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An In-Depth Look at Multi-Protocol Label Switching (MPLS) for Enhancing Traffic Engineering and Network Efficiency

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Abstract: *Growing data traffic and the need for more efficient, reliable and high-speed networks have also promoted Traffic Engineering technologies such as Multiprotocol Label Switching (MPLS). MPLS uses label-based packet switching, which in turn allows for increased route optimization, better latency and service quality. This paper reviews the fundamentals of MPLS, its architecture, and its role in traffic engineering (MPLS-TE). Some of the significant enhancements include Informative Path of MPLS-TE regarding network congestion avoidance, resilience guarantee, and bandwidth fruition. Additionally, challenges such as integration with multilayer networks, bandwidth-delay constraints, and the potential of software-defined networking (SDN) in MPLS are examined. This detailed research shows how MPLS creates a foundation technology that helps build new traffic engineering and network management capabilities.*

Keywords: MPLS, Traffic Engineering, MPLS-TE, Quality of Service (QoS), Label Switching, Network Scalability, Software-Defined Networking (SDN), Bandwidth Optimization, Congestion Management, Multilayer Networks

I. INTRODUCTION

As the world undergoes explosive growth in digital technologies, when the need for telecommunications services continues to grow rapidly, the adoption of efficient traffic engineering solutions has become crucial. The majority of network service providers make extensive use of one of the more modern networking technologies, MPLS [1]. MPLS uses label switching, yet Internet Protocol (IP) uses IP switching. A technique called MPLS forwards packets according to the data in the labels. The MPLS label is a 32-bit field with a specific structure[2].

Many public and commercial networks rely on MPLS as the foundational technology for their numerous autonomous systems. This architecture is designed to address the current network's issues with volume, scalability, and traffic engineering via the use of connections. Depending on the needed connection speed, SDH or WDM is often considered to be at the transmission network's peak, with MPLS operating at the lowest possible level. Furthermore, unlike high-level encapsulated text-based processing, MPLS data packet forwarding is tag-based. Any system protocol and any network protocol at the physical or link layers may be supported by this multiprotocol system[3].

MPLS is a technology for managing network traffic that makes it easier to direct traffic than to choose the quickest route possible. Secure connections and routers with unknown failures will be used for vital traffic, which may be defined on the network. However, the question remains as to whether it is more appropriate to position MPLS nodes at the network's periphery to receive packet traffic from customers or to incorporate MPLS capabilities onto a portion of core nodes to leverage the flexibility and multiplexing of packet switching, thereby enhancing broadband delivery.

The goal of MPLS, a member of the packet-switching network family, is to address the shortcomings of IP-based forwarding. Performing an IP lookup, determining the next hop using its routing table, and forwarding the packet to the next hop creates a lot of overhead at each router's interface in a typical IP network[4]. In contrast, MPLS does not scan the packet itself but instead relies only on the label contents to determine packet forwarding.

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The fundamental idea behind MPLS architecture is to keep network switching components' control and data planes physically separate [5]. The forwarding components that carry out basic label-switching activities in accordance with the classical label-swapping paradigm make up the data plane. In contrast, the control plane coordinates the whole network via tasks like signaling and routing. This allows traffic to travel freely throughout the entire network.

A. Structure of the paper

The following paper is organized as follows: Section II provides the fundamentals of MPLS, Section III provides the traffic engineering in MPLS (MPLS-TE), Section IV defines the enhancing network efficiency with MPLS, and Sections V and VI provide the Literature Review on the topic and Conclusion with future work.

II. FUNDAMENTALS OF MPLS

The use of MPLS may simplify and accelerate the management of network traffic. MPLS enables network segmentation and QoS while being quick, cheap, and adaptable. Applications that are sensitive to latency, like as audio and video, may also benefit from MPLS's improved transport capabilities. Despite the fact that MPLS technology has been available for a while, companies are increasingly starting their own corporate deployments and using service provider solutions [6]. MPLS is a technique that has introduced an IP protocol-oriented connection. Application and network services on the network may, therefore, take full use of MPLS. Simply said, MPLS integrates IP network routing with a label-switching mechanism, making it a connection-oriented technology.

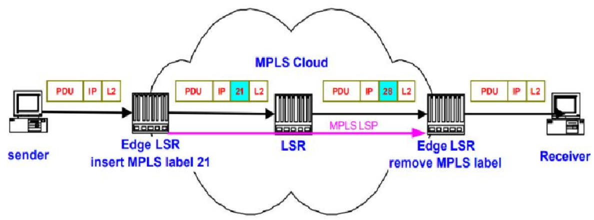

Figure 1: Multiprotocol Label Switching (MPLS)

A state-of-the-art forwarding technique is MPLS. It adds functionality to routing that allows for route controlling and packet forwarding. A header is an integral part of every MPLS packet.

- The header in an ATM-free environment has a 20-bit label, a 3-bit Experimental field (formerly called the Class of Service, or Cos, field), a 1-bit label stack indication, and an 8-bit TTL field.
- The VCI/VPI field encodes a label in an ATM context, which is the only information included in the header [7].
- Before sending a packet on its way, a LSR that is capable of MPLS checks the label and, in certain cases, the experimental field.
- There are several similarities between the label-switching procedure and the VCI/VPI processing of ATM. The MPLS header is stripped from a packet before it leaves an MPLS domain.
- Figure 1 depicts the whole process. The pathways that connect the ingress LSRs to the egress LSRs are known as label-switched pathways (LSPs). Signaling protocols such as RSVP or LDP are used by MPLS in order to establish LSPs.

A. Architecture of MPLS

MPLS network service, which entails tagging IP data packets on the receiving node or router with a locally relevant indicator, assigning them a defined duration, and categorizing them with a short duration. Then, the packets are sent to the router according to the tag [8]. Furthermore, the modified router or node employs such markings to distribute or transmit IP data packets throughout the network without making use of network layer addresses. With this MPLS design, the MPLS network is responsible for finishing the IP data packet routing process by making use of the mark in the MPLS header. Within the MPLS domain, IP packets must have the MPLS header inserted into them before transmission. By incorporating the MPLS header within the protocol's native tag section, data-link layer switching

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solutions like ATM[9]. The MPLS header must be positioned between the Layer 2 and Layer 3 TCP/IP connection headers in the event that the Layer 2 technology rejects the native tag region.

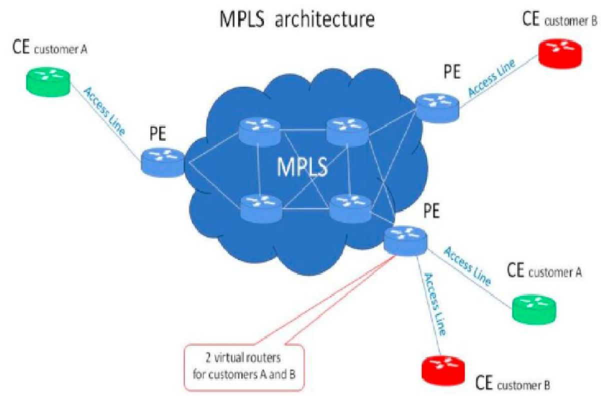

Figure 2: Architecture of MPLS

MPLS Label

There are two types of routers that make up MPLS: LSRs, or Label Switching Routers, and LERs, or Label Edge Routers. To expedite packet delivery, these routers make use of labels.

- **Label switch routing (LSR):** LSR is a kind of router that operates in the MPLS domain and often locates provider clouds. Upon receiving a packet, an LSR simply examines its lookup table to find the next hop value[10]. The next step is to detach the label by the header and reattach it before delivering the packet to the next hop.
- **Label edge router (LER):** The MPLS network rebrands the terminal router as an LER [26]. There are two main types of LER routers: inbound and outbound. Starting with the entry router, the MPLS network ultimately returns to its origin as its output.
- **Label Switched Path (LSP):** The ingress LER assigns each IP packet to a certain FEC, and when it passes through the MPLS domain, the packet takes a default route, also called an LSP. Data packets or traffic that travel across the MPLS domain are known as the mark-swapping route (LSP). The network needs two LSPs to provide duplex connection since the LSP is unidirectional. The FEC will detect the arrival of several layer 3 data packets in the LSR stream [11]. The tagged packets are then sent to the appropriate FEC LSP. A single LSP may support many FEC classes.
- **Label Distribution Protocol (LDP):** The two LSRs involved in MPLS must determine the function of the labels that will be used for data transmission between them. One method for marking data transmission on MPLS networks is the LDP. Through a sequence of procedures and messages known as LDP, LSR is able to map out a switched-label route (LSP) over the network by transferring routing information directly from the network layer to the pathways used by the data link interface switches[12].

III. TRAFFIC ENGINEERING IN MPLS (MPLS-TE)

MPLS traffic engineering (MPLS-TE) is a technology that enhances the capabilities of MPLS (Multiprotocol Label Switching) to enable more granular control over traffic flow within a network. Traffic engineering refers to the practice of optimizing the flow of network traffic in a way that ensures efficient use of network resources, avoids congestion, and achieves better overall performance. In traditional IP networks, traffic is routed based on the shortest path convention, which tends to result in inefficient usage of the network and congestion. MPLS-TE allows operators to move beyond shortest-path routing by explicitly setting up paths through the network that distribute traffic in a desired way[13].

A. Key Features of MPLS-TE

MPLS-TE enables traffic engineering to build Label-Switched Paths (LSPs) that are based on constraints such as bandwidth, latency and QoS. It effectively uses the available network resources, minimizes network traffic, and provides a fast-rerouting path.

Constraint-Based Routing:

An approach to IP traffic routing in MPLS-TE is known as CBR. CBR uses resource availability and link status information to find the least expensive path between a source and destination. QoS rules set by authorities or agency policies enforce bandwidth caps. In QoS contexts, the limitations on throughput, latency, or loss are called QoS constraints, and the corresponding routing is called QoS routing [14].

Explicit Routing:

Explicit routing in MPLS Traffic Engineering (TE) is a way to specify which routers and interfaces a tunnel should use or avoid. This process lets you make an extra path for your tunnel in case the primary route fails [15]. Administrators or algorithms can plan Label-Switched Paths based on manual selection and constraint-based actions to manage network resources better [16].

Label-Switched Paths (LSPs):

An MPLS domain is characterized by an LSP, whereby each LSR uses labels to make forwarding choices locally, enabling packets to be switched to known outgoing labels on separate interfaces. Through an MPLS network MPLS establishes a one-way forwarding route that sends packets through dedicated paths while using label-based forwarding rather than IP lookup methods for improved network performance [17].

Traffic Distribution:

When bandwidth is available in MPLS, the system directs traffic through multiple network paths. The system known as MPLS Traffic Engineering (TE) completes this task. MPLS-TE networks distribute data flows to balance traffic demand while avoiding network congestion and maximizing all available resources. IP routing, in tradition, sends traffic through the easiest path, which spreads network usage unfairly. MPLS-TE helps overcome this limitation with advanced methods to spread network traffic [18].

B. Mechanisms in MPLS Traffic Engineering

MPLS-TE employs several key mechanisms to optimize network performance:

- **Path Calculation:** MPLS Traffic Engineering (TE) path calculation determines the best path for traffic to travel across a network. The product selects the shortest available path using the CSPF method under specified conditions.
- **Resource Reservation:** RSVP and its extension RSVP-TE are used for resource reservation in MPLS Traffic Engineering (TE). RSVP-TE allows the establishment of MPLS-LSPs.
- **Traffic Policing and Shaping:** Network traffic uses these techniques to direct available internet speed and regulate who has access to the system. MPLS Traffic Engineering (TE) is a method for controlling traffic flow through an MPLS core network.
- **Load Balancing:** MPLS Traffic Engineering depends on load balancing to distribute traffic across many network paths so network resources are used effectively. Load balancing keeps network resources active instead of allowing them to remain idle while others get too busy.
- **Fault Tolerance:** When links or nodes fail, MPLS-TE automatically uses pre-planned backup paths to keep the network up and running. The system must be able to keep services running without disruption, which is especially important for networks that need zero downtime and stable performance.

IV. ENHANCING NETWORK EFFICIENCY WITH MPLS

MPLS is one of the most critical technologies that seeks to ensure optimization of a given network by simplifying the means of data transportation as well as resource allocation. With the aid of short path labels, the bulk transfer of packets is forwarded without delay, which results in greatly lessened dependency on lengthy routing table searches, also known as lookups. This mechanism results in the acceleration of the rate of data transfer besides reducing the time taken by data to get to a certain place (data latency). One critical benefit attendant to MPLS is its unmatched element of Quality

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of Service (QoS) provision. When it comes to the use of QoS policies, MPLS first focuses on how it manages or allocates this resource, avoiding having critical and sensitive applications perform poorly as a result of bandwidth and latency issues. This advantage is particularly useful for some of the most sensitive services, including VoIP and video conferencing.

A. MPLS and Quality of Service (QoS)

The IETF in 1997 set up the yet popular Multiprotocol Label Switching (MPLS) that enables the efficient delivery of data and telecommunication packets using the Internet Protocol (IP)[5]. It is not necessary to open and inspect the IP packet in order for the allocated tag to determine packet forwarding. The term "MPLS network" describes a kind of wide area network that uses the MPLS concept to transfer IP packets[19].

- Improvements to the basic idea of MPLS have made it applicable to optical networks using both WDM and SDH technologies.
- In this context, "GMPLS" refers to the comparable version of the network that may integrate many technologies. Consequently, GMPLS networks represent the next state of the art in wide area IP networking.
- To make the connection-oriented MPLS network (G) a cost-effective and widely applicable network solution, it needs more performance characteristics to handle profiles and unique traffic needs.

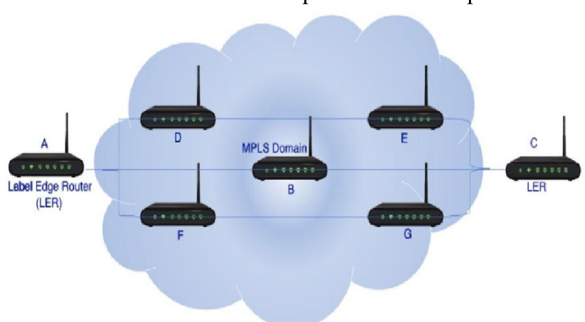

Figure 3: General Architecture of the MPLS Network.

B. Scalability and Flexibility in Large-Scale Networks

In particular, an emphasis is made on the ability to scale up large networks and provide enough flexibility to accommodate growing needs of the society for transmitting information and using different services. Conventional structures of networks have challenges with the scalability problem, which affects both performance and complexity in management [20]. SDN is one of the newer methods that have emerged to meet these difficulties. With SDN, the data plane and the control plane are no longer connected, which allows for dynamic resource allocation and centralized network administration.

- This disconnection makes scaling easier since administrators can make changes in the network without touching individual devices.
- SDN enables flexibility since, through programmatic interfaces, networks can be modified to suit changed traffic and application demands.
- There has been an example of the integration of SDN in wireless networks using Mininet-Wi-Fi and the Ryu Controller, with enhancements in scalability and performance results from a study.

C. Load Balancing and Congestion Management

Network performance must account for both load distribution and traffic control needs in highly active areas. The building block of congestion management is traffic engineering, which MPLS utilizes in managing the data flow over the network. This reduces the probability of traffic density, which is a common problem in many overall designs for manufacturing systems. With the deployment of numerous Label Switched Paths (LSPs) through source and destination nodes, it's possible for MPLS to traffic[21]. Hence, the network load is balanced since the data packets have to be forwarded through the connection(s) previously defined to be efficient.

- In contrast to many traditional routing protocols that employ shortest-path techniques, multiprotocol label switching (MPLS) works even for real-time scenarios, taking care of factors such as link utilization and traffic density.
- Apart from increasing throughput, MPLS traffic engineering also permits the diversion of traffic from congested or deteriorating links, significantly reducing latency and jitter.
- This is exceptionally useful for latency-sensitive services such as video conferencing, VoIP, and monetary transactions, where even a few seconds of delay can adversely affect the user's experience.
- It allows the incorporation of quality-of-service mechanisms, enabling network operators to give priority to critical traffic and to abide by the service level agreements during peak periods.

D. Resiliency in Unicast MPLS Networks

It is believed that MPLS networks will be able to offer integrated services because of their connection-oriented design. Additionally, specialized services may get assistance. People who rely on the Internet for important communication services probably think it can handle a lot of traffic. More and more people are starting to pay attention to MPLS resilience, and the IETF is putting a lot of effort into creating a standard timeline for MPLS-based recovery. The present routing algorithms have limits when it comes to improving the recovery time, which is why MPLS-based recovery was developed[22]. The development of MPLS-based recovery is one of his numerous objectives. Among these objectives are:

- Network reliability should be maximized by MPLS-based recovery.
- It is important that MPLS-based recovery works for both whole end-to-end paths and parts of such paths.
- Recovery procedures based on MPLS should reduce data loss and packet reordering to a minimum.
- Recovery based on MPLS should reduce signaling overhead for recovery route construction and maintenance to a minimum.
- The restrictions on traffic after the switchover should be maintained using MPLS-based recovery.
- To safeguard traffic at different levels of granularity, MPLS-based recovery should work.

V. LITERATURE OF REVIEW

In this section presents a literature review on MPLS for Enhancing Traffic Engineering and Network Efficiency. A summary of the reviewed studies is provided in Table I for a concise overview.

In, Sllame, AboJreeda and Hasaneen (2022) using GNS3 as a modeling and simulation environment and a Wireshark tool, analytical research is conducted to look at the responses made within MPLS networks, including time (network convergence) of fail/reconnection/rerouting and route reestablishment. Two real-world examples of MPLS networks have been developed; one uses OSPF as its routing protocol, while the other uses IS-IS to test how the network reacts and behaves when links and nodes fail. According to the findings, when it came to network convergence with MPLS networks, IS-IS performed better than OSPF[23].

In, Taruk et al. (2019) provide a high-level overview of the operation of an OSPF routing protocol via the application of traffic engineering techniques to WMMs in a MPLS framework. The next step is to create a topology for the wireless mesh network employing MPLS network models and simulator tools. This will allow us to analyze and evaluate the aspects associated with optimizing the OSPF routing algorithm[24].

In, Alja' afreh, Obaidat and Alouneh (2022) establishes a foundation for traffic engineering by providing a concise overview of MPLS, constrained-based routing, and OSPF protocols. Multiprotocol Label Switching (MPLS) allows data to enter the network more smoothly. Signaling protocols like BGP, RSVP, and LDP are used by the LSR in MPLS to create LSPs. Instead of taking the quickest route, LSPs will only follow pathways that are explicitly specified. The capacity to route data traffic on the system on a chip over the network is only one of many significant applications made possible by MPLS technology, which also permits high-performance forwarding architecture[25].

In, S, Singhal and Kanna (2023) it provides an all-inclusive routing model that can depict wireless routing properly under various bandwidth operating situations, serving as a flexible and all-encompassing modeling tool for developing MPLS PCM and testing the MPLS wireless communication protocol. Along with the presentation, illustration, and testing of an interdisciplinary approach to guarantee accuracy, precision, and efficiency, the topic of multi-frequency path stochastic behavior (VLC) domain MPLS Probabilistic Channel Modelling (MPLS PCM) is covered. The focus is on a conventional 5G network design that prioritizes compatibility and adaptability with the existing setup[26].

In, Nedyalkov and Georgiev (2021) performance evaluations of MPLS and MPLS TE-based virtual IP networks are conducted. Prior to conducting investigations with configured MPLS TE, the network functioning with MPLS was examined. Popular IP network monitoring tools and mathematical distributions for packet arrival times were used in the research[27].

Table 1: Literature Review on In-Depth Look at Multi-Protocol Label Switching (MPLS) for Enhancing Traffic Engineering and Network Efficiency

Reference	Key Topic	Focus Area	Findings/ Insights
[23]	MPLS Network Convergence	Comparison of OSPF and IS-IS in MPLS networks using simulation tools	IS-IS outperforms OSPF in network convergence timing under link/node failure conditions. GNS3 and Wireshark provided detailed insights into fail/reconnection/re-routing behavior.
[24]	OSPF Traffic Engineering with MPLS	Optimization of OSPF in Wireless Mesh Networks (WMN) using MPLS	Implementation of MPLS with OSPF in WMNs improves traffic flow and network performance. Simulator-based topological design offers insights into factors affecting OSPF optimization.
[25]	Traffic Engineering with MPLS and LSPs	Use of MPLS for constrained routing and traffic engineering	MPLS establishes Label Switched Paths (LSPs) using protocols like LDP, BGP, and RSVP. Enables high-performance forwarding and smooth traffic flow, bypassing shortest-path constraints.
[26]	MPLS Probabilistic Channel Modeling (PCM)	Application of MPLS PCM in 5G networks and wireless communication	Introduces MPLS PCM for modeling wireless routing under variable conditions. Ensures flexibility, precision, and compatibility with 5G architectures. Tested using interdisciplinary methodologies.
[27]	MPLS vs. MPLS TE Performance	Comparison of MPLS and MPLS TE in virtual IP networks	MPLS TE enhances network performance by optimizing packet flow and arrival times. Mathematical modeling and monitoring tools validate the findings.

VI. CONCLUSION AND FUTURE WORK

This review elucidates the need to consider MPLS as an enabler of change for contemporary networking since it is characterized by superb scalability, speed, and reliability brought about by traffic engineering's label-switching. The promoting feature of MPLS is its capability to isolate and rank the traffic that allows the offering of service solutions with low latency, beginning with voice and video services. This design, where flexibility is coupled with high QoS, has been shown to be capable of handling issues such as congestion and path failures etc. However, MPLS has some problems – in multilayer networks, cross-layer information is usually limited, and its presence negatively affects performance. Studies involving MPLS and software-defined networks or dynamic traffic engineering have been seen to improve the capabilities of this technology.

Possible research direction regarding MPLS can focus on the possible connection of MPLS with new technologies such as 5G and IoT in order to meet the standards set by the modern world. Increased interaction between MPLS and optical layer networks increases resource utilization in addition to the grooming of traffic. Also, integrating artificial intelligent traffic prediction and optimization in MPLS based networks can also improve its functionality. The official support of SDN as the additional system for MPLS in traffic management and the research of new algorithmic solutions for bandwidth and delay will guarantee MPLS's further importance in the context of networks' modern development.

REFERENCES

[1] I. Aijaz and S. M. Idrees, "on Cognitive Communications EAI Endorsed Transactions Performance Evaluation of Multi-protocol Label Switching-Traffic Engineering Schemes," no. June, 2021, doi: 10.4108/eai.8-10-2020.166550.

[2] A. Immadisetty, "MASTERING DATA PLATFORM DESIGN: INDUSTRY-AGNOSTIC PATTERNS FOR SCALE," *Int. J. Res. Comput. Appl. Inf. Technol.*, vol. 7, no. 2, pp. 2259–2270.

[3] R. Hussain, "A EXPLORATION OF MULTI-PROTOCOL LABEL SWITCHING (MPLS) NETWORK : A REVIEW A EXPLORATION OF MULTI-PROTOCOL LABEL SWITCHING (MPLS) NETWORK : A REVIEW," no. September, 2020.

[4] R. Q. Shawl, R. Thaker, and E. J. Singh, "OPEN ACCESS A Review : Multi Protocol Label Switching (Mpls)," vol. 4, no. 1, pp. 66–70, 2014.

[5] D. O. Awduche and B. Jabbari, "Internet traffic engineering using multi-protocol label switching (MPLS)," vol. 40, pp. 111–129, 2002.

[6] A. Rahman, A. H. Kabir, K. A. M. Lutfullah, M. Z. Hassan, and M. R. Amin, "Performance Analysis and the Study of the behavior of MPLS Protocols," pp. 226–229, 2008.

[7] Xipeng Xiao, A. Hannan, B. Bailey, and L. M. Ni, "Traffic engineering with MPLS in the Internet," *IEEE Netw.*, vol. 14, no. 2, pp. 28–33, 2000, doi: 10.1109/65.826369.

[8] J. Wu and A. M. L. Switching, "A Layered MPLS Network Architecture," pp. 0–3, 2010.

[9] M. Aazam, A. M. Syed, and E. Huh, "Redefining Flow Label in IPv6 and MPLS Headers for End to End QoS in Virtual Networking for Thin Client," no. July, 2019, doi: 10.1109/APCC.2013.6766016.

[10] A. Jamali and D. El Ouadghiri, "An Enhanced MPLS-TE For Transferring Multimedia packets," vol. 3, no. 8, pp. 8–13, 2012.

[11] A. Farrel, "Encoding of Attributes for Multiprotocol Label Switching (MPLS) Label Switched Path (LSP) Establishment Using Resource ReserVation Protocol-Traffic Engineering (RSVP-TE)," pp. 1–23, 2009.

[12] M. Lasserre and V. Kompella, "Virtual Private LAN Service (VPLS) Using Label Distribution Protocol (LDP) Signaling," pp. 1–31, 2007.

[13] I. Minei and J. Lucek, "Traffic Engineering with MPLS (MPLS-TE)," in *MPLS-Enabled Applications*, 2010. doi: 10.1002/9780470976173.ch2.

[14] Y. Zhang, M. Li, Y. Chen, Y. Y. Chiang, and Y. Hua, "A Constraint-Based Routing and Charging Methodology for Battery Electric Vehicles With Deep Reinforcement Learning," *IEEE Trans. Smart Grid*, 2023, doi: 10.1109/TSG.2022.3214680.

[15] I. Chaieb, J.-L. Le Roux, and B. Cousin, "MPLS-TE Routing: Adopting a Generic Architecture and Evaluating Various Implementation Approaches," 2007.

[16] T. Braun, V. Arya, and T. Turletti, "Explicit routing in multicast overlay networks," *Comput. Commun.*, 2006, doi: 10.1016/j.comcom.2006.02.022.

[17] A. Castro *et al.*, "Experimental assessment of bulk path restoration in multi-layer networks using PCE-based global concurrent optimization," *J. Light. Technol.*, 2014, doi: 10.1109/JLT.2013.2290588.

[18] X. Ma, H. Guo, X. Tang, X. Gao, and X. Wang, "Emergency traffic distribution and related traffic organization method under natural disasters," *Sustain. Oper. Comput.*, 2023, doi: 10.1016/j.susoc.2022.09.001.

[19] E. Science, "Quality of services in mpls networks," no. October, 2020, doi: 10.5281/zenodo.3949674.

[20] L. W. Networks *et al.*, "applied sciences Performance and Scalability Analysis of SDN-Based," 2023.

[21] S. Krile and S. Level, "Congestion Control for Highly Loaded DiffServ / MPLS Networks," 2008, doi: 10.1109/ICCIT.2008.149.

[22] O. Banimelhem, J. W. Atwood, and A. Aganval, "Resiliency issues in MPLS networks RESILIENCY ISSUES IN MPLS NETWORKS," no. June 2003, 2020, doi: 10.1109/CCECE.2003.1226073.

[23] A. M. Sllame, A. AboJreeda, and M. Hasaneen, "Evaluating the Fast Rerouting with MPLS Networks as a Fault Tolerance Mechanism with OSPF and IS-IS routing protocols," in *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, 2022, pp. 53–58. doi: 10.1109/MI-STA54861.2022.9837598.

[24] M. Taruk, E. Budiman, M. Wati, and Haviluddin, "OSPF Wireless Mesh with MPLS Traffic Engineering," in *2019 International Conference on Electrical, Electronics and Information Engineering (ICEEIE)*, 2019, pp. 119–122. doi: 10.1109/ICEEIE47180.2019.8981478.

[25] M. Alja' afreh, M. Obaidat, and S. Alouneh, "Incorporating MPLS for Better SoC Utilization and Traffic Engineering," in *2022 Seventh International Conference on Fog and Mobile Edge Computing (FMEC)*, 2022, pp. 1–7. doi: 10.1109/FMEC57183.2022.10062535.

[26] S. B. S, P. Singhal, and R. K. Kanna, "Optimization of Network Performance using MPLS," in *2023 3rd International Conference on Advancement in Electronics & Communication Engineering (AECE)*, 2023, pp. 715–718. doi: 10.1109/AECE59614.2023.10428461.

[27] I. Nedyalkov and G. Georgiev, "Performance Comparison of IP Network Using MPLS and MPLS TE," in *2021 12th National Conference with International Participation (ELECTRONICA)*, 2021, pp. 1–4. doi: 10.1109/ELECTRONICA52725.2021.9513712.