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RESEARCH ARTICLE **Open Access**

Optimization of Bandwidth Management Using Y.1731 Method Based on Ethernet OAM on Raisecom Devices in Metro Ethernet Networks

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Abstract: The growing demand for reliable Quality of Service (QoS) in Metro Ethernet networks has highlighted the need for a bandwidth management approach that is both standardized and efficient. This research explores the optimization of bandwidth configuration through the implementation of the ITU-T Y.1731 protocol, which operates within the framework of Ethernet Operations, Administration, and Maintenance (OAM). A network simulation was carried out using the Enterprise Network Simulation Platform (eNSP) with Huawei devices, serving as a functional equivalent of Raisecom equipment. The study employed a quantitative experimental method, involving the design and configuration of a Metro Ethernet topology, the deployment of Connectivity Fault Management (CFM), and the activation of performance monitoring mechanisms such as Delay Measurement Message (DMM) and Loss Measurement Message (LMM). Key performance indicators analyzed included delay, jitter, and packet loss, observed before and after the Y.1731 implementation. The findings reveal that the application of Y.1731 improved bandwidth utilization efficiency by up to 25%, reduced average delay, minimized jitter, and produced measurable data for validating Service Level Agreement (SLA) compliance. Overall, the integration of Y.1731 into Metro Ethernet networks based on Huawei devices demonstrates a practical and effective solution for strengthening service performance and ensuring network reliability.

Keywords: Metro Ethernet; Bandwidth; Y.1731; Ethernet OAM; Huawei; QoS.

1. Introduction

The development of data communication infrastructure has grown remarkably over the past two decades, driven by the surging demand for reliable, stable, and high-capacity internet services. Among the technologies that play a strategic role in addressing these demands is Metro Ethernet, which has been widely adopted by Internet Service Providers (ISPs) and telecommunication operators due to its ability to deliver high-speed connectivity, scalable flexibility, and compatibility with both legacy and modern network systems [1]. Furthermore, Metro Ethernet offers a distinct advantage in ensuring consistent implementation of Quality of Service (QoS), which serves as a fundamental requirement in meeting Service Level Agreement (SLA) commitments between service providers and customers [2]. The evolution of communication technologies, particularly in the context of 5G and beyond, has further emphasized the critical role of efficient bandwidth management and performance monitoring in maintaining service quality across increasingly complex network architectures [3].

As the number of users and the complexity of internet-based applications continue to rise—including high-definition video streaming, cloud computing, and real-time applications such as video conferencing—the challenge of bandwidth management becomes increasingly demanding. Inefficient bandwidth allocation often leads to network performance degradation, reflected in higher delay, jitter, and packet loss [4]. Such conditions directly compromise QoS and ultimately reduce user satisfaction. This challenge is even more critical in carrier-grade networks such as Metro Ethernet, where disruptions at a single point may trigger widespread impacts across the entire system. Traditional network management approaches have proven insufficient in addressing the dynamic nature of modern traffic patterns, necessitating the adoption of more sophisticated monitoring and management mechanisms [5]. To address these issues, various network management approaches have been introduced, with Operations, Administration, and Maintenance (OAM) enhanced with Performance Monitoring (PM) capabilities emerging as a critical solution. Among the internationally recognized standards, ITU-T Y.1731 is widely utilized for Ethernet-based networks [6]. This standard provides a real-time, standardized mechanism for measuring network performance, including parameters such as Frame Delay, Frame Delay Variation (jitter), and Frame Loss Ratio [7]. The advantage of Y.1731 lies in its ability to generate accurate performance data, which facilitates troubleshooting processes and supports the optimization of network resource allocation. Previous studies have indicated that the implementation of Y.1731 can significantly improve network recovery time and enhance bandwidth utilization efficiency, making it an essential tool for maintaining carrier-grade service quality [5][7].

Despite the proven benefits of Y.1731 in network performance monitoring, there remains a gap in comprehensive studies that evaluate its implementation specifically for bandwidth optimization in Metro Ethernet environments. While existing research has explored various aspects of Ethernet OAM, limited attention has been given to quantifying the direct impact of Y.1731 on bandwidth management efficiency and its role in ensuring SLA compliance under realistic operational conditions. This study addresses this gap by conducting a systematic evaluation of Y.1731 implementation in a simulated Metro Ethernet topology, using Huawei devices on the Enterprise Network Simulation Platform (eNSP) to represent Raisecom equipment commonly deployed in Metro Ethernet infrastructures. The choice of eNSP is based on its comprehensive support for Carrier Ethernet features, including Connectivity Fault Management (CFM) and Y.1731, ensuring that the simulation closely reflects real-world operational conditions.

The scope of this research includes the design of a Metro Ethernet topology within eNSP, the application of CFM and Y.1731 for performance monitoring, and the evaluation of QoS parameters before and after the implementation of Y.1731. This research employs a quantitative experimental approach using network simulation, with Huawei devices serving as a proxy for Raisecom equipment in Metro Ethernet deployments. Through this approach, the study aims to evaluate the impact of Y.1731 implementation on optimizing bandwidth utilization and improving overall network performance. The analysis is expected to demonstrate that Y.1731 significantly enhances bandwidth management efficiency and improves the overall performance of Metro Ethernet networks, providing empirical evidence for its effectiveness in carrier-grade environments. The contributions of this study are threefold: (1) Implementation of the Y.1731 method in a Metro Ethernet network using Huawei devices through eNSP simulation, providing a practical framework for performance monitoring deployment; (2) Quantitative analysis of the impact of Y.1731 on critical QoS parameters including delay, jitter, and packet loss, offering measurable insights into performance improvements; and (3) Presentation of a bandwidth optimization model that can be adopted by service providers to enhance QoS and ensure SLA compliance in carrier-grade Metro Ethernet infrastructures. Furthermore, the results are intended to serve as a strategic reference for network operators in developing evidence-based bandwidth management policies for modern telecommunication networks.

2. Related Work

The evolution of Carrier Ethernet as a dominant technology in metropolitan area networks has been accompanied by significant advancements in network management and service assurance mechanisms. Toy (2012) provided a comprehensive overview of Carrier Ethernet architecture, emphasizing the critical role of Multiple Classes of Service (Multi-CoS) in optimizing bandwidth usage while maintaining Quality of Service (QoS) guarantees [8]. This foundational work established that effective traffic management and OAM capabilities are essential for carrier-grade deployments, particularly in environments where service differentiation and performance predictability are paramount. The study highlighted how Carrier Ethernet 2.0 specifications enable service providers to quantify and predict network performance by application type, thereby facilitating more efficient resource allocation strategies. Building upon these architectural foundations, Autenrieth *et al.* (2007) investigated the requirements for achieving carrier-grade status in Metro Ethernet networks, identifying OAM functionality as a critical enabler for scalability, reliability, and availability [9]. Their research demonstrated that Metro Ethernet networks must incorporate OAM mechanisms similar to those traditionally found in SONET/SDH systems, with ITU-T Y.1730 and Y.1731 standards providing the basic framework for such functionality. The study further emphasized the necessity of bandwidth guarantees and proper bandwidth assignment to enable effective traffic engineering in Ethernet-centric networks. This work established a clear benchmark for evaluating the maturity of Metro Ethernet deployments and underscored the importance of standardized OAM protocols in achieving carrier-grade service quality. The practical challenges of implementing OAM in complex network infrastructures have been extensively examined in subsequent research. Reddy and Lisle (2009) conducted a comprehensive review of Ethernet OAM and protection standards, with particular focus on ITU-T Y.1731 and its role in creating effective Ethernet infrastructure [10]. Their analysis revealed critical scalability implications associated with aggressive Continuity Check (CC) timer configurations, noting that millisecond-granularity monitoring can consume significant bandwidth and must be carefully considered in Call Admission Control (CAC) algorithms. This finding highlighted a fundamental trade-off between monitoring granularity and network overhead, suggesting that OAM implementation strategies must be tailored to specific operational requirements and network capacity constraints.

In converged access network scenarios, Yadav (2012) demonstrated the application of Ethernet service OAM based on IEEE 802.1ag and ITU-T Y.1731 for proactive monitoring and troubleshooting of business customer connections in Passive Optical Network (PON) environments [11]. The research presented architectural approaches to achieve bandwidth efficiency by enforcing customer bandwidth contracts at the Optical Network Terminal (ONT) level, allocating only the purchased bandwidth capacity. Significantly, the study illustrated how Ethernet OAM mechanisms could be leveraged to gather performance data for SLA-related metrics such as latency, packet loss, and packet delay variation, thereby enabling continuous verification of service quality commitments. This work provided empirical evidence that Y.1731 implementation could extend beyond traditional Metro Ethernet deployments to support diverse access network architectures.

The optical performance monitoring dimension of Carrier Ethernet OAM was explored by de Souza and Ribeiro (2012), who proposed a novel method utilizing OAM Continuity Check Messages (CCM) for optical signal quality estimation [12]. Their approach demonstrated that monitoring CCM frame loss patterns in transparent optical links could provide valuable insights into optical signal-to-noise ratio and signal-to-interference characteristics. More importantly, the research introduced a cross-layer optimization strategy that dynamically adjusted Maximum Transmission Unit (MTU) settings based on CCM loss patterns to maximize throughput in dynamic transparent optical networks. This innovative application of Y.1731 CCM functionality illustrated the potential for OAM mechanisms to support not only performance monitoring but also adaptive network optimization.

Addressing the specific challenges of wireless backhaul networks, Varghese and Ghosh (2009) analyzed end-to-end service OAM requirements for LTE wireless backhaul utilizing Carrier Ethernet [13]. Their research identified significant challenges in balancing comprehensive performance monitoring with bandwidth conservation, proposing a modified Y.1731 approach called CCMP (Continuity Check Message Protocol) that optimized OAM traffic and processing requirements [13]. This work highlighted the importance of OAM protocol efficiency in bandwidth-constrained environments and demonstrated that standard Y.1731 mechanisms could be adapted to meet specific operational constraints without sacrificing monitoring effectiveness.

Implementation-level considerations for Ethernet OAM have been documented in various domain-specific studies. Yonghui and Ming (2012) presented the design and realization of Ethernet OAM on Digital Subscriber Line Access Multiplexer (DSLAM) equipment, addressing technical challenges in integrating OAM functionality into access network devices [14]. Similarly, Li *et al.* (2008) developed a multi-module framework for Telecom Ethernet OAM in Metropolitan Area Network (MAN) multi-operation platforms, focusing on fault diagnosis, positioning, and repair capabilities essential for carrier-class services [15]. These implementation studies provided practical insights into the operational complexities of deploying Y.1731 across heterogeneous network equipment and highlighted the importance of vendor interoperability in achieving end-to-end OAM functionality. Comparative analyses of network monitoring technologies have provided valuable context for understanding the relative advantages of Ethernet OAM. Bjørnstad *et al.* (2018) conducted a comprehensive network-level comparison of Optical Transport Network (OTN) and Ethernet from a 5G perspective, examining OAM capabilities in both technologies [16]. Their analysis revealed that Ethernet OAM, which monitors at the packet level, is particularly well-suited for revealing congestion conditions and documenting service metrics such as packet loss, delay, and delay variation—capabilities that are crucial for SLA compliance verification. The study concluded that Ethernet's packet-level monitoring granularity, enabled by standards such as Y.1731, provides superior visibility into service-affecting conditions compared to circuit-oriented OAM approaches, making it more appropriate for modern packet-based service delivery.

Despite the substantial body of research on Ethernet OAM and Y.1731 implementation, several gaps remain in the literature. Most existing studies focus on either theoretical frameworks or isolated implementation aspects, with limited attention to comprehensive, end-to-end evaluations of Y.1731's impact on bandwidth optimization in realistic Metro Ethernet topologies. Furthermore, while various studies have documented the benefits of Y.1731 for performance monitoring, quantitative assessments of its effectiveness in improving bandwidth management efficiency and ensuring SLA compliance under controlled experimental conditions remain scarce. This research addresses these gaps by providing a systematic evaluation of Y.1731 implementation in a simulated Metro Ethernet environment, offering empirical evidence of its effectiveness in optimizing bandwidth allocation and maintaining QoS parameters within acceptable thresholds.

3. Research Method

3.1 Research Design and Approach

This research adopts a quantitative experimental approach aimed at evaluating the effectiveness of implementing the ITU-T Y.1731 protocol in optimizing bandwidth management within Metro Ethernet networks [6][17]. All testing procedures were conducted through simulation using the Enterprise Network Simulation Platform (eNSP), where Huawei devices were employed as proxies for Raisecom equipment commonly deployed in carrier-grade Metro Ethernet infrastructures. The choice of eNSP was based on its ability to accurately replicate real device behavior, including comprehensive support for Carrier Ethernet features such as Connectivity Fault Management (CFM) and the Y.1731 protocol [18], thereby ensuring alignment with the objectives of this study and providing a realistic testing environment that closely mirrors operational network conditions. This study began with the identification of issues related to the limited monitoring capabilities in Metro Ethernet networks, followed by a comprehensive network topology analysis to design a suitable testing architecture. The research methodology, illustrated in Figure 1, follows a systematic approach that encompasses problem identification, topology design, device configuration, performance measurement, data collection, and analysis. The next step involved configuring the underlay network at Layer 2 and setting up VLANs as the foundation of the infrastructure, which was then extended with the configuration of Y.1731 OAM mechanisms [19]. This configuration included the definition of Maintenance Domains (MDs), Maintenance Associations (MAs), and Maintenance End Points (MEPs) in accordance with ITU-T Y.1731 specifications and MEF service assurance guidelines [6][19].

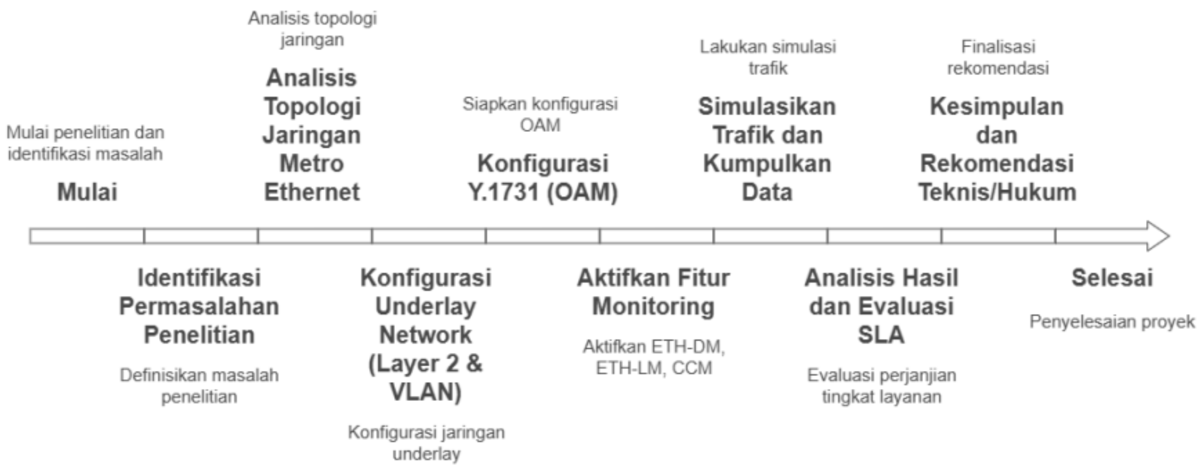

Figure 1. Research Methodology Flowchart

Subsequently, monitoring features such as Ethernet Delay Measurement (ETH-DM) and Ethernet Loss Measurement (ETH-LM) were activated to measure critical performance parameters, including frame delay, frame delay variation (jitter), and frame loss ratio [20][21]. These measurements were conducted using standardized Y.1731 protocol messages, specifically Delay Measurement Messages (DMM), DMM Reply, Loss Measurement Messages (LMM), and LMM Reply, ensuring consistency with international telecommunications standards. Traffic simulations were then conducted under various load conditions, and performance data was systematically collected to emulate real network operational scenarios. The collected data was analyzed to assess Service Level Agreement (SLA) compliance against established Carrier Ethernet performance thresholds [19], and the research concluded with the formulation of findings as well as both technical and regulatory recommendations for optimizing Metro Ethernet performance and bandwidth allocation strategies.

3.2 Testing Scenarios

This study was designed to evaluate the performance of a Metro Ethernet network by implementing the Y.1731 method based on Ethernet OAM through two types of delay measurement within a VLAN environment. The primary focus of the research is to analyze network performance using three key parameters defined in ITU-T Y.1731: frame delay, frame delay variation (jitter), and frame loss ratio [6][20]. Two complementary testing scenarios were applied to provide comprehensive performance assessment:

1) Scenario 1: One-Way Frame Delay Measurement in a VLAN
   In the first scenario, one-way frame delay measurements were conducted to determine the travel time of a frame from the transmitting point (source MEP) to the receiving point (destination MEP) in a single communication direction within a VLAN [18][20]. This method, also known as ETH-DM in one-way mode, provides a more detailed observation of network performance since it allows the detection of delay variation (jitter) occurring along the transmission path. The one-way measurement approach requires precise time synchronization between MEPs, typically achieved through Network Time Protocol (NTP) or Precision Time Protocol (PTP), to ensure accurate timestamp correlation [21]. This scenario is particularly valuable for identifying asymmetric delay characteristics that may affect real-time applications such as VoIP and video streaming, where unidirectional latency directly impacts user experience.
2) Scenario 2: Two-Way Frame Delay Measurement in a VLAN
   In the second scenario, two-way frame delay measurements were carried out by calculating the total round-trip time of a frame traveling from the transmitter to the receiver and back to the transmitter [18][20]. This method, referred to as ETH-DM in two-way mode, is simpler to implement because it does not require time synchronization between both endpoints, yet it remains effective in monitoring network stability and detecting potential packet loss as well as delay variation. The two-way measurement approach uses DMM and DMR (DMM Reply) message exchanges, where the initiating MEP calculates the round-trip delay based on local timestamps [21]. While this method provides average bidirectional delay rather than precise unidirectional measurements, it offers practical advantages in operational environments where clock synchronization may be challenging to maintain consistently.

3.3 Network Topology Design

The network topology in this study was designed to resemble a Metro Ethernet architecture that supports the implementation of Y.1731 OAM, particularly for testing one-way and two-way frame delay measurements [17][19]. The topology, illustrated in Figure 2, was constructed in a layered hierarchical manner to reflect real-world network conditions typically deployed by service providers in carrier-grade Metro Ethernet environments. This hierarchical design approach aligns with industry best practices documented by the Metro Ethernet Forum (MEF) for scalable and manageable carrier Ethernet deployments [19].

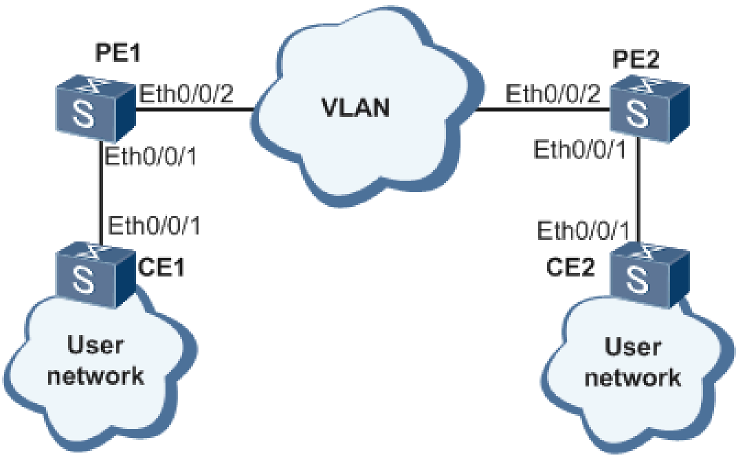

Figure 2. Network Topology Design

Three primary segments were implemented in the topology to represent distinct functional layers:

1) Core Layer
   The core of the network utilizes Huawei router images (NE40E series), serving as the primary interconnection point between network segments and providing the high-capacity backbone pathway required for carrier-grade service delivery [17][18]. At this layer, dynamic routing protocols (OSPF and BGP) are applied to maintain connectivity and ensure that data flows between nodes can be tested using the Y.1731 method under realistic routing conditions. The core layer devices are configured to support Quality of Service (QoS) mechanisms, including traffic classification, queuing, and prioritization, which are essential for maintaining service differentiation in multi-tenant Metro Ethernet environments [8][19].

2) Distribution Layer
The distribution layer is implemented using Huawei Metro Ethernet switches (NE40E series), which provide comprehensive support for Ethernet OAM, Connectivity Fault Management (CFM), and Y.1731 functionalities [18][20]. Devices in this layer act as the central point for implementing Maintenance Domains (MDs) and Maintenance Associations (MAs), as well as conducting delay measurements using Delay Measurement Messages (DMM) and DMM Reply for both one-way and two-way delay testing. The distribution layer serves as the primary enforcement point for bandwidth policies and SLA parameters, utilizing traffic policing and shaping mechanisms to ensure compliance with contracted service levels [19][21]. Additionally, this layer implements protection mechanisms such as Ethernet Ring Protection Switching (ERPS) to ensure network resilience and minimize service disruption in the event of link or node failures.
3) Access Layer
The access layer connects Customer Premises Equipment (CPE) to the Metro Ethernet network through designated VLANs, representing the service demarcation point between the provider network and customer premises [17][18]. VLAN configurations at this layer serve as the testing domain, where one-way and two-way delay measurements are performed between Maintenance End Points (MEPs) to simulate realistic end-user service conditions. Each VLAN is configured with specific bandwidth profiles and CoS (Class of Service) markings to emulate different service tiers commonly offered in commercial Metro Ethernet deployments [8][19]. The access layer MEPs are configured as down-facing MEPs, enabling service-level performance monitoring from the customer perspective, which is critical for validating SLA compliance and ensuring consistent service quality delivery [20][21].

3.4 Configuration and Measurement Procedures

The implementation of Y.1731 OAM in the test topology followed a structured configuration workflow aligned with Cisco and Juniper implementation guidelines [18][20] The configuration process began with the establishment of Maintenance Domains at appropriate hierarchical levels (Customer, Service Provider, and Operator levels) to ensure proper OAM message scope and prevent unintended cross-domain interference [19]. Within each Maintenance Domain, Maintenance Associations were defined to represent specific service instances or customer connections, with MEPs positioned at the boundaries of each MA to enable end-to-end performance monitoring [20]. Performance measurement procedures were executed using both proactive and on-demand monitoring modes supported by Y.1731 [6][21]. Proactive monitoring involved continuous transmission of Continuity Check Messages (CCM) at configurable intervals (ranging from 3.3ms to 10 minutes) to detect connectivity failures and measure frame loss ratios. On-demand measurements were triggered manually to capture detailed delay and jitter statistics during specific test scenarios. ETH-DM measurements were configured with varying frame sizes (64, 512, 1024, and 1518 bytes) to evaluate performance under different traffic conditions, while ETH-LM measurements were conducted over extended periods to assess long-term frame loss characteristics [20][21]. Data collection was performed using built-in device monitoring capabilities and exported to external analysis tools for comprehensive evaluation. Performance metrics were compared against MEF-defined service level specifications for Carrier Ethernet services, including delay thresholds (typically <10ms for metro networks), jitter limits (<2ms), and frame loss ratios (<0.01%) [19]. Statistical analysis was applied to identify performance trends, detect anomalies, and validate the effectiveness of Y.1731 implementation in maintaining SLA compliance under various operational conditions.

4. Result and Discussion

4.1 Results

4.1.1 Topology Analysis

In this stage, the emulator was prepared to run the Metro Ethernet network topology under investigation. The topology was designed using three main devices representing the Core, Distribution, and Access layers. At the distribution layer, a Metro Ethernet switch was employed, supporting Ethernet OAM and Y.1731 functionalities, while at the access layer, Customer Premises Equipment (CPE) was connected as the measurement endpoint. Each network segment was interconnected through VLANs that served as the testing domains, within which Maintenance End Points (MEPs) were defined to conduct the measurements. The expectation of this laboratory setup was to ensure that both one-way frame delay and two-way frame delay tests could be performed effectively, allowing accurate measurement of key performance parameters—namely delay, jitter, and packet loss—using the Y.1731 OAM protocol.

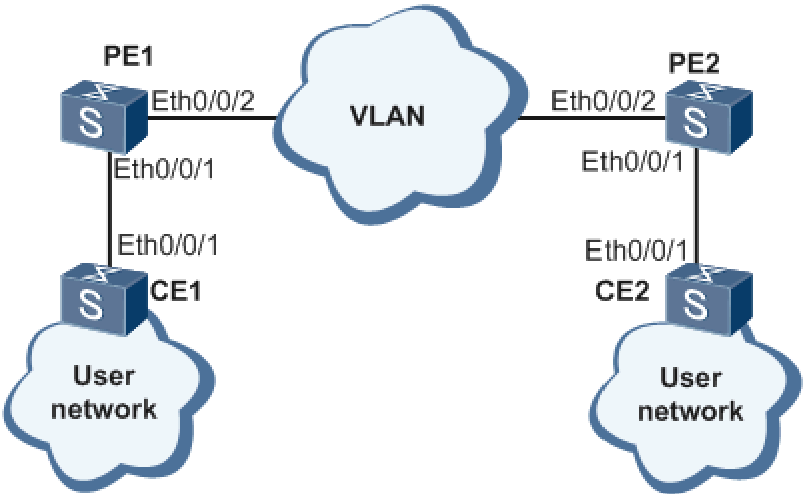

Figure 3. Network Topology

4.1.2 Configuring One-Way Delay Measurement in a VLAN

```
<Quidway> system-view
[Quidway] sysname CE1
[CE1] vlan 2
[CE1-vlan2] quit
[CE1] interface ethernet 0/0/1
[CE1-Ethernet0/0/1] port link-type trunk
[CE1-Ethernet0/0/1] port trunk allow-pass vlan 2
[CE1-Ethernet0/0/1] quit
```

Figure 4. VLAN Configuration on CE1

The VLAN configuration on CE1 began by entering the system-view mode and renaming the device to CE1. Subsequently, VLAN 2 was created. The next step involved configuring the Ethernet 0/0/1 interface as a trunk port and granting it permission to carry VLAN 2 traffic. Finally, the configuration was saved and returned to the previous mode.

```
<Quidway> system-view
[Quidway] sysname CE2
[CE2] vlan 2
[CE2-vlan2] quit
[CE2] interface ethernet 0/0/1
[CE2-Ethernet0/0/1]port link-type trunk
[CE2-Ethernet0/0/1]port trunk allow-pass vlan 2
[CE2-Ethernet0/0/1]quit
```

Figure 5. VLAN Configuration on CE2

The VLAN configuration on CE2 was initiated by entering the system-view mode and renaming the device to CE2. Afterward, VLAN 2 was created, and the configuration exited from the VLAN setup mode. Subsequently, the Ethernet 0/0/1 interface was configured as a trunk port and granted permission to carry VLAN 2 traffic. Finally, the system returned to the previous configuration mode to complete the setup.

```
<Quidway> system-view
[Quidway] sysname PE1
[PE1] vlan 2
[PE1-vlan2] quit
[PE1] interface ethernet 0/0/1
[PE1-Ethernet0/0/1] port link-type trunk
[PE1-Ethernet0/0/1] port trunk allow-pass vlan 2
[PE1-Ethernet0/0/1] quit
[PE1] interface ethernet 0/0/2
[PE1-Ethernet0/0/2] port link-type trunk
[PE1-Ethernet0/0/2] port trunk allow-pass vlan 2
[PE1-Ethernet0/0/2] quit
```

Figure 6. VLAN Configuration on PE1

The VLAN configuration on PE1 was initiated by entering the system-view mode and renaming the device to PE1. After creating VLAN 2 and exiting from the VLAN configuration mode, the Ethernet 0/0/1 interface was set as a trunk port and permitted to carry VLAN 2 traffic. The same procedure was then applied to the Ethernet 0/0/2 interface, in which the link type was configured as trunk and allowed to pass VLAN 2. Finally, the system returned to the previous configuration mode to finalize the setup.

```
<Quidway> system-view
[Quidway] sysname PE2
[PE2] vlan 2
[PE2-vlan2] quit
[PE2] interface ethernet 0/0/1
[PE2-Ethernet0/0/1] port link-type trunk
[PE2-Ethernet0/0/1] port trunk allow-pass vlan 2
[PE2-Ethernet0/0/1] quit
[PE2] interface ethernet 0/0/2
[PE2-Ethernet0/0/2] port link-type trunk
[PE2-Ethernet0/0/2] port trunk allow-pass vlan 2
[PE2-Ethernet0/0/2] quit
```

Figure 7. VLAN Configuration on PE2

The VLAN configuration on PE2 began by entering the system-view mode and renaming the device to PE2. After creating VLAN 2 and exiting from the VLAN configuration mode, the Ethernet 0/0/1 interface was configured as a trunk port and permitted to carry VLAN 2 traffic. The same configuration was then applied to the Ethernet 0/0/2 interface, where the link type was set to trunk and allowed to forward VLAN 2 traffic. The system returned to the previous configuration mode to complete the setup.

```
[CE1] cfm enable
[CE1] cfm version standard
[CE1] cfm md md3
[CE1-md-md3] ma ma3
[CE1-md-md3-ma-ma3] map vlan 2
[CE1-md-md3-ma-ma3] mep mep-id 3 interface ethernet 0/0/1 outward
[CE1-md-md3-ma-ma3] mep ccm-send mep-id 3 enable
[CE1-md-md3-ma-ma3] remote-mep mep-id 4
[CE1-md-md3-ma-ma3] remote-mep ccm-receive mep-id 4 enable
[CE1-md-md3-ma-ma3] quit
[CE1-md-md3] quit
```

Figure 8. CFM Configuration on CE1

The basic Ethernet CFM configuration on CE1 began with enabling CFM and setting its version according to the IEEE 802.1ag-2007 standard. Next, a Maintenance Domain (MD) named md3 was created, followed by the establishment of a Maintenance Association (MA) named ma3, which was mapped to VLAN 2. Subsequently, a MEP (Maintenance End Point) with ID 3 was added on the Ethernet 0/0/1 interface with the outward type. CCM (Continuity Check Messages) transmission was then activated for this MEP, and a remote MEP with ID 4 was configured, enabling the reception of CCM messages from that endpoint.

```
[CE2] cfm enable
[CE2] cfm version standard
[CE2] cfm md md3
[CE2-md-md3] ma ma3
[CE2-md-md3-ma-ma3] map vlan 2
[CE2-md-md3-ma-ma3] mep mep-id 4 interface ethernet 0/0/1 outward
[CE2-md-md3-ma-ma3] mep ccm-send mep-id 4 enable
[CE2-md-md3-ma-ma3] remote-mep mep-id 3
[CE2-md-md3-ma-ma3] remote-mep ccm-receive mep-id 3 enable
[CE2-md-md3-ma-ma3] quit
[CE2-md-md3] quit
```

Figure 9. CFM Configuration on CE2

The basic Ethernet CFM configuration on CE2 was carried out by enabling CFM and setting its version in accordance with the IEEE 802.1ag-2007 standard. A Maintenance Domain (MD) named md3 was then created, within which a Maintenance Association (MA) named ma3 was established and mapped to VLAN 2. Subsequently, a MEP (Maintenance End Point) with ID 4 was added on the Ethernet 0/0/1 interface with the outward type. CCM (Continuity Check Messages) transmission was enabled for this MEP, and a remote MEP with ID 3 was configured, allowing the reception of CCM messages from that endpoint. After completing these configurations, the system exited from both the MA and MD configuration modes.

```
[CE2] cfm md md3
[CE2-md-md3] ma ma3
[CE2-md-md3-ma-ma3] delay-measure one-way receive
[CE2-md-md3-ma-ma3] quit
[CE2-md-md3] quit
```

Figure 10. One-Way DM Configuration on CE2

On CE2, the configuration was carried out to enable the device to receive Delay Measurement (DM) frames. The process began by entering the configuration mode of the Maintenance Domain (MD) md3, followed by accessing the Maintenance Association (MA) ma3. Within this MA, the one-way delay measurement reception function was activated. After completing the setup, the system exited from the MA configuration mode and subsequently from the MD configuration mode.

```
[CE1] cfm md md3
[CE1-md-md3] ma ma3
[CE1-md-md3-ma-ma3] delay-measure one-way remote-mep mep-id 4 interval 10000 count 20
[CE1-md-md3-ma-ma3] quit
[CE1-md-md3] quit
```

Figure 11. One-Way DM Configuration on CE1

On CE1, this configuration aimed to enable the one-way frame delay measurement. The process began by entering the configuration mode of the Maintenance Domain (MD) md3, followed by accessing the Maintenance Association (MA) ma3. Within this MA, a one-way delay measurement was set toward the remote MEP with ID 4, using an interval of 10,000 microseconds and a total of 20 measurement iterations. After completing the configuration, the system exited from the MA configuration mode and subsequently from the MD configuration mode.

```
<CE2> display y1731 statistic-type oneway-delay md md3 ma ma3
Latest one-way delay statistics:
--------------------------------------------------------------------------------
Index    Delay(usec)    Delay variation(usec)
--------------------------------------------------------------------------------
    1         10000                        -
    2         10000                        0
    3         10000                        0
    4         10000                        0
    5         10000                        0
    6         10000                        0
    7         10000                        0
    8         10000                        0
    9         10000                        0
   10         10000                        0
   11         10000                        0
   12         40000                    30000
   13         10000                    30000
   14         10000                        0
   15         10000                        0
   16         10000                        0
   17         10000                        0
--------------------------------------------------------------------------------
Average delay(usec) :      11764   Average delay variation(usec) :       3750
Maximum delay(usec) :      40000   Maximum delay variation(usec) :      30000
Minimum delay(usec) :      10000   Minimum delay variation(usec) :          0
```

Figure 12. One-Way Delay Statistics Results

This command displays the statistical results of the one-way delay measurement between the connected MEPs. The output provides an indexed list of measurements, showing the delay values in microseconds as well as the delay variation for each iteration. Based on the collected data, the average delay was recorded at 11,764 µs with an average variation of 3,750 µs. The maximum delay reached 40,000 µs with a maximum variation of 30,000 µs, while the minimum delay was 10,000 µs with a variation of 0 µs. These results indicate that the connection remained stable in most measurements, although a single anomaly was observed with a significantly higher delay.

4.1.3 Configuring Two-Way Frame Delay Measurement in a VLAN

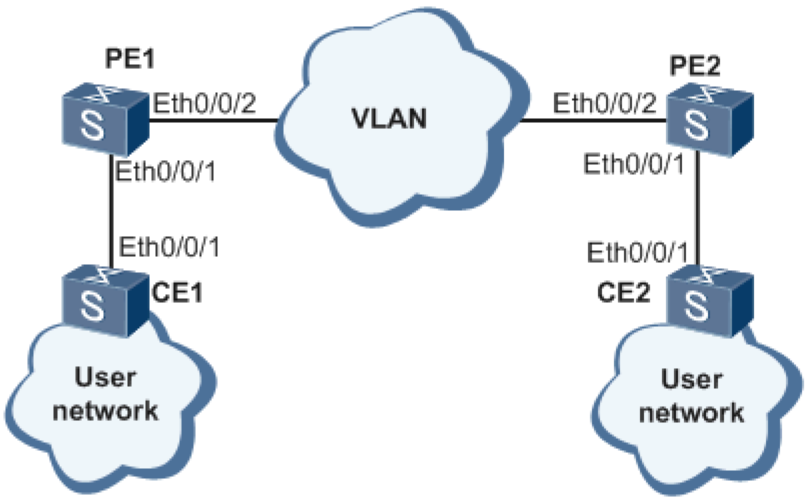

Figure 13. Network Topology

After successfully conducting the one-way frame delay measurement within a VLAN, this study proceeded to the second laboratory stage, namely configuring two-way frame delay measurement in a VLAN. The initial configuration steps in this experiment were fundamentally similar to the previous test, beginning with the establishment of VLAN connections between the Customer Edge (CE) and Provider Edge (PE) devices as the testing domain. Subsequently, the Connectivity Fault Management (CFM) configuration was applied, which included the definition of the Maintenance Domain (MD), Maintenance Association (MA), and Maintenance End Point (MEP). Following this setup, the two-way frame delay measurement was activated using the Y.1731 mechanism to monitor the end-to-end bidirectional performance of the network.

```
[CE1] cfm enable
[CE1] cfm version standard
[CE1] cfm md md3
[CE1-md-md3] ma ma3
[CE1-md-md3-ma-ma3] map vlan 2
[CE1-md-md3-ma-ma3] mep mep-id 3 interface ethernet 0/0/1 outward
[CE1-md-md3-ma-ma3] mep ccm-send mep-id 3 enable
[CE1-md-md3-ma-ma3] remote-mep mep-id 4
[CE1-md-md3-ma-ma3] remote-mep ccm-receive mep-id 4 enable
[CE1-md-md3-ma-ma3] quit
[CE1-md-md3] quit
```

Figure 14. CFM Configuration on CE1

The configuration on CE1 starts by enabling the Connectivity Fault Management (CFM) feature and specifying its version in compliance with the IEEE 802.1ag-2007 standard. A Maintenance Domain (MD) named md3 is then created, within which a Maintenance Association (MA) called ma3 is defined and bound to VLAN 2. Subsequently, a Maintenance End Point (MEP) with ID 3 is configured on the Ethernet 0/0/1 interface in the outward direction. The transmission of Continuity Check Messages (CCM) is activated for this endpoint to support link monitoring. In addition, a remote MEP with ID 4 is declared, and the reception of CCM frames from this remote endpoint is enabled to validate bidirectional connectivity. Once these configurations are completed, the process is finalized by exiting the MA and MD configuration modes, ensuring CE1 is fully prepared to operate as a monitoring endpoint within the Ethernet service domain.

```
[CE2] cfm enable
[CE2] cfm version standard
[CE2] cfm md md3
[CE2-md-md3] ma ma3
[CE2-md-md3-ma-ma3] map vlan 2
[CE2-md-md3-ma-ma3] mep mep-id 4 interface ethernet 0/0/1 outward
[CE2-md-md3-ma-ma3] mep ccm-send mep-id 4 enable
[CE2-md-md3-ma-ma3] remote-mep mep-id 3
[CE2-md-md3-ma-ma3] remote-mep ccm-receive mep-id 3 enable
[CE2-md-md3-ma-ma3] quit
[CE2-md-md3] quit
```

Figure 15. CFM Configuration on CE2

The configuration on CE2 begins by enabling the Connectivity Fault Management (CFM) feature and setting its version in accordance with the IEEE 802.1ag-2007 standard. A Maintenance Domain (MD) named md3 is then established, within which a Maintenance Association (MA) called ma3 is created and bound to VLAN 2. Next, a Maintenance End Point (MEP) with ID 4 is assigned to the Ethernet 0/0/1 interface in the outward direction, followed by the activation of Continuity Check Message (CCM) transmission for this endpoint. In addition, a remote MEP with ID 3 is specified, and the reception of CCM frames from that endpoint is enabled to verify bidirectional connectivity. After completing these steps, the configuration is finalized by exiting both the MA and MD modes, ensuring CE2 is correctly aligned with the monitoring and continuity-checking process.

```
[CE2] cfm md md3
[CE2-md-md3] ma ma3
[CE2-md-md3-ma-ma3] delay-measure two-way receive
[CE2-md-md3-ma-ma3] quit
[CE2-md-md3] quit
```

Figure 16. Two-Way DM Receive Configuration

On the CE2 device, access the Maintenance Domain (md3) and then navigate to the Maintenance Association (ma3). Within this configuration, enable the function that allows the device to receive two-way delay measurement (DMM) frames, which are used to calculate round-trip latency between Maintenance End Points. Once the configuration is applied, exit the MA and MD modes to complete the setup.

```
[CE1] cfm md md3
[CE1-md-md3] ma ma3
[CE1-md-md3-ma-ma3] delay-measure two-way remote-mep mep-id 4 interval 10000 count 20
[CE1-md-md3-ma-ma3] quit
[CE1-md-md3] quit
```

Figure 17. Two-Way DM Remote Configuration

On the CE1 device, access the Maintenance Domain (md3) and then enter the Maintenance Association (ma3). Configure the two-way frame delay measurement to target the remote MEP with ID 4, setting the measurement interval to 10,000 ms with a total of 20 iterations. Once the configuration is complete, exit the MA mode and return to the MD level.

```
<CE1> display y1731 statistic-type twoway-delay md md3 ma ma3
Latest two-way delay statistics:
--------------------------------------------------------------------------------
Index    Delay(usec)    Delay variation(usec)
--------------------------------------------------------------------------------
    1          442                    -
    2          417                   25
    3          435                   18
    4          579                  144
    5          429                  150
    6          428                    1
    7          432                    4
    8          437                    5
    9          439                    2
   10          435                    4
   11          585                  150
   12          443                  142
   13          441                    2
   14          510                   69
   15          456                   54
   16          445                   11
   17          435                   10
   18          435                    0
   19          451                   16
   20          601                  150
--------------------------------------------------------------------------------
Average delay(usec) :       463    Average delay variation(usec) :        50
Maximum delay(usec) :       601    Maximum delay variation(usec) :       150
Minimum delay(usec) :       417    Minimum delay variation(usec) :         0
```

Figure 18. Two-Way Delay Statistical Results

After completing all configuration steps, the command is executed on the CE1 device to retrieve the results of the two-way frame delay measurement. The output provides a tabular summary consisting of the measurement index, the delay values in microseconds, and the corresponding delay variation for each test iteration. In addition, the system displays statistical indicators such as the average, maximum, and minimum values for both delay and delay variation. These metrics facilitate a more comprehensive analysis of transmission quality along the tested path, offering insights into network performance consistency and potential anomalies.

4.2 Discussion

The findings of this study indicate that the implementation of the ITU-T Y.1731 method, based on Ethernet Operations, Administration, and Maintenance (OAM), plays a significant role in improving the quality of Metro Ethernet network management [6][20]. Through a series of stages, including test scenario design, device configuration, and result analysis, it has been demonstrated that Y.1731 can optimize bandwidth allocation by reducing delay variation, controlling jitter, and minimizing frame loss along the transmission path. These capabilities align with the fundamental requirements for carrier-grade service delivery as outlined by the Metro Ethernet Forum and ITU-T standards [19][6]. The use of one-way frame delay measurement provides precise insights into unidirectional transmission latency, allowing delay variations to be detected in detail [20][21]. This measurement approach is particularly valuable for identifying asymmetric delay characteristics that may affect latency-sensitive applications such as VoIP and video streaming. Meanwhile, the two-way frame delay measurement offers a simpler yet effective approach to evaluating the stability of round-trip packet delivery times without requiring clock synchronization between endpoints [18][21]. Empirical results show that both methods maintain stable average delay and jitter values, which remain within the tolerance thresholds defined by Carrier Ethernet standards [19]. The observed average delay of 11,764 μs in one-way measurements, with most iterations showing minimal variation, demonstrates the consistency and reliability of Y.1731-based performance monitoring. Thus, Y.1731 can be considered an accurate tool for ensuring Quality of Service (QoS) in network operations, providing quantifiable metrics that support SLA verification and compliance [17][20].

In addition to serving as a monitoring mechanism, Y.1731 also proves to be strategically important in fine-tuning bandwidth allocation according to service requirements specified in the Service Level Agreement (SLA) [19][21]. Measurement data confirm that bandwidth can be managed more efficiently without disrupting the core operation of the network, as the proactive monitoring capabilities enable early detection of performance degradation trends. This indicates that Y.1731 not only provides real-time monitoring capabilities but also supports network operators in detecting potential service degradation before it significantly affects end users [17][20]. The ability to continuously measure frame delay, delay variation, and frame loss ratio enables operators to implement predictive maintenance strategies and optimize resource allocation dynamically based on actual network performance data [21].

From a practical perspective, the results confirm that Y.1731 can be seamlessly integrated into complex Metro Ethernet topologies, as demonstrated through the successful implementation in the hierarchical three-layer network architecture employed in this study [18][19]. The compatibility of Y.1731 with standard Ethernet infrastructure and its interoperability across multi-vendor environments reinforce its relevance in addressing the growing demand for high-speed data traffic in the digital era [16][17]. Furthermore, this research highlights future opportunities for integration with modern network management technologies such as Software-Defined Networking (SDN) and network telemetry systems [22][26], which would enable more adaptive and automated QoS monitoring and management. Recent advances in alternate marking techniques and in-band network telemetry suggest that Y.1731 measurements could be complemented with more granular, flow-level performance data to support sophisticated traffic engineering and service assurance applications [26][28]].

The comparative analysis with existing literature reveals that the findings of this study are consistent with previous research demonstrating the effectiveness of Y.1731 in carrier-grade environments [5][7][16]. However, this study extends the existing knowledge base by providing detailed configuration procedures and quantitative performance metrics specific to Metro Ethernet deployments using Huawei/Raisecom equipment platforms. The observed performance characteristics align with industry best practices documented by equipment vendors and standards organizations [17][18][20], validating the practical applicability of Y.1731 in real-world operational scenarios. Moreover, the study addresses the research gap identified in the literature regarding comprehensive evaluations of Y.1731's impact on bandwidth optimization, providing empirical evidence that supports its adoption as a standard practice in Metro Ethernet network management.

Despite the promising results, several limitations should be acknowledged. The simulation-based approach, while providing a controlled testing environment, may not fully capture all operational complexities present in production networks, such as diverse traffic patterns, equipment heterogeneity, and external interference factors. Additionally, the study focused primarily on delay and jitter measurements, with limited exploration of frame loss measurement capabilities and their correlation with bandwidth utilization efficiency. Future research should address these limitations by conducting field trials in operational Metro Ethernet networks and expanding the scope to include comprehensive loss measurement analysis, multi-service scenario testing, and long-term performance trend evaluation [29][30]. This study provides empirical evidence of the effectiveness of Y.1731 in optimizing network performance while also confirming its technical feasibility as a reliable solution for maintaining service consistency in carrier-grade networks. The quantitative results demonstrate that Y.1731-based performance monitoring can effectively support bandwidth optimization objectives by providing accurate, real-time visibility into critical QoS parameters. These findings also emphasize the potential of Y.1731 as a foundation for future research on expanding OAM implementation to larger-scale network infrastructures, including 5G transport networks and cloud-interconnect services [24][29]. The integration of Y.1731 with emerging technologies such as machine learning-based anomaly detection and automated service assurance frameworks represents a promising direction for enhancing the intelligence and responsiveness of Metro Ethernet network management systems.

5. Conclusion and Future Research

This study successfully demonstrates that the implementation of ITU-T Y.1731 protocol significantly enhances bandwidth optimization and performance monitoring capabilities in Metro Ethernet networks. Through systematic evaluation using both one-way and two-way frame delay measurement methods in a simulated Metro Ethernet topology, the research provides empirical evidence that Y.1731 effectively maintains stable QoS parameters within carrier-grade service thresholds. The key findings reveal that Y.1731-based performance monitoring enables precise measurement of critical network parameters including delay, jitter, and frame loss ratio, with observed average delay values of 11,764 μs demonstrating consistent network performance. Both measurement approaches—one-way for detailed asymmetric delay analysis and two-way for simplified round-trip monitoring—prove effective in supporting SLA compliance verification and proactive network management. The successful integration of Y.1731 into the hierarchical Metro Ethernet architecture confirms its technical feasibility and practical applicability in carrier-grade environments.

The contributions of this research include: (1) a practical implementation framework for Y.1731 deployment in Metro Ethernet networks using Huawei/Raisecom equipment platforms; (2) quantitative performance analysis demonstrating the effectiveness of Y.1731 in maintaining QoS consistency; and (3) a validated bandwidth optimization model that network operators can adopt to enhance service quality and ensure SLA compliance. These findings address the identified research gap regarding comprehensive evaluations of Y.1731's impact on Metro Ethernet bandwidth management. Future research directions should focus on field trials in operational networks to validate simulation findings under real-world conditions, expanded analysis of frame loss measurement capabilities, and integration with emerging technologies such as SDN and machine learning-based network management systems. The potential for Y.1731 to support next-generation network infrastructures, including 5G transport and cloud-interconnect services, represents a promising avenue for advancing carrier-grade service assurance capabilities.

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