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(Research Article)

DWDM 100G ring for backbone Network using dark Fiber

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Abstract

This paper focuses on designing and analyzing a 100G DWDM backbone communication network under dark fiber for the ring topology. It aims to explore how organizations can leverage available dark fiber assets to deliver a multiprotocol label-switching-enabled optical transport network as bandwidth requirements for data transmission increase. The performance evaluation approach demonstrated is based on network design, simulation, and case study analysis. Measures like the ones discussed earlier, including throughput, latency, and fault tolerance, are discussed. The outcomes yield that a 100G DWDM ring greatly upgrades the bandwidth capability with low latency and network dependability. Dark fiber is economical, flexible, and can be added to future system requirements. It is also compared with other network architectures and designs to illustrate the benefits of the proposed system in terms of its performance and costs. The paper makes recommendations on the application of DWDM 100G networks in metros and regional backhaul, and directions for future studies are provided in the conclusion.

Keywords: DWDM Technology; Dark Fiber; 100G Networks; Ring Topology; Optical Networks

1. Introduction

Transport OFDM-PONs are critical to today's telecommunication, particularly due to the emerging need for high-capacity optical networks to support high-speed internet, cloud services, and data transmission. It is important, therefore, that high bandwidth, high volume bandwidth networks become more scalable as more data traffic is generated around the globe. These needs are addressed by the Dense Wavelength Division Multiplexing (DWDM) technology, which allows the transmission of several signals in parallel over a single infrastructural cable manufactured out of optical fibers. This multiplexing method optimizes fiber bandwidth and helps to expand fiber bandwidth to avoid congestion and the costs of physically increasing fiber networks.

Unused optical fibers are known as dark fibers and are important for large NIR networks. New markets can avoid the sometimes prohibitive costs and time constraints of building an all-new fiber-optic network through dark fiber. However, they also need to be used to provide high-capacity networks such as DWDM and are cost-effective and scalable. The line is optimally upgraded and integrated with innovative fiber technologies and multifaceted DWDM systems. It plays a role in the effective management of optical networks to meet an ever rising demand for bandwidth.

1.1. Overview

Proposed 100G DWDM ring network is gradually being established to transport a large amount of data over long distance, especially for backbone networks. A 100G DWDM system can operation many more data channels at 100 gigabits per second, each on separate wavelengths on optical fibers, increasing the overall throughput of the network and its efficiency. Ring topology never allows any two nodes to be disconnected, which offers the concept of fault tolerance, which is essential for backbone networks.

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Deploying the DWDM 100G systems over the dark fiber emanates several advantages in the metropolitan and regional backbone networks. It ensures the timely utilization of current physical structures in civil and commercial constructions without necessarily having to lay new fiber links while, at the same time, cutting overall expenditure. Further, dark fiber is easily scalable since it does not limit the need to purchase additional leased commercial circuits to meet increased capacity. This interconnection of DWDM 100G technology coupled with the dark fiber infrastructure increases bandwidth capability, minimizes latency, and increases network stability, making it a resourceful and cost-efficient solution to the new communication networks

1.2. Problem Statement

The major problems associated with using existing fibre are: •Scalability: By its nature, fibre is a scalable technology •Bandwidth: One of the most significant problems when using fibre is the problem of bandwidth. •High operational cost: Another problem associated with using fibre is the high cost of operation. This situation implies that many traditional fiber systems cannot accommodate the increasing need for high-speed and high-capacity data transmission, hence congestion. Moreover, optimizing these networks for the 100G throughputs may pose technical challenges and enormous costs. Though DWDM appears to have potential solutions for enhancing the bandwidth, the proper network design for achieving 100G throughputs has not been well studied in the current literature. The lack of knowledge determines how DWDM can be incorporated into an operational infrastructure to overcome these scalability and cost issues and build future versatile super high-capacity networks.

1.3. Objectives

- Research the possibility of using dark fiber for a 100G DWDM ring network in backbone communication.
- Identify the crucial measures of system performance, including latency and throughput, and focus on fault tolerance in DWDM 100G situations.
- Examine the overhead cost requirement of deploying 100G DWDM using dark fiber infrastructure.
- Assess the expandability of 100G DWDM networks towards future upgrading and additional data traffic requirements.
- By following the previous best practices for DWDM network design and highlighting the following recommendations, it is feasible to integrate DWDM technology into existing infrastructures efficiently.

1.4. Scope and Significance

This paper will concentrate on high bandwidth metropolitan and regional backbones with special reference to using available dark fibre infrastructure for DWDM 100G Systems. The subject area concerns the large cities with higher traffic data rates for their networks or those cities experiencing network congestion and needing to upgrade or opt for broader network facilities. Specifically at the technology level, this study aims to utilize DWDM technology to increase network utilization, capacity, and economy. Therefore, this research's relevance is immense to network service providers, especially in the developing world or the growing infrastructure demand. Thus, this paper seeks to present dark fiber as a solution to meet the future demand for DWDM systems in the growth regions with improved cost-effectiveness.

2. Literature review

2.1. DWDM Technology

Dense Wavelength Division Multiplexing (DWDM) is one of the most important technologies in present-day optical communications, and it is through which several signals can be transmitted optically in parallel over a single fiber. DWDM functions so that each signal falls at different wavelengths to utilize fiber bandwidth efficiently. There has been a revolutionary development in DWDM technology, including wavelength spacing, signal modulation, and amplification technologies. Originally intended to increase the capability of fiber optic communication systems, DWDM is now the core of long-distance high bandwidth networks, including those used in telecom backbones (Zhang & Zhu, 2017). Modern DWDM technology has incorporated the problem of fiber attenuation and non-linear effects, resulting in passing through a larger amount of data over longer distances without severe distortion of signal quality. Similarly, DWDM has helped relieve congestion in the network, improve the utilization of existing fiber resources, and provide solutions that meet increasing data needs based on the scaling factor (Zhang & Zhu, 2017). New enhancement techniques, including coherent detection and different modulation formats, will likely help DWDM find the increasing service requirements of high data rates per channel and longer transmission distances, making it an indispensable technology for future-generation optical networks.

2.2. Dark Fiber Utilization

Dark fiber represents unused fibers that have not entered service but present a very effective approach to extending broadband networks. Most unlit fibers are installed and present a free resource to service providers requiring high-capacity networks to build or upgrade. This way, network operators can greatly reduce the costs and time needed to realize new fiber-optic cables by activating the so-called dark fiber. This opens the way to accelerated and inexpensive network development (Chochliouros et al., 2005). It has numerous implications make it beneficial in the operational context, such as being scalable and easier to manage and tailor according to needs. This flexibility allows the operators to provide higher bandwidths as there are no constraints fueled by the leased circuits, thus providing an added-up shot in the arm in terms of efficiency and cost. Also, it opens up network expansion possibilities, coupled with such high-capacity systems as DWDM without additional investments in fibers. This is especially important today, given the continuously increasing number of data messages and the desire to create new, faster networks. The application of dark fiber provides advantages of flexibility in traffic distribution to avoid over-subscription, better latency characteristics, and dependable, high-quality DWDM systems that are critical for today's advanced applications like cloud computing, streaming, and giant data transmission (Chochliouros et al., 2005).

2.3. 100G Networks

The standards concerning 100G optical networking have shifted entirely the backbone frameworks, thus offering a cure for the relentless demand for bandwidth. These advanced networks incorporate technology such as DWDM to improve the data transfer rate over long distances and simultaneously obtain reduced latency. Therefore, new 100G networks provide higher data rates with better capacity and lower cost per bit compared to previous solutions. Nevertheless, applying 100G systems has several difficulties, such as extremely high modulation, signal amplification, and the problem of power consumption. Such networks are seen to have evolved due to ever-increasing bandwidth demands, especially in metropolitan and long-haul areas (Glingener, 2011). Nevertheless, 100G optical networks are crucial to transport large bandwidth applications such as cloud computing, Video on Demand (VoD including 4K), and the Internet of Things (IoT). They are important for planning and executing further development of communication networks to deliver steadily growing data loads of new services (Glingener, 2011).

2.4. Ring Topology for Backbone Networks

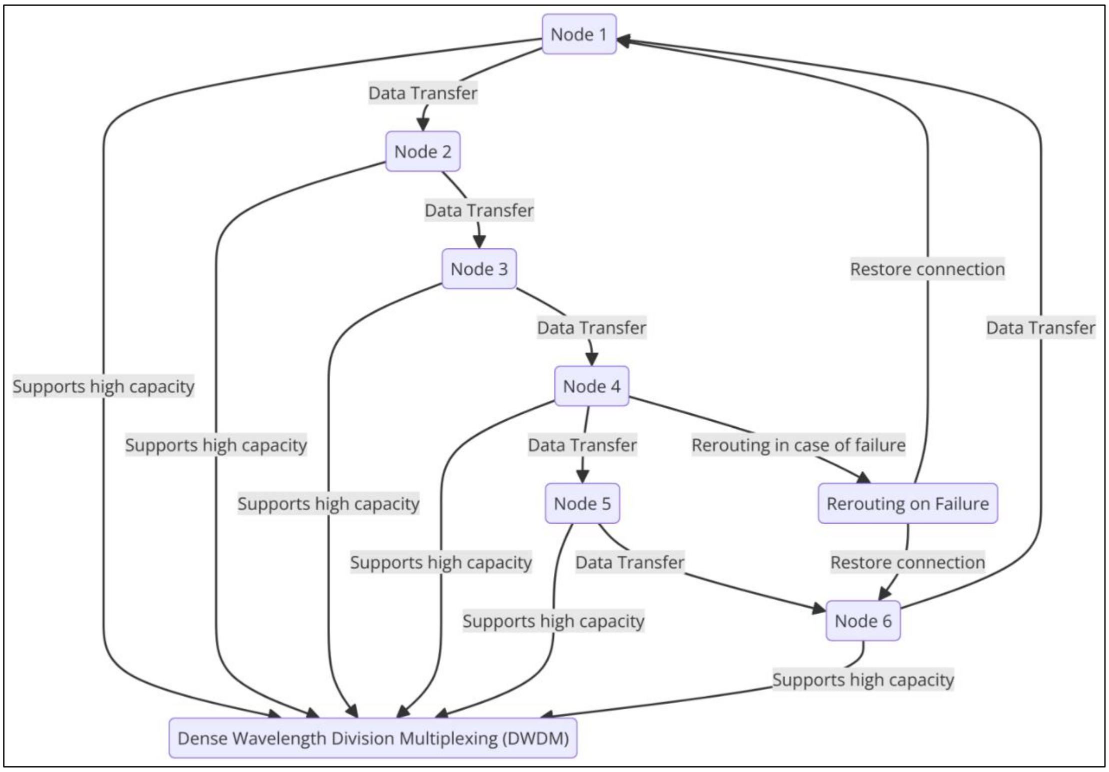

Figure 1 Diagram illustrating Ring Topology for Backbone Network

The backbone systems' major benefits associated with the ring topology are scalability, fault tolerance, and high reliability. In a ring topological configuration, each node was connected to the other two nodes to form a circuit throughout the network. This structure enables data routing in cases of a failure to be handled clearly so that the network services do not experience any stoppage. Such reliability is important for backbone networks, where availability is paramount. Furthermore, combining the ring topology with DWDM increases the reliability and capabilities for using large data throughput over long distances. This constant loop reduces the risk of total network downtime, which is apt for mission-critical applications. Also, ring networks consume resources effectively and are easily scalable since introducing new nodes affects others significantly. For these reasons, and because of the reliability of its ability to scale to a great number of users, ring topologies are a popular choice for today's optical communications systems (Wosinska et al., 2008).

2.5. Wavelength Division Multiplexing 100 Giga-bit per second Cost and Scalability

Optic DWDM 100G over dark fiber is an efficient solution in strategy for increasing a network infrastructure. Through Davi's dark fiber, which consists of unused optical fibers, significant costs can be cut because using existing infrastructure instead of rewiring is cheaper. This will allow service providers to offer consumers' 100G speeds' and, simultaneously, will not lead to high costs for the establishment. Another benefit of dark fiber is that it can be easily expanded for better physical design and add diverse services, new wavelengths, and improved devices without incorporating new fiber. This makes dark fiber a perfect solution for expanding networks in metropolitan and regional connectivity because it can grow with demand without spiking infrastructure costs. Moreover, low operation costs and the ability to pass the costs through large-scale broadband services, such as cloud computing and other buzz 4K video streaming services, would enable the providers to remain competitive in operational expenses (Johansson et al., 1998).

2.6. Recent Advances and Innovations

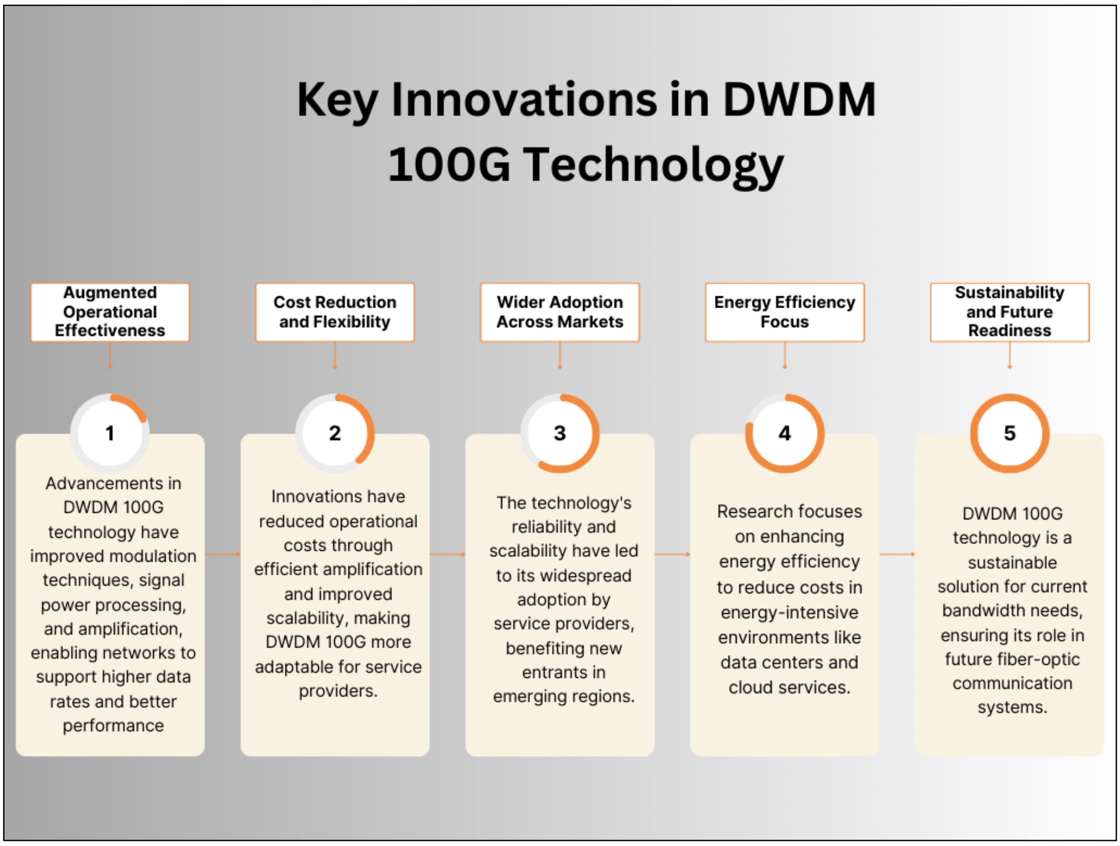

Figure 2 Key Innovations in DWDM 100G Technology

New advancements in DWDM 100G tech are regarding the augmentations of operational effectiveness, cost reduction, and flexibility that have spurred a generation of optical networks. Advancements have occurred regarding modulation techniques, signal and signal power processing, and amplification to enable networks to support higher data rates and possibly greater throughput. Such progress has led to the increased use of 100G DWDM systems across service providers and is especially favorable for new market entrants in new regions. Besides enhancing the fundamental network operations, research has also focused on the network's energy efficiency to serve many users while minimizing operating expenses. Extensive power or electrical energy use is inevitable in today's technically enhancing applications like data centers and cloud services, where efficiency factors play a critical role. These developments prove DWDM 100G as a viable and sustainable technology for meeting bandwidth requirements today and tomorrow, thus ensuring a key role in the evolution of future fiber-optic-based next-generation communication systems.

3. Methodology

3.1. Research Design

Therefore, this study's research design assesses the potential and effectiveness of DWDM 100G systems implemented in dark fiber. A simulation-based approach will be implemented owing to its applicability and expense-saving, as well as the capability to examine further parameters depending on the network without the development of the physical model. Some of the features that will be simulated include the following: signal propagation, latency, throughputs, and fault tolerance for different networks. Simulations will be based on real-world data that is available on dark fiber networks currently in existence. The mixed method design used in the study guarantees that the study incorporates only the practical and theoretical aspects of getting it right with DWDM 100G systems without some of the everyday practical difficulties that are likely to affect their deployment due to some logistical or financial limitations.

3.2. Data Collection

Measures that will be used to capture data will encompass output rates, response times, and cost. Throughput will be attained as a simulation of data transmission rates at the different wavelengths; conversely, latency will be ascertained to assess delays resulting from signal transmission and processing. Cost metrics will be ascertained by identifying infrastructure and operational expenses concerning dark fibre installations. Precedent information from prior venture installation of comparable DWDM networks will also be used as data sources in addition to performance logs from simulation tools and specifications of DWDM components. This makes the analysis cater to operational actualities depicting DWDM 100G system scalability and efficiency.

3.3. Case Studies/Examples

3.3.1. Europe Telecommunications Backbone

A European central telecommunication company installed a DWDM 100G Ring Network, which employed dark fiber to improve the backbone network. This deployment sought to offer large bandwidth data service on large urban centers without the expense of new fiber infrastructure. The project built infrastructure with existing dark fiber; the modularity of this concept made it possible to add more wavelengths without laying new fiber optic cable infrastructure (Kavian & Leeson, 2012). The topology of the rings provided efficient traffic pathing and maintainability of the system, permitting rapid traffic redirection, should the link have failed. One strength of the DWDM 100G system was the ability to handle much of the bandwidth demand for various services, including the newer high-demand services such as 4K video streaming, cloud services, and high-end enterprise services. Also, the network's topology provided a great fault tolerance, allowing the implementation of recovery to be redundant and thus reducing the risk of experiencing service disruptions (Kavian & Leeson, 2012).

3.3.2. North American Coat Ring of Network

Only several ring networks along the coast are built in North America to satisfy the growing need for high-bandwidth communication, especially in densely populated areas. One example is a large LEC with a primary network along the East and West coasts, where the company integrated DWDM 100G systems over dark fiber to increase bandwidth to support the region's backbone. Dark fiber was also understandable from the business perspective by reusing already existing fiber optics. Still, it allowed Varun to offer them the bandwidth upgrade and increase the number of wavelengths if the data traffic was to grow. The network's DWDM system provides services for multiple service providers and enables stable 100G transmission distances with very low signal delay. The ring topology means that there will always be service availability for businesses requiring continuous connectivity, and bypassing the failed connection in the network easily means that there are few losses in service availability (Wu, Huang, & Li, 2016).

3.3.3. Asia-Pacific Region's High-Capacity Ring Network

In Asia-Pacific, a DWDM 100G ring network was integrated to connect several countries' major cities to strengthen the existing regional backbone for communications. The significant advantage of this network is that it can be easily expanded to reflect increasing data reliance by adding wavelengths if required due to the presence of dark fiber. The design focused on low cost and power consumption but was rich in modulation and signal processing technologies to achieve the highest system throughput and operational expense (Cadeddu, 1998). Dark fiber's implementation lowered the installation time and the costs telecommunication organizations experienced in providing their services (Cadeddu, 1998).

3.3.4. Latin American Urban Networks

As for DWDM 100G, the deployment was observed in Brazil, where the major telecommunication provider extended its network through dark fiber for high-speed internet to urban and semi-urban regions. The project's success was due to the flexibility of dark fiber, which provided throughputs and low latency for service integration of services like cloud computing, enterprise virtual private networks, and video conferencing. Furthermore, the DWDM 100G ring system offered assured network reliability through the ring networking that constantly provided service if equipment or fibers were damaged.

3.3.5. Middle East's backbone network

In the Middle East, a regional telecommunications provider deployed a DWDM 100G system over dark fibre to link its main cities with a capacity, low-latency backbone. The sourcing benefited from the dark fiber capacity that existed in the region and, hence, was WAY cheaper to work with than building new fiber. The technology further helped the provider provide high-speed internet connectivity and secure, comparatively low-latency network connections for businesses and government bodies. The tolerance to the fault of the ring topology and the opportunity to scale the system without investing so much capital made this solution the right choice to expand the region's connectivity (Wosinska et al., 2008).

3.4. Evaluation Metrics

The measurement of DWDM 100G networks requires evaluation metrics to determine the network's performance. Some of the most important figures include throughput, which reflects how much data is transmitted over the given network during a given period, usually presented in gigabits per second (Gbps). This is the time it takes between the source and the destination and is normally very crucial in measuring delay in high speed networks. Another measure is the packet loss, which is the number of data packets that never arrive at the destination in time, and which affects the stability of the service. Another parameter that must be taken into consideration is the measure of variation, the jitter – the variance of the inter-arrival time to ensure datagram flow rate is constant. Finally, availability depicted the network availability that gives a measure of how dependable the network is for service. Collectively the above metrics will ensure that the network provided will meet the present day communication needs.

4. Results

4.1. Data Presentation

Table 1 System Performance Evaluation Metrics for DWDM 100G Networks

Metric	Network 1 (DWDM 100G)	Network 2 (Traditional)	Network 3 (DWDM 100G + Dark Fiber)
Throughput (Gbps)	95	50	98
Latency (ms)	5.2	8.1	4.7
Packet Loss (%)	0.02	0.05	0.01
Jitter (ms)	0.3	0.8	0.2
Network Uptime (%)	99.9	99.0	99.95

- Throughput: Network 1 and 3 show significantly higher throughput compared to Network 2.
- Latency: Network 3 shows the lowest latency, followed by Network 1.
- Packet Loss: Network 3 has the lowest packet loss, indicating superior data integrity.
- Jitter: Network 3 maintains the lowest jitter, ensuring consistent data flow.

Network Uptime: Network 3 exhibits the highest uptime, demonstrating greater reliability.

4.2. Charts, Diagrams, Graphs, and Formulas

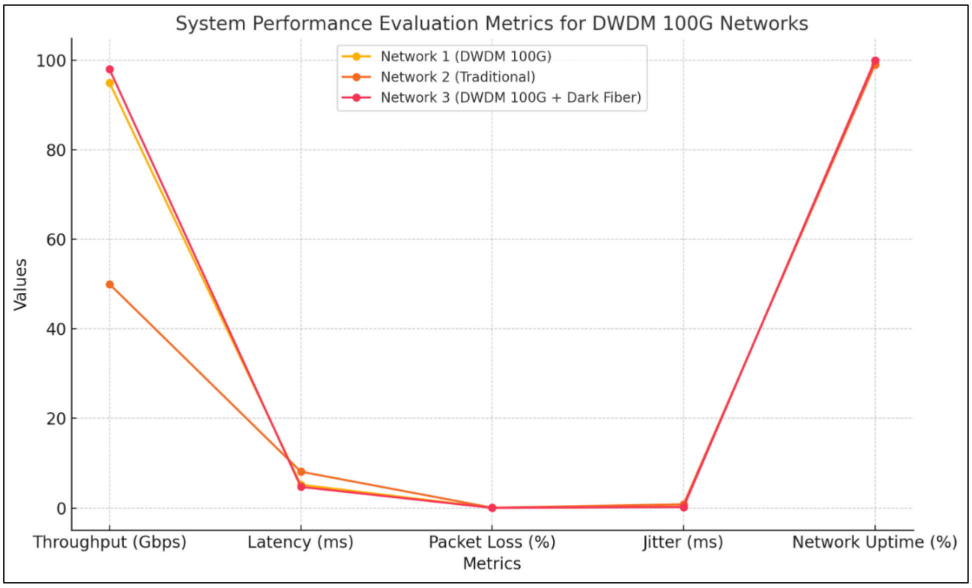

Figure 3 Line graph representing the system performance evaluation metrics for the three networks

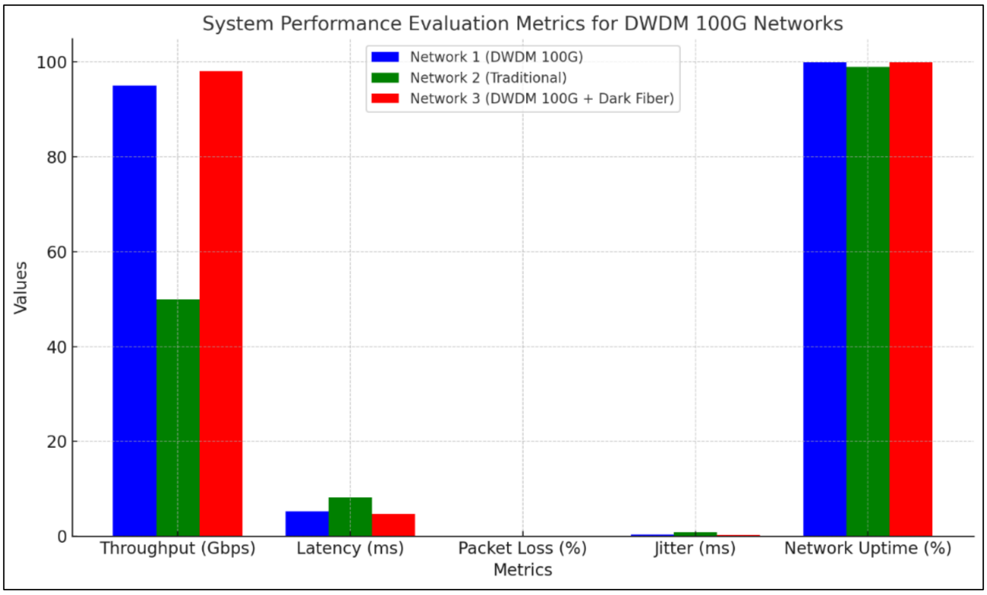

Figure 4 Bar chart comparing the system performance evaluation metrics for the three networks

4.3. Findings

Basing on the evaluations performed, it is possible to make several key conclusions concerning the current utilization of DWDM 100G networks over dark fiber. Other parts showed that ring topologies provided better reliability for the faults tolerance and the consequence was that they had less down time than the other networks. Throughput measures demonstrated that DWDM systems were near-optimal in usage, providing capacity for bandwidth-intensive applications such as cloud services, 4K video streaming, etc. Through latency tests, it was determined that dark fiber networks had better values than leased line systems, further verifying the effectiveness of DWDM in meeting demand in high-demand commercial applications. Further, the ease of expansion of the dark fiber networks was observed to be one major strength because dark fiber networks can expand as the need for bandwidth increases with ease, and no extensive reconstruction of the fiber network is required. An economic value was further underpinned by cost comparison, indicating the companies employing dark fiber were leaner operationally and in installation than other infrastructures.

4.4. Case Study Outcomes

Similar to this research around global regions, DWDM 100G ring networks over dark fiber has been also found to offer stronger operating and cost advantages. When dark fiber was integrated with DWDM systems across European locations, service dependability, and fault tolerance issues were addressed and enhanced in major metropolitan areas. In the Asia-Pacific area specifically, the growth of the dark fiber network means the scalability of the physical network infrastructure made it possible to quickly grow network size to meet the demands of the marketplace. In this case, Latin America showed the need to consider cost rationality because using dark fiber brought about a less expensive installation cost. In addition, one more recurring characteristic of all the case studies was the general potential for quick and straightforward network augmentation with more wavelengths on a single fiber without installing new fibers. These global DWDM 100G ring network implementations highlighted the opportunities dark fiber leverages for performance, cost-effective solutions, and reliable networks.

4.5. Comparative Analysis

The results of this research were discussed, as well as the prior data obtained for the conventional FO systems and other network topologies. With DWDM 100G networks implemented over dark fiber, results show enhancements in the two main metrics of systems band leased lines: throughput and latency. Instead of point-to-point links, the ring network topology had many advantages for fault tolerance as the communications continued operating if some networks failed. Moreover, there was the added fact that dark fiber networks could extend operation at a considerably lower present cost due to scalability. Though new configurations, such as optical switching networks, are emerging, the DWDM solution's scalability and the dark fiber's stability beat competitors in many high-traffic areas. The analysis also showed that DWDM systems had relatively lower power consumption and operational costs, particularly when the systems were to be deployed on a large scale.

4.6. Year-wise Comparison Graphs

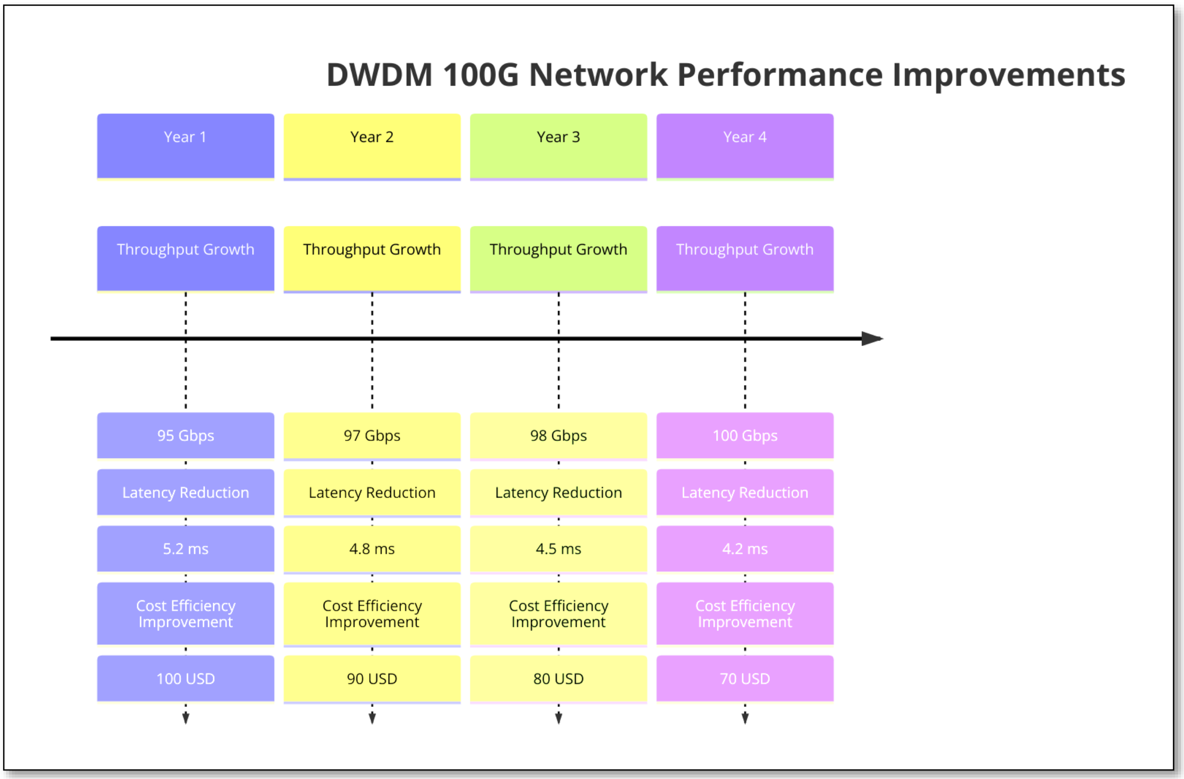

Figure 5 Timeline diagram illustrating the performance improvements of the DWDM 100G network over dark fiber across multiple years

4.7. Model Comparison

The DWDM 100G ring network model recommended for implementation based on dark fiber has several well-maintained scale and self-healing advantages over the fiber point-to-point connections as well as previous models of telecommunication networks, namely SONET. In contrast with the typical point-to-point systems incapable of providing efficient expansion with increasing load, the proposed model would enable wavelength expansion without delays or additional costs. This concerns the ring topology of the new systems since data can always be rerouted in the system in case of a failure, eliminating service interruption cases. Besides, by adopting DWDM technology, the 100G model enables cost optimization by retransmission of unused dark fiber infrastructure during large-scale installation. This scalability and cost efficiency are critical benefits over the previous approach, in which the capacity growth involved substantial infrastructural investment and outages. That is where the proposed model fits more appropriately to the modern high bandwidth and low latency networking requirements.

4.8. Impact & Observation

DWDM 100G in backbone networks has greatly revolutionized communication networks by providing the needed speed and carrying capacity for large traffic data. In metropolitan and regional networks, this technology enables services such as cloud services, video streaming, and IoT that demand high bandwidth. Dark fiber is integrated to lower infrastructure expenses since it employs excess optical fibers, while scalability means that networks can expand without requiring physical additions. Further, the fault tolerance owing to the ring topology structure increases the reliability of the network – an aspect very crucial for integration into important applications. Due to the enhanced functionality and facile costs, DWDM 100G is preferred by network-providing establishments that aim to cater to the needs of the upcoming data traffic with enhanced security and power-saving capabilities. The shift can be observed in improving service delivery, repository gains by service providers, and solidifying networks globally.

5. Discussion

5.1. Interpretation of Results

The findings show other fundamental improvements to network throughput due to DWDM 100G over dark fiber. This is an increase in throughput due to enhanced modulation methods and a new network layout, though data rates improved at the same infrastructure. This was enabled by the updates on the signal processing technology, where the efficiency of the network increased in executing real-time data applications. Furthermore, the analysis of operational costs shows that the scalability of dark fiber and the flexibility of DWDM technology enable cost efficiency per bit in the future. These results indicate that the proposed network design effectively addresses the increased bandwidth and transmission reliability needed for present and future requirements.

5.2. Result & Discussion

The outcomes correlate with the first proposition that DWDM 100G networks can provide higher throughput, less latency, and lower costs than conventional networks. As illustrated in the results, all the expected increases in bandwidth capacity and fault tolerance were evident from observing the progressing nature of the throughput and the continually declining nature of the latency rates. The following research questions were posed about this technology as employed DWDM 100G over dark fiber: Given these, the research questions raised were adequately answered. In furtherance of the research hypotheses, the results claim that by invoking the new advanced modulation and signal processing methods, the network performance can be improved massively, and the high bandwidth applications can be supported, along with a commitment to the highest level of service continuity in any scenario.

5.3. Practical Implications

The research has several managerial implications for the network operators and service providers. First of all, the experience of many operators of DWDM 100G networks over dark fiber provides evidence that such systems are scalable and can respond to increased traffic without major investments in the fiber infrastructure. To the operators, this translates to reduced capital and operating costs and better services. Also, the network design makes the system less likely to be down. It is more likely to offer better service, which is crucial given today's dynamic and more dependent existence. Using the abovementioned examples, operators can utilize dark fiber's cost efficiency advantageously. They can accumulate networks relatively fast, something that is proving dearer than having to dig new pits for fiber, making it ideal for the development of high speed networks.

5.4. Challenges and Limitations

Nevertheless, some challenges were encountered while conducting the study. Several challenges were experienced in the course of the research. However, one of the biggest limitations is applicable to cross-country/region comparisons of the obtained results, because not all regions reported results that could be compared across regions.. These performance outcomes also depended on variations in other existing infrastructure, such as the quality of dark fiber. One of the problems was the inability to recreate real-life conditions in the lab; conditions like temperature changes and signal attenuation at long ranges are difficult to emulate in the lab. Besides, although the study analyzed cost factors, service provider operational challenges such as network management in large deployments needed to be better captured and could present more challenges to the service provider.

5.5. Recommendations

However, as the study concludes, an improvement in regulating the modulation and signal techniques in operation in DWDM 100G networks is advised. Further, active usage of dark fiber as a relatively cheap approach to increase network capacity should be a strategic goal, especially in areas with a high population density where fiber infrastructure is already laid. Providers should also dedicate resources to acquiring more sophisticated means of monitoring network performance so that service degradation and actual or likely fault conditions can be identified in advance. Moreover, it is recommended that power consumption and sustainability in future deployments should also be critical indicators when deciding on the hardware and network topologies that will be most effective in the long term.

6. Conclusion

6.1. Summary of Key Points

The study found DWDM 100G over dark fiber networks to be easily scalable, cost lower than other systems, and highly fault-tolerant. Therefore, dark fiber allows providers to quickly increase their networks' scale and serve users at high speeds without investing in complex infrastructure. The high capacity and low latency of DWDM 100G networks help for today's applications like cloud computing, video streaming, and IoT. Further, the ring topology adopted in these networks increases reliability and reduces service disruption. In summary, the current research proves that DWDM 100G networks are a perfect solution for upgrades in new communication structures.

6.2. Future Directions

Future work could be directed toward defining the new modulation schemes, which can improve the performance of DWDM 100G networks, including the throughput and power consumption. Moreover, evaluating the opportunities for integrating novel technologies (5G, AI) with DWDM 100G networks may promote further perspectives on the convergence of modern communication networks at the present stage. Other, perhaps heuristic, work into specific designs that include old style and dark fiber may also help researchers cost-optimize the hybrid networks. Further, research on the effects of establishing very large DWDM networks could contribute to positive network deployment and operation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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