Passive Optical Network Configurations - Performance Analysis

Half-Day Tutorial by John S. Vardakas and Michael D. Logothetis

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Synopsis

The Passive Optical Network (PON) is a fiber-based access network that provides huge bandwidth in a cost-effective manner. The basic building blocks of a PON are a centralized Optical Line Terminal (OLT), located in the central office, and a number of Optical Network Units (ONUs) located at the users' premises. A Passive Optical Splitter/Combiner (PO-SC) broadcasts traffic from the OLT to the ONUs (downstream direction) and transmits traffic from the ONUs to the OLT (upstream direction). PONs come in different flavors, depending on the multiple access scheme they deploy in both directions, such as Time Division Multiple Access (TDMA), Wavelength Division Multiplexing (WDM) and Optical Code Division Multiple Access (OCDMA).

PONs are now deployed as the primary solution for the provision of Fiber-To-The-Home (FTTH) services, by utilizing their ability to share the fiber bandwidth among customers in cost-gainful way. However, the ever-increasing bandwidth demands, driven by the emergence of bandwidth-hungry applications, enhance the need for PON configurations that will fully utilize the advantages of the optical fiber. Therefore, it is important for the service providers to discover the capabilities of the PON and predict its performance under different subscriber demands. The performance analysis of PONs through the development of efficient mathematical models can provide numerous advantages. Firstly, contrary to the method of simulation, the mathematical models provide a concrete way for the determination of crucial performance metrics, such as blocking probabilities, delay, jitter and utilization of the network's resources. The calculation of these metrics can be performed in relatively very short time, in comparison to the time-consuming simulations, which are typically performed by using troublesome and expensive simulation tools. Furthermore, mathematical models are a resourceful tool that could be used by service providers in order to answer questions involving trade-offs between the amount of resources allocated for a specific service-class and the QoS that will be experienced by the subscribers, and to predict network performance under extreme traffic conditions. In addition, the development of analytical models for the performance evaluation of networks is the first step for the derivation of network optimization models that aims at minimizing the network operational cost, while maintaining the QoS experienced by the subscribers above the Service Level Agreements (SLA) levels. As a result, the development of mathematical models for the performance analysis of PONs can provide the best possible network resources with the highest QoS to the network subscribers.

We aim at presenting the basic features of the following PON configurations:

- Time Division Multiple Access (TDMA) PONs:
  - (i) Asynchronous Transfer Mode (ATM) PON
  - (ii) Broadband PON (BPON)
  - (iii) Gigabit PON (GPON)
  - (iv) Ethernet PON (EPON)
- Wavelength Division Multiplexing (WDM) PONs
- Optical Code Division Multiple Access (OCDMA) PONs

The foremost part of the presentation refers at the introduction of analytical models for the calculation of crucial PON performance metrics, such as blocking probabilities and packet delay. Different cases are considered:

- EPONs
  - (i) Packet delay analysis for the limited service of the EPON, where a single service-class is considered.
  - (ii) Packet delay analysis for the fixed service of the EPON, where multiple service-classes are considered.
  - (iii) Packet delay analysis for the limited service of the EPON, where multiple service-classes are considered. Discussion on other EPON services (gated, constant credit, linear credit, elastic).
- Hybrid WDM-TDMA PONs
  - (i) Call-level analysis for the case of stream traffic from multiple service-classes of infinite traffic source population.

(ii) Call-level analysis for the case of stream traffic from multiple service-classes of finite traffic source population.

(iii) Call-level analysis for the case of stream and elastic traffic from multiple service-classes of infinite traffic source population.

(iv) Call-level analysis for the case of stream traffic from multiple service-classes of infinite traffic source population, where calls alternate between transmission periods (ON) and idle periods (OFF).

(v) Call-level analysis for the case of stream traffic from multiple service-classes of finite traffic source population, where calls alternate between transmission periods (ON) and idle periods (OFF).

- OCDMA PONs

(i) Call-level analysis for the case of multi-rate bursty traffic from infinite number of traffic sources.

(ii) Call-level analysis for the case of multi-rate bursty traffic from infinite number of traffic sources, under the code reservation policy.

(iii) Call-level analysis for the case of multi-rate bursty traffic from infinite number of traffic sources, where blocked calls are allowed to retry, requesting less resources (number of codewords).

(iv) Call-level analysis for the case of multi-rate bursty traffic from finite number of traffic sources.

Basic References

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Potential audience and prerequisite knowledge

This tutorial will enable engineers and telecom/computer network managers, to learn about the different PON configurations. Also, they will learn how analytical models are built and used for the determination of different performance metrics of PONs. No special prerequisite knowledge of audience is expected rather than basic teletraffic theory, (notion of traffic load and properties and elementary analysis of Markovian loss systems).

Why the proposed topic is interesting and timely

The PON is one of the most successful access architecture that can provide high capacity and long reach abilities with high split ratios, thereby can support more users in wider areas. The implementation of a completely new access network that requires enormous investment should be target on the satisfaction of the subscribers' needs along with minimizing building and operational costs. Mathematical models are resourceful tools that can be used for the provision of the optimal network resources allocation that result in the highest QoS to the network subscribers

Biographical sketch of the authors

John S.Vardakas was born in Alexandria, Greece, in 1979. He received his Dipl. - Eng. degree in Electrical and Computer Engineering from the Democritus University of Thrace, Greece, in 2004. Since 2006, he follows postgraduate studies in the Wire Communications Laboratory, Department of Electrical and Computer Engineering, University of Patras, Greece. Currently he is a PhD candidate. His research interests include teletraffic engineering in optical and wireless networks. He has already published **11 journal papers** and **over 23 papers** in conferences and book. He has **70 third-party citations.** He has reviewed many conference and journal papers. He is a member of the IEEE, the Optical Society of America (OSA) and the Technical Chamber of Greece (TEE).

Michael D. Logothetis was born in Stenies, Andros, Greece, in 1959. He received his Dipl.-Eng. degree and Doctorate in **Electrical Engineering**, both from the **University of Patras**, Patras, Greece, in 1981 and 1990, respectively. From 1982 to 1990, he was a Teaching and Research Assistant at the Laboratory of Wire Communications, University of Patras, and participated in many national and EU research programmes, dealing with telecommunication networks, as well as with office automation (including natural language processing). From 1991 to 1992 he was Research Associate in **NTT's Telecommunication Networks Laboratories,** Tokyo, Japan. Afterwards, he was a Lecturer in the **Department of Electrical & Computer Engineering of the University of Patras**, and since 2009 he has been elected (full) **Professor** in the same Department. He teaches the courses: **Broadband Telecom Networks; Telecom Systems I; Computer Networks, Teletraffic Theory, and Introduction to Communications**. His research interests include **teletraffic theory and engineering, traffic/network control, simulation and performance optimization of communications networks**. He has published **over 136 conference/journal papers and books** (more than 21 journals during the last seven years) and has **over 421 third-party citations (h=12)**. He has published a teletraffic book in Greek (2nd issue in 2011). He has organised the 5th IEEE International Conference on Communications Systems, Networks and Digital Signal Processing, **CSNDSP 2006**, sponsored mainly by IEEE and OTE (Greek PTT). Since 2010, he is a member of the **Steering Committee** of the **CSNDSP**. He has reviewed many conference and journal papers. He served/is serving on the Technical Program Committee of several international conferences. Also, he has organized and chaired several technical sessions and has offered two **tutorial lectures in two conferences**. He has become a **Guest Editor** in four journals: a) *Mediterranean Journal of Electronics and Communications, b) Mediterranean Journal of Computers and Networks, c) IET Circuits, Devices & Systems and d) Ubiquitous Computing and Communication Journal*. He participates in the **Editorial Board** of the following two international journals: *"IARIA International Journal On Advances in Telecommunications"* and "*Advances in Electronics and Telecommunications – Poznan University of Technology*". He is a member of the IARIA (**Fellow Member**), IEEE (**Senior Member**), IEICE, ETRI, FITCE and the Technical Chamber of Greece (TEE).