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Performance Evaluation of Gigabit Passive Optical Network (GPON) in Various Network Topologies: A Comparative Analysis

Adil[1], Atif Raza Zaidi[2], Rabia Javed[2], Muhammad Asif Raza[3], and Muhammad Imran[2,3*]

[1]Department of Computer Science, NUML, Multan, Pakistan.
[2]Department of Computer Science, Times Institute, Multan, Pakistan.
[3]Department of Computer Science, BZU, Multan, Pakistan.
*Corresponding Author: Muhammad Imran. Email: m.imran@bzu.edu.pk.

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Abstract: This study is about the assessment of Gigabit Passive Optical Network (GPON) in various organization topologies, including the ring, star, and tree geographies, which can be assessed by numerous elements like idleness, throughput, and versatility. This analysis intended to recognize the geography that gives the best execution to GPON arrangements. Giving the "triple play" administrations in which sound, video, and high-velocity information access incorporates is a significant method for satisfying clients' popularity. GPON is a "future-based" innovation, with for all intents and purposes limitless data transfer capacity accessibility for an exceptionally minimal cost. Most optical access networks comprise a passive optical network (PON) among various clients to get to an organization. This paper gives the advancement of the utilization of GPON and its execution with various geographies and gives an outline of GPON guidelines for better execution. To accomplish and satisfy the rising requests of clients the world's unquestionable necessity is to move over to optical organizations. GPON is an uninvolved optical organization innovation with practically limitless transmission capacity accessibility at the least expense. Optical access networks comprise both neighborhood and wide region organizations to give availability at short and significant distance correspondence. The uninvolved optical organization (PON) is normally divided between various supporters by utilizing different organization geographies. GPON advancements have developed over the long haul to fulfill the developing needs for rapid availability and the eventual fate of the world. In the ongoing execution, the upstream frequency of 1310 nm and downstream frequency of 1490 nm is ordinarily utilized. These frequencies consider the productive transmission of information in the two captions. In any case, from here on out, the utilization of WDM (wavelength division multiplexing) in PONs is expected. WDM empowers various frequencies to be utilized simultaneously, consequently expanding the limit of the organization. The presentation assessment uncovered that the ring geography of GPON displayed the most reduced dormancy among the tried designs and gave the greatest execution. The information parcels in the ring geography followed a more limited way, bringing about diminished transmission delays.

Keywords: GPON; Network Topologies; Comparative Analysis; Gigabit, Optical.

1. Introduction

The Gigabit Passive Optical Network (GPON) is a promising technology for delivering triple-play services to end users with unlimited bandwidth. It's a cost-effective and scalable solution by uses optical fiber cables to transmit data over long distances. The selection of network topology plays an important role in determining the performance and efficiency of GPON networks. Understanding the performance of GPON in different network topologies, such as ring, star, and tree, is essential for the optimization of a network design and fulfilling the increasing demands of end users. Passive Optical Network (PON) technology can be used as Local Area Network (LAN) to provide significant features to end users, its benefits include cost savings for large businesses and organizations [1]. The Gigabit PON (GPON) is standardized by the International Telecommunications Union (ITU). Moreover, it is used widely around the world for providing the fiber-to-the-home (FTTH) with triple-play service. Gigabit PON is a point-to-multipoint network architecture that is now being implemented for higher bandwidth. GPON has several advantages because of its higher bandwidth, including TV overlay [2].

End users require data connectivity, higher bandwidth availability, and advanced network access capable of emerging latest technologies. GPON has gained popularity and demand due to its ability to provide unlimited bandwidth with the best network topologies. GPON supports unlimited bandwidth capacity and a large number of end-users with multiple types of network topologies [3]. This study aims to evaluate and provide the performance parameters of the GPON network in different network topologies, which include ring, star, and tree topologies. The evaluation process of the GPON network over different topologies focuses on parameters such as latency, throughput, and scalability of the network [4].

Latency is the overall delay which represents the delay experienced by data packets as they pass through the network. Latency can affect real-time applications and end-user experience. The parameter throughput measures the amount of data over a network that can be transmitted in a unit of time, throughput also indicates the network's data capacity. The scalability parameter refers to expanding the ability of the network without compromising the performance of the network [5].

This research comprehensively analyzes the performance and basic parameters used by GPON when implemented with different network topologies. The results of this research will provide the problems and deficiencies of each topology implemented with the GPON network and can guide the selection of network topology as required best for servicers. The performance evaluation of GPON in different network topologies will enhance the better understanding of network designers for optimizing GPON deployments for efficient and reliable triple-play services. The GPON technology is widely deployed in different parts of the U.S. and Europe according to ITU-T G.984. According to the Ethernet-First-Mile standard, the EPON (for Ethernet PON) is broadly deployed in Korea and Japan [4-7].

2. An Overview of GPON

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should The Gigabit Passive Optical Network (GPON) is a promising technology for delivering triple-play services to end users with unlimited bandwidth. It's a cost-effective and scalable solution by uses optical fiber cables to transmit data over long distances [8].

The GPON technology consists of two primary components which include the Optical Line Terminal (OLT) and the Optical Network Unit (ONU) or Optical Network Terminal (ONT) [9]. The OLT is a central point to control and manage the communication and routing between the internet service provider and the end user. The ONU/ONT, located at the customer level receives and transmits data to the OLT via the optical fiber network as shown in Figure 1.

2.1 Optical Splitter

The key feature of GPON is the use of passive optical splitters to distribute signals from the OLT to multiple ONUs/ONTs.

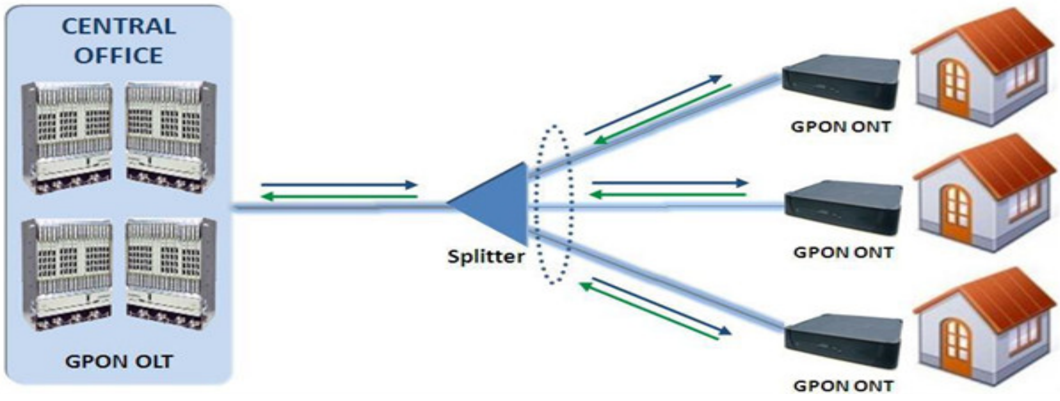

Figure 1. GPON networking with splitter

Optical splitters can be used for the sharing of a single fiber optical cable by splitting the signal into multiple paths. Optical splitters are passive devices that work without an external power to reduce the cost of the overall project [11]. The splitting ratio determines the number of end terminals that can be connected by an OLT. The typical PON connects a single fiber from an Optical Line Terminal (OLT) to multiple Optical Network Units (ONUs) [12-15].

2.2 Optical Network Terminal (ONT)

The ONTs connect end users with the GPON network and primarily provide the optical to electrical signal conversions moreover ONTs also provide Advanced Encryption Standard (AES) encryption via ONT key [16].

2.3 Optical Line Terminal (OLT)

The Optical Line Terminal (OLT) is a main component in GPON architecture it's like the heart of the network [17]. The OLT performs the main controlling and management of the optical network it also controls upstream and downstream data flow during transmission. The primary function of OLT is to perform routing of the traffic and connect the GPON network with internet service providers. OLT acts like a gateway and handles signaling and traffic management [18].

2.4 Optical distribution frames (ODF)

The optical distribution frame is an interface between active transmission equipment and outside optical cables, a single ODF cabinet can connect up to 1400 fiber channels.

2.5 Transmission containers

Transmission containers (T-CONT) are used for the management of upstream bandwidth allocation in the GPON. T-CONTs are secondly used to improve the upstream bandwidth use on the GPON. ONU sends n traffic using one or more T-CONTs; they enhance the quality of service (QoS) [18-21]. In the downstream direction, the OLT transmits data, including voice, video, and data services, downstream data transmission typically occurs on a wavelength of 1490 nm.

3. GPON Topologies

The GPON network topologies are Important for network deployment and achieving optimal performance by optical network.

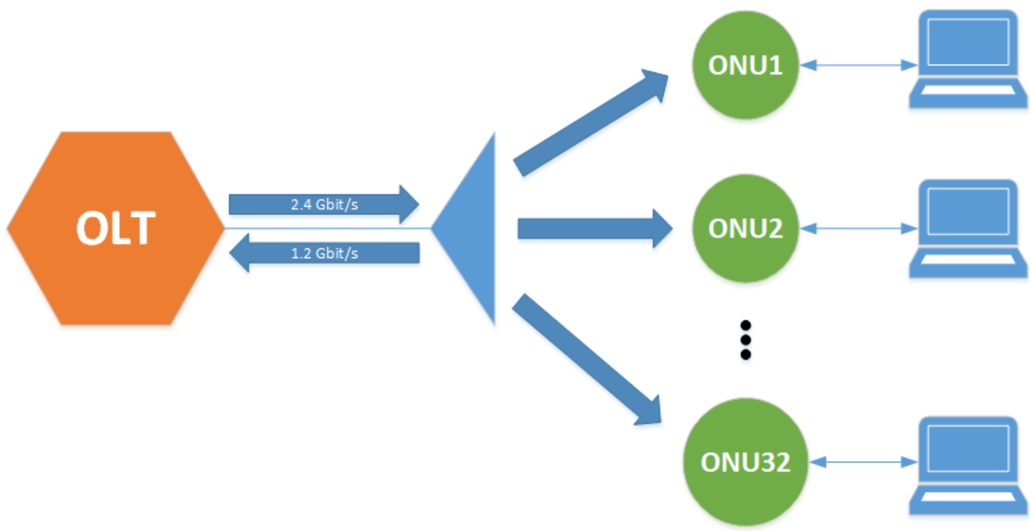

Figure 2. P2MP Topology configuration

3.1 Point-to-Multipoint (P2MP) Topology

The P2MP topology is widely used in GPON networks with efficient configurations. It consists of connections between the Optical Line Terminal (OLT) and multiple Optical Network Units (ONUs). Multiple optimal network units use optical splitters to get feed from the optical line terminal [22]. The optical splitter enables the main OLT to distribute downstream traffic towards multiple ONUs, where each ONU gets data. The P2MP topology provides an efficient and scalable solution for serving multiple users by using a single fiber infrastructure as shown in above Figure 2.

3.2 Ring Topology

The Ring topology consists of a closed loop of the GPON network where each unit will be connected with two other optical units like each ONU connected to its neighboring ONUs. The ring topology offers redundancy and a fault tolerance mechanism [23]. If a network failure occurs at any point of the network in the ring, the traffic can be rerouted in the opposite direction to keep alive the network, ensuring uninterrupted service. The ring topology provides robustness and high availability in optical networks.

3.3 Tree Topology:

The tree topology consists of both the P2MP and ring topologies. It represents a hierarchical structure in which the OLT is connected to a passive splitter; where the branches of secondary splitters serve individual ONUs. Tree topology configuration provides better scalability and flexibility in expanding the optical network to accommodate and facilitate additional ONUs [23]. The tree topology is best for deployments that require efficient resource allocation and the ability to serve a large number of end users.

3.4 Star Topology:

The star topology consists of connecting each ONU unit directly to the OLT through individual optical fiber links. In the star topology configuration, each ONU unit has a dedicated connection to the OLT, providing high security and control. The star topology provides efficient bandwidth allocation and ensures that each ONU operates independently and efficiently without being affected by other network devices. The star topology requires more optical fiber connections and resources. The star topology has limitations in aspects of scalability compared to other topology configurations.

3.5 Hybrid Topologies:

Hybrid topologies consist of multiple GPON topology configurations to provide services at a large scale. The combination of both ring and tree topologies can provide fault tolerance and scalability of optical networks. Hybrid topologies can provide efficient network designs to meet user requirements and optimize the performance of the overall network over multiple deployment scenarios. The selection of optical network topology depends on factors such as network size, network scalability needs, optical network fault tolerance, deployment, and implementation cost.

4. Materials and Methods

To evaluate the performance of Gigabit Passive Optical Network (GPON) in different network topologies, such as ring, star, and tree topologies, a comprehensive testing methodology was employed. This methodology focused on main performance factors, including latency, throughput, and scalability. There is A testing environment was created with GPON equipment for each topology. The latency is the overall delay of data packets on the optical network was measured by calculating the round-trip time (RTT) for data packets transmitted between the Optical Line Terminal (OLT) and Optical Network Units (ONUs) in each topology configuration. Another parameter throughput was measured by implementing data transfer tests using varying sizes of data packets and measuring the achieved data rates during the testing process. The parameter scalability was tested and evaluated by merging additional ONUs into the existing optical network and measuring any degradation in performance.

4.1 Latency Testing

Latency, which represents the overall delay experienced by data packets during their transmission, was measured using a series of the round-trip time (RTT) measurements. The testing environment consisted of an Optical Line Terminal (OLT) and multiple Optical Network Units (ONUs) or Optical Network Terminals (ONTs) deployed and implemented in each respective network topology configuration [16]. Data packets were sent from the main component OLT to the ONUs and sent back, with the elapsed time recorded for each round-trip. There was Average RTT was calculated to determine the latency for each topology configuration.

4.2 Throughput Testing

The parameter throughput indicating the data-carrying capacity of the optical network was evaluated through data transfer tests. There were varying packet sizes were used to assess the network's ability to handle different data loads during the transmission [15]. The testing process involved transferring data packets from the OLT to the ONUs and measuring the tested data rates. The throughput was measured as the amount of data transferred per unit of time, considering different packet sizes and network topology configurations.

4.3 Scalability Testing

The performance parameter scalability refers to the network's ability to accommodate additional users and traffic and expanding the existing infrastructure was assessed by expanding the network with additional ONUs. The performance of each topology was evaluated by increasing the number of ONUs and measuring any degradation in performance during the testing process. Latency and throughput were monitored to determine the network's scalability and its ability to handle increasing user demands using the GPON over various topology configurations [22].

4.4 Performance Metrics

After the successful measurements for latency, throughput, and scalability, during testing other relevant performance metrics were also considered which included jitter, loss of data packets during transmission, and Quality of Service (QoS) parameters, these parameters provided insights into the overall performance and reliability of the GPON network as reflected in Figure 3.

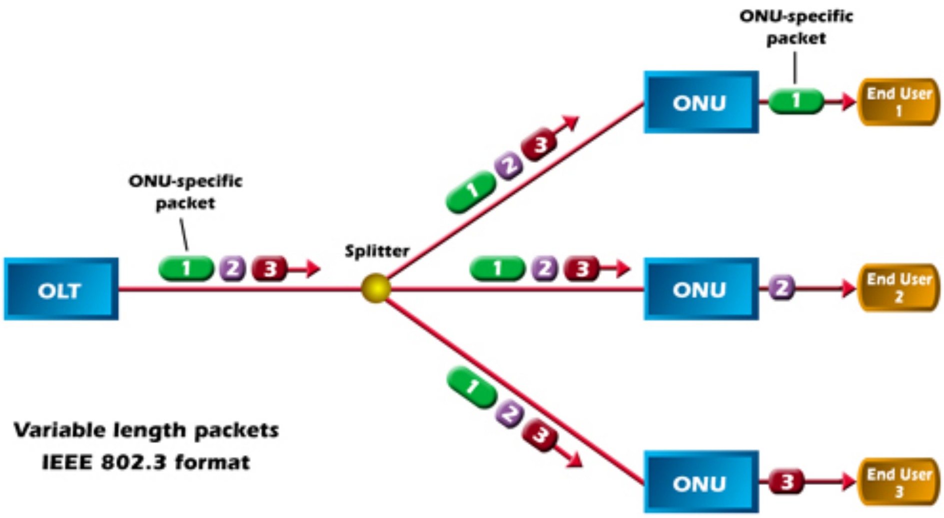

Figure 3. Performance evaluation of GPON

4.5 Reliability and Statistical Analysis

To confirm the reliability and stability of the results, multiple iterations of the testing process were conducted for each network topology configuration. The measurements were averaged for all these iterations of the testing process to obtain more exact and accurate performance metrics. There were Statistical analysis techniques were tested to validate the results and the significance of any differences between the network topologies.

By implementation of this methodology, a comprehensive evaluation and analysis of the latency, scalability, and throughput parameters of GPON on different network topologies were tested. The results obtained from this testing environment provide insights into the performance and advantages of each optical network topology [16]. This information is valuable for network designers and researchers to make decisions about the selection and optimization of GPON network topologies based on specific requirements and performance-based objectives.

5. Results

The results of the successful testing process revealed performance evaluation that the ring topology configuration has exhibited the lowest latency among the tested topology configurations. The data packets behave in the ring topology of those that follow a shorter path, resulting in reduced transmission delays. However, the star topology represents the highest throughput for larger packet sizes. The star topology eliminated the need for signal splitting due to dedicated fiber connections, enabling higher data rates. In consideration of scalability, the tree topology represents superior performance during comparison with other topologies. The hierarchical structure revealed the best results with an expansion of the network by adding more ONUs without significant degradation in performance. The ring topology represents moderate scalability, while the star topology has limitations and restrictions due to the need for dedicated optical fiber connections for each ONU [17]. The GPON technology technical specifications are developed by the FSAN (full-service access network) group.

The single-mode optical fiber can support a 20 to 30 km distance range and throughput of 69 Tb/s and single optical fiber carries multiple wavelengths to transport signals. The GPON technology uses TDMA (time division multiple access) protocols for upstream transmission and for downstream it broadcasts to all ONTs. There will be all traffic multiplexed to OLT. The main component of optical network OLT can process approximately 200 Gb/s switching capacity [22]. The GPON technology supports several line rates for the upstream and downstream directions during the transmission. This feature is enabled by the GEM (GPON Encapsulation Method) encapsulation method. The GEM can be enhanced to support future technologies of optical networks.

6. Conclusions

Conclusions are based on the performance evaluation of the optical network topologies. The ideal PON topology depends on the specific requirements of the deployment that should be gained. For low-latency applications or cases where minimizing delay is critical, the ring topology configuration may be the correct choice. On the other hand, the star topology offers higher throughput, it should be suitable for applications demanding higher data transfer rates. For the scalability priority and user requirements for the expansion of the optical network, the tree topology provides the best performance without compromising latency or throughput significantly in optical networks. The findings of this research can guide network designers to select the appropriate GPON topology configuration which should be based on their specific performance requirements and deployment constraints. Further research on GPON technology can explore the performance of hybrid topologies that combine the advantages of multiple topology configurations to optimize performance and fulfill user demands. The GPON technology implementations, while utilizing a common optical infrastructure, are very difficult to execute. The GPON technology looked similar to SONET/SDH technologies to create an efficient Ethernet transport mechanism.

7. Future Work and Discussion

Future work in the area of performance evaluation of GPON technology in different network topology configurations can explore the following aspects:

Performance Metrics; This research focused on throughput, latency, and scalability, parameters future work can analyze and interpret deeper into the other performance metrics such as packet loss, jitter, and Quality of Service (QoS). That will be the understanding of how these parameter metrics vary across different network topologies and will provide a more accurate and comprehensive evaluation of GPON performance.

Dynamic Topology Configuration Adaptation; analyzing the dynamic topology adaptation mechanisms that can facilitate the optical network topology based on varying traffic conditions and user requirements. This topology could dynamically reconfigure the optical network topology to achieve optimal performance which is based on real-time traffic demands.

Optical Network Traffic Analysis; Analyze different types of optical network traffic, such as voice, video, and data, to process how different topologies handle and perform during specific traffic patterns. This analysis can help determine the most efficient and suitable topology configuration for different application scenarios and traffic behaviors.

Resource Allocation; The optimization techniques for resource allocation in GPON networks should be searched for various topologies. This search should include developing algorithms and strategies to allocate bandwidth and manage the queueing mechanisms, and there should be prioritized traffic on the application as required.

Energy Efficiency; There should be a search for the energy-efficient techniques of GPON networks across different topology configurations. The development of energy-efficient mechanisms and algorithms to optimize power consumption in various network topologies should consider both the active and passive components of the optical network.

Emerging Technologies; There should be an integration of GPON with the latest emerging technologies such as Network Function Virtualization (NFV) and Software-Defined Networking (SDN). Analyze how these technologies can increase the performance, manageability, and flexibility in different GPON network topologies.

Security Enhancements; There should be keenly proposed robust security and privacy processes present in each GPON topology configuration. This mechanism includes searching encryption protocols, authentication mechanisms, and unauthorized access detection systems to ensure the confidentiality and integrity of data transmitted over optical networks.

Real-World Implementation; There should be field trials and deployment studies of GPON networks with different network topologies. Assess the performance in practical scenarios, considering performance factors such as network congestion, weather conditions, and environmental noise.

Cost Analysis; Perform cost analyses to decrease all over-project costs. The comparison of different GPON topologies configurations, considering factors such as initial deployment costs, maintenance expenses, scalability, and the potential for future upgrades.

Hybrid Topologies; analyzing the performance of hybrid optical network topologies that combine elements of different GPON configurations. Explore the benefits and challenges of such topologies, and evaluate their performance in terms of latency, throughput, scalability, and other relevant metrics.

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