in the downstream and upstream direction, respectively.

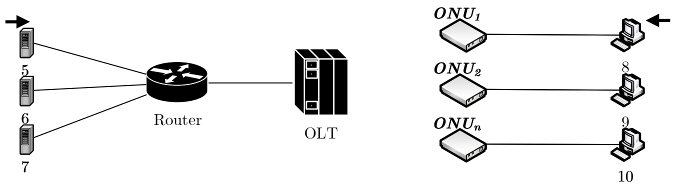

Fig. 1. Designed topology (three ONUs).

To obtain information about the complexity of the simulation, the time of the simulation was set to 10 s (we obtained the values from the NS-3 simulator console). Next, the number of ONUs and public/client stations was changed. The results of the simulations, i. e., the time and memory complexity, are summarized in Fig. 2. It can be seen that the time consumption is exponential and that the memory requirements also increase with an increasing number of ONUs. When performing simulation/s with more than a single ONU, no changes occur at the beginning of the simulation due to the generation of routing tables. This process lasted approximately 35 s (256 ONUs).

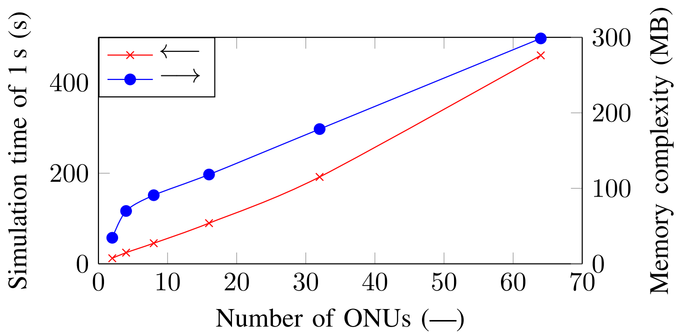

Fig. 2. Visualization of the complexity of the simulation 1 (notebook).

Consideration must also be given to the fact that the simulations were carried out on a PC and that the transmission rate within an optical network was negligible when compared to the maximum possible one. To demonstrate the difference in the simulation requirements, the simulation was then performed on a dedicated PC with the same parameters, which generated traffic to the extent that the queue was filled and the data were subsequently dropped. The results are summarized in Fig. 3. It can be seen that simulation requirements changed rapidly when the simulated network load increased. The main reason for the different times of simulations is more CPU cores for simulation (simulation 1 has 2 cores on Core2 Duo CPU, simulation 2 operates with 8 cores on Xeon CPU family). Note that more CPU cores do not mean an adequate time reduction of the simulation.

It can be seen that, to lower the time and memory requirements, the simulation does not have be performed on a large

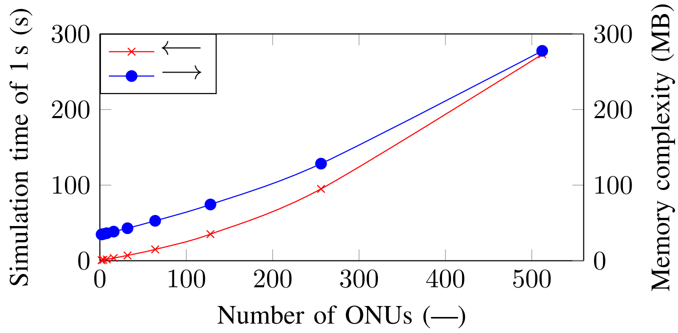

Fig. 3. Visualization of the complexity of the simulation 2 (server).

number of ONUs for a long time and at too high/maximum transmission rates. As the project addresses the issue of security, it is unnecessary to use a large number of end units for long simulation times.

IV. Conclusion

We briefly introduced the time and memory complexity for a fundamental simulation of XG-PON in NS-3 with the XG-PON package. Our simulation topology does not reflect the real topology, but it is not necessary, because the simulations are focused on the complexity of the services. Note that the encapsulation method is performed by a central processing unit (CPU), but not with dedicated hardware as is in a real ONU. The model contains two services, one with 150 kB/s for the downstream and 37.5 kB/s for the upstream directions. The transmission speeds are much lower in comparison with the real transmission speed, but a service represents the transmission container with a unique allocation ID.

Future work will implement the real triple play services in XG-PON and in the security issue simulations in the NS-3 tool.

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