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Passive Optical Network (PON) Technologies in FTTH Implementation

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ABSTRACT

The development of high-speed internet service needs to encourage the implementation of fiber optic-based network technology, especially Fiber To The Home (FTTH). Passive Optical Network (PON) technology is the main foundation in providing this service, with various variants such as EPON, GPON, XG-PON, and NG-PON2. This study comprehensively discusses the technical characteristics, performance, and implementation challenges of each of these technologies. The results of the analysis show that GPON is still the main choice because of its efficiency and support for existing infrastructure, while XG-PON and NG-PON2 offer higher capacity but face challenges in terms of cost and technical complexity. Performance evaluation based on parameters such as Power Link Budget, Signal-to-Noise Ratio (SNR), and Bit Error Rate (BER) shows that XG-PON has better network performance than GPON, while NG-PON2 excels in capacity and service flexibility with TWDM technology. This study provides insight into selecting the right PON technology based on capacity needs, geographic conditions, and resource constraints, and encourages the development of sustainable FTTH infrastructure in the digital era.

Keywords: FTTH, GPON, XG-PON, NG-PON2, TWDM, PON, Power Link Budget

1. INTRODUCTION

The development of current communication technology demands innovation in the provision of internet and multimedia services that are able to meet the needs of the community for high speed, capacity, and quality of service. One of the main solutions adopted is a fiber optic network, especially Fiber To The Home (FTTH), which can provide large bandwidth and optimal connection stability. FTTH technology is the main choice because of its ability to support various services such as broadband internet, subscription television, and other data communication services simultaneously in one efficient and reliable network. According to an article written by A. G. Utama, I. A. Hambali, and D. M. Saputri, the development of this technology includes a Triple Play Service, namely a fast internet access service (data), voice (telephone network, PSTN), and video (Cable TV) in one network infrastructure at the customer's home (Utama, Hambali, & Saputri, 2018).

In its implementation, optical fiber is pulled into the user's home, replacing copper cables that are usually used in conventional networks. Optical fiber has the ability to transfer data at high speeds and overcome the problem of electromagnetic interference that often occurs in copper cables. With FTTH, users can enjoy the same symmetrical internet speed, both for downloading and uploading data, which can reach hundreds of Mbps to several Gbps (Syahrin, 2023).

In the development of FTTH networks, international standards such as ITU-T G.984.2 are the main reference to ensure that the technical parameters used meet the required quality and performance standards. The two main technologies used in FTTH networks today are Gigabit Passive Optical Network (GPON) and Xtreme GPON (XGPON). GPON, which is developed based on the ITU-T G.984 series standard, offers transmission speeds of up to 2.5 Gbps and has been widely implemented in various regions as an efficient broadband solution. Meanwhile,XGPON, which is a development of GPON based on the ITU-T G.987 series standard, can provide a much larger bandwidth capacity, reaching 10 Gbps, so that it can accommodate increasing service needs in the future.

The transition from GPON to XGPON not only involves increasing capacity, but also requires redesigning network components and configurations to support this more advanced technology. Key components such as Optical Line Terminal (OLT) and Optical Network Terminal (ONT) are modified to be compatible with the standard.XGPON, although the basic function remains the same. In addition, in a study conducted by Mohammad Hamdani & Hamdani . M GPON technology uses several passive components, namely connectors, splitters, and optical cables. The use of splitters with certain configurations is an important factor in determining network performance, especially in terms of transmission distance and power required to maintain signal quality.

The performance evaluation of both technologies is done through the analysis of critical parameters such as Power Link Budget, Rise Time, Signal-to-Noise Ratio (SNR), and Bit Error Rate (BER). These parameters are very important to ensure that the network can operate optimally in real conditions in the field. Research shows thatXGPONcapable of delivering better performance in terms of capacity and transmission distance, especially when supported by the right splitter configuration and optimal power settings.

In addition to the technical aspects, the migration process from GPON to XGPON also involves careful planning stages, starting from site selection, field data collection, to the analysis of the technical parameters mentioned. This process is carried out in stages so as not to disrupt ongoing services and to ensure the successful implementation of the new technology. Thus, the development and comparison of performance between GPON and XGPON are very important to determine the strategy for increasing network capacity in the future, as well as ensuring that the FTTH network built can meet the needs of the community and industry in a sustainable manner.

In general, this study aims to provide a comprehensive overview of the advantages and disadvantages of each technology, as well as support decision-making in the development of more efficient fiber optic networks that are able to compete in the increasingly advanced digital era. With this innovation and capacity increase, it is hoped that broadband services in Indonesia can increase significantly, support the development of the digital economy, and expand access to information to all levels of society.

2. METHOD

The research method used in this study is the qualitative descriptive with a literature study approach. This method was chosen because it can describe in depth various technical and implementation phenomena related to Passive Optical Network (PON) technology in Fiber To The Home (FTTH) networks. This study aims to collect and analyze technical information and performance comparisons of EPON, GPON, XG-PON, and NG-PON2 technologies based on previous studies (Sukmadinata, 2011).

Research data were obtained through literature reviews from various credible sources, such as scientific journals, reference books, and international standard documents such as ITU-T G.984 for GPON and ITU-T G.987 for XG-PON. The articles reviewed included network performance studies, evaluation of technical parameters such as Power Link Budget, Signal-to-Noise Ratio (SNR), and Bit Error Rate (BER), as well as studies of technology implementation in various regions. The selection of literature was based on the relevance of the theme, the currency of the information, and the validity of the sources used (Yustini et al., 2021; Salami & Adewole, 2022).

The analysis in this study was conducted with a comparative approach to PON technology. Each technology was analyzed based on its upstream and downstream capacity, bandwidth efficiency, architectural flexibility, and its ability to coexist with previous generation technologies. This comparison aims to provide an objective picture of the advantages and disadvantages of each technology in the context of optical network development in Indonesia (Soelkifly et al., 2018).

In addition to technical aspects, this study also examines implementation challenges in the field, such as the readiness of Optical Distribution Network (ODN) infrastructure, the availability of Optical Line Terminal (OLT) and Optical Network Terminal (ONT) devices, as well as cost and human resource factors. Case studies of implementation in Indonesia are used as a reference to examine the extent to which technologies such as NG-PON2 can be realistically adopted, given the high investment requirements and system complexity (Hamdani & Hamdani, 2018; DJPPI, 2023).

Through this method approach, the research results are expected to provide a comprehensive understanding for policy makers and service providers in choosing PON technology that suits local needs, both in terms of technical, geographical, and economic aspects. With careful planning and selection of the right technology, it is hoped that the implementation of FTTH in Indonesia can run optimally and sustainably in supporting the national digital transformation (Yustini et al., 2021; Soelkifly et al., 2018).

3. RESULTS AND DISCUSSION

Passive Optical Network (PON) technology has become the main foundation in the development of Fiber to the Home (FTTH) infrastructure worldwide. This technology enables the distribution of high-speed internet services efficiently and energy-efficiently. Based on the results of the literature review, there are four commonly used PON technologies, namely EPON, GPON, XG-PON, and NG-PON2. Each technology has different technical and architectural characteristics, which can be adjusted to the needs and infrastructure conditions in a region.

EPON (Ethernet Passive Optical Network)

It is an early generation of PON based on the Ethernet protocol and provides symmetrical bandwidth of 1 Gbps for upstream and downstream. The main advantages of EPON lie in the simplicity of the protocol and high compatibility with existing Ethernet-based network infrastructure. According to an article written by Salami and Adewole in 2022, Internet traffic patterns and applications caused congestion in the local loop between a customer and the local exchange. To overcome this problem, Ethernet passive optical network (EPON) is seen as one of the most suitable technologies at the moment as the devices are ubiquitous from the home network all the way through to regional, national and worldwide backbone networks. Implementation of EPONs can be highly cost-effective (Salami & Adewole, 2022). However, capacity limitations make this technology less than optimal for today's increasingly high internet needs. In an article written by Horvath, Munster, Oujezsky, & Vojtech in 2018, At present, EPON technology is not very popular around the world due to the decreasing price and better efficiency of GPON technology (Horvath, Munster, Oujezsky, & Vojtech, 2018).

GPON (Gigabit-capable PON)

GPON mbecome the most widely implemented PON technology globally, including in Indonesia. GPON offers a downstream capacity of 2.5 Gbps and an upstream of 1.25 Gbps. The ITU-T G-984 is a standard issued by the ITU-T for GPON technology. This technology supports high speed, increased security, and a choice of 2-layer protocols (ATM, GEM, Ethernet) (Yustini, Asril, Nawi, Hafizt, & Warman, 2021). With better bandwidth efficiency and QoS (Quality of Service) management than EPON, GPON can serve more users in one distribution network. In addition, GPON also supports point-to-multipoint topology which can reduce implementation costs.

XG-PON

Present as a development of GPON to meet the need for higher speed internet access. XG-PON offers downstream capacity of up to 10 Gbps and upstream of 2.5 Gbps. One of the advantages of XG-PON is its ability to coexist with GPON in the same Optical Distribution Network (ODN) infrastructure, so that the technology migration process can be carried out gradually and cost-effectively. However, in terms of implementation, XG-PON still faces challenges with the relatively high price of the device, as well as the need for more complex bandwidth management. In a study conducted by Al Fathi, Setiawan, & Hafiza, measurements on the XG-PON network using OptiSystem were -12.503 and mathematically -11.596. XG-PON has a better Power Link Budget compared to GPON. This means that XG-PON has greater performance in its network compared to GPON, the test results show a figure of -15.563 when measured with OptiSystem and if calculated systematically, it is -14.596.

OF-PON2

It is the latest PON technology that integrates Time and Wavelength Division Multiplexing (TWDM). In NG-PON2, the multiplexing technique used is TWDM with a Wavelength Division Multiplexing (WDM) scheme for the downstream link direction and a Time Division Multiplexing (TDM) scheme for the upstream link direction (Soelkifly, Kurnia, Hidayat, Kuen, & Sugesti, 2018). NG-PON2 offers a very large capacity, up to 40 Gbps in total with the use of four wavelengths of 10 Gbps each. This technology enables more flexible service capacity and is very suitable for metropolitan areas with high user density and industrial applications such as cloud services, 8K video, and large-scale IoT. However, NG-PON2 has obstacles in terms of very high costs, technical complexity, and limitations of commercially available ONT and OLT devices, especially in developing countries.

Based on the reviewed literature, the implementation of XG-PON and NG-PON2 still faces major obstacles, especially in terms of cost and readiness of infrastructure devices. Optical Line Terminal (OLT) and Optical Network Terminal (ONT) devices used in NG-PON2 have higher prices than the previous generation. In developing countries like Indonesia, this challenge is exacerbated by the uneven distribution of optical network infrastructure and the lack of human resources with technical competence in the FTTH field.

In terms of network architecture, all PON technologies generally use point-to-multipoint topology with signal separation using optical splitters. The maximum service range is usually in the range of 10–20 km, depending on the optical loss and the number of splitters used. However, NG-PON2 has the ability to support more users per port with better distribution efficiency. Based on PMT data on the DJPPI website, the length of SKKL Fiber Optic has stretched 118,257.54 KM and land Fiber Optic has stretched 716,935.55 KM, passing through 34 Provinces, 503 Cities/Regencies, 5,564 Sub-districts, and 47,483 Villages/Sub-districts. The length of land fiber optic has increased by more than 269% since December 2019.

To maintain compatibility, GPON and XG-PON have been designed to coexist in the same ODN (Optical Distribution Network) infrastructure. This is important in the technology migration process so as not to incur additional costs for replacing previously installed optical cables and splitters.

From the analysis results, it can be concluded that the choice of PON technology in FTTH implementation is highly dependent on capacity requirements, geographical conditions, investment costs, and target users. In rural or suburban areas, GPON is still the most logical and economical choice. On the other hand, in city centers with high user density and large data demand, investment in XG-PON or NG-PON2 begins to be a worthy consideration for the long term.

4. CONCLUSIONS

Along with the development of communication technology, the internet is required to provide faster, more stable, and high-quality services, which can be effectively met through the implementation of FTTH (Fiber to the Home) based fiber optic networks. In this context, Passive Optical Network (PON) technologies such as EPON, GPON, XG-PON, and NG-PON2 are the main choices in building optical network infrastructure.

GPON has been widely implemented globally, including in Indonesia, which offers bandwidth efficiency and adequate QoS management, making GPON an economical solution for areas with medium user density. However, to meet the increasing data needs, especially in metropolitan areas, more advanced technologies such as XG-PON and NG-PON2 are starting to become strategic alternatives. XG-PON provides significant improvements in capacity and infrastructure compatibility, while NG-PON2 offers service flexibility and much higher capacity through TWDM technology, although it still faces cost and complexity constraints.

Overall, the selection of PON technology must consider data capacity requirements, geographic conditions, and the sustainability of operational and investment costs. With careful planning, XG-PON and NG-PON2 technologies can be future solutions to improve the quality of FTTH services in Indonesia, accelerate digital transformation, and expand access to information evenly to all levels of society.

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