Journal of Artificial Intelligence and Engineering Applications

Website: https://ioinformatic.org/

June 2026. Vol. 5. No. 3; e-ISSN: 2808-4519

Failure Analysis of Switching Scheme Failures in Loop Protect Multiplexer Telecommunication Networks at PT. PLN (Persero) UP2B DKI Jakarta & Banten

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Abstract

PT. PLN (Persero), through UIP2B JAMALI, relies on a loop-topology Loop Protect Multiplexer as its telecommunications backbone to support real-time SCADA, VoIP, and protection services. However, from 2022 to 2024, 36 switching failure incidents occurred in UP2B DKI Jakarta–Banten. This study analyzes the root causes, operational impacts, and recommendations for continuous system reliability improvement. The research employs a case study method and the PPDIOO approach to examine switching failures of the Loop Protect Multiplexer in UP2B DKI Jakarta Banten. Data were collected through observations of fault history (2022–2024) and interviews. BER testing and QoS parameters refer to the ITU-T Y.1564 standard to formulate recommendations for improving the reliability of the 150 kV backbone network. Testing results indicate that under normal conditions, the system meets SLA requirements in accordance with ITU-T Y.1564, with stable throughput and zero frame loss. However, when one link fails, frame loss occurs during switching despite stable throughput, resulting in SLA failure. The root cause lies in a reactive and non-seamless switching mechanism, creating cross-layer impacts on critical services within PT. PLN (Persero).

***Keywords**: Loop Protect Multiplexer; Switching Failure; ITU-T Y.1564; Redundancy Mechanism; PT. PLN (Persero).*

1. Introduction

PT. PLN (Persero), as a company with sensitive assets, where asset management contributes significantly to its business success, needs to implement asset management properly and in accordance with asset management standards. Specifically, the Java, Madura, and Bali Load Regulatory Center Main Unit (UIP2B JAMALI) is responsible for implementing load distribution, planning, and evaluating the operation of systems involving substations, extra-high-voltage substations, and power plants in the Java, Madura, and Bali regions. The operation of substations and extra-high-voltage substations requires a structured telecommunications system.[1] This aims to ensure the stability and reliability of the electricity distribution system, while minimizing the risk of disruptions that could impact the reliability of the electricity system in the Java, Madura, and Bali regions.

To meet these needs, the Java, Madura, and Bali Load Regulatory Center Main Unit has a distributed telecommunications network utilizing multiplexers as a telecommunications backbone. This device plays a crucial role in combining various communication signals such as SCADA, voice/VoIP UC, and protection into a single fiber optic transmission line. With the use of a Multiplexer, information transmission can be carried out in real time and reliably, ultimately supporting the system's response speed under normal operating conditions and during disruptions[2][3]. This Multiplexer implementation is designed in a loop topology that enables a redundancy protection mechanism, where the system is designed to provide a backup path in the event of a disruption to the main path. This topology selection also takes into account the efficient use of existing physical fiber optic transmission media and the geographic conditions of the substation[4][5]. With its circular shape, the loop topology allows for more flexible and optimal connectivity for regional infrastructure deployment. Therefore, this configuration is known as the Loop Protect Multiplexer and is applied to the electricity system of PT. PLN (Persero).

Based on operational data from PT. PLN (Persero)'s Jakarta & Banten Load Regulator Implementation Unit, switching scheme failures frequently occur. Between 2022 and 2024, disruptions occurred 36 times, impacting equipment/services integrated into the Loop Protect Multiplexer network, as shown in the following graph:

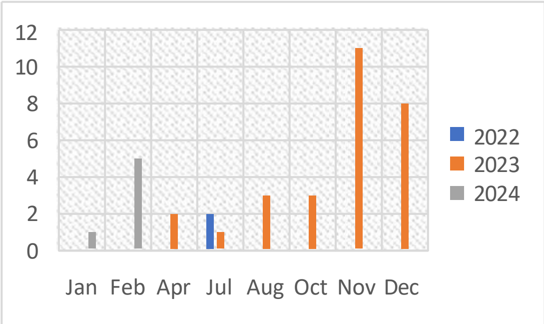


Fig 1: Disruption Trend Chart 2022 – 2024

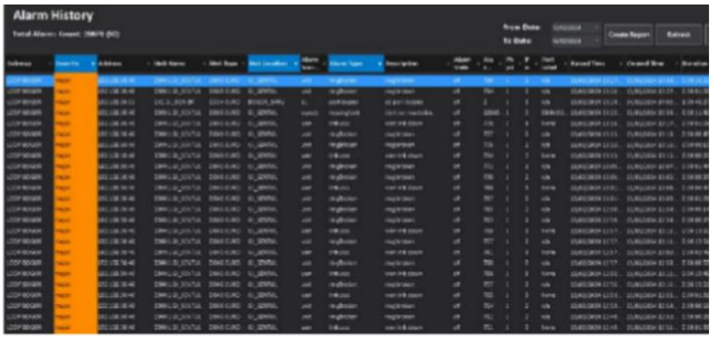


Fig 2: Switching Failure Trouble Logger

Based on the disruption history described previously, there are indications of problems with the switching mechanism in the Loop Protect Multiplexer system that have the potential to disrupt the continuity of backbone communication services. This condition underlies the need for a comprehensive analysis of the causes of disruptions, as stated in the title of this study: "Analysis of Switching Scheme Failures in the Loop Protect Multiplexer Telecommunication Network at PT. PLN (Persero) UP2B DKI Jakarta and Banten." Conceptually, the loop topology is designed to provide path redundancy and maintain communication continuity when a disruption occurs on one of the links. However, in the operational practice of the 150 kV electricity system, switching scheme failures are still found, indicating a gap between the theoretical design and actual performance in the field. To date, there has been no study that specifically and structuredly analyzes the causes of switching failures, their impact on the operational stability of the electric power system, and the formulation of corrective measures based on technical evaluations in the operational environment of PT. PLN (Persero) UP2B DKI Jakarta and Banten.
Therefore, this research is present to fill this gap through analysis based on historical disturbance data and technical testing, in order to identify the root cause of the problem, evaluate its implications for the electricity system, and formulate recommendations for improving the reliability of the switching mechanism in the Loop Protect Multiplexer in a sustainable manner.

2. Research Methods

This research uses a descriptive-analytical approach with a case study method on the Loop Protect Multiplexer system in the operational environment of PT. PLN (Persero) UP2B DKI Jakarta and Banten. The research method focuses on analyzing switching scheme failure disturbances through collecting primary data obtained directly in the field. Data collection techniques are carried out through two main approaches, namely observation and interviews. Observations are carried out by collecting and recording historical data on switching scheme failure disturbances on the AVARA Multiplexer during the period 2022 to 2024, with a focus on the loop segments that most frequently experience disturbances in the working areas of UP2B DKI Jakarta and Banten. The data obtained include the frequency of disturbances, the duration of disturbances, network conditions when disturbances occur, and the system response to the switching mechanism. In addition to observation, this study also uses the interview method as a supporting technique to gain a deeper understanding of the operational conditions of the system, which is carried out directly with the Telecommunications Sub-Division Staff of PT. PLN (Persero) UIP2B JAMALI on June 5, 2025 to identify the advantages and disadvantages of the Loop Protect Multiplexer system that has been implemented and to obtain information related to the disturbance handling procedures and technical evaluations that have been carried out.

2.1. Network System Analysis Methods

This research uses the PPDIOO approach, which consists of six stages of the network development cycle, applied systematically. The PPDIOO approach involves preparation, planning, design, implementation, operation, and optimization, enabling optimal network service maintenance[6].
In this case study, the Loop Protect Multiplexer switching failure occurred. This stage facilitates root cause identification, Bit Error Rate testing, and the formulation of technical solutions to improve backbone communication reliability in the 150 kV system at the Jakarta and Banten UP2B. This stage includes the following steps:

2.1.1 Prepare, tahap ini dilakukan identifikasi awal terhadap terhadap gangguan komunikasi pada sistem *Loop Protect Multiplexer* dan identifikasi kebutuhan uji sistem *Loop Protect* berdasarkan histori gangguan

2.1.2 Plan: This stage determines the scope of the evaluation, specifically on one of the Loop Protect Multiplexers that has experienced disruptions in the work area of PT PLN (Persero) UP2B DKI Jakarta and Banten.

Fig 3: PPDIOO Life Cycle

2.1.3 Design: This stage is carried out to develop a data collection scheme and test device performance. The test design used is the Bit Error Rate Test (BER-Test) to assess the reliability of the communication path and the device's ability to withstand disruptions[7].

2.1.4 Implement: This stage includes field observations and direct testing using the Bit Error Rate Test (BER-Test) on the observed network loop.

2.1.5 Operate: This stage analyzes the collected data to evaluate the actual operational performance of the Loop Protect Multiplexer. Observations are also made of the system's response to disruptions and the restoration of the communication path between the GI and the Control Center.

2.1.6 Optimize: This stage, based on the results of the data analysis, identifies system weaknesses and potential operational risks. This stage produces technical recommendations for improving reliability. communication systems, such as adjusting protection configurations, improving the quality of transmission media, or evaluating replacement devices.

2.2 Testing Parameters

To evaluate the performance of the Loop Protect Multiplexer communication system, several technical parameters were used, referring to international standards. These parameters were chosen because they represent fundamental aspects in measuring network quality of service (QoS) and communication system reliability in the electricity system.

Table 1: Parameter Uji

Parameter	Definisi Teknis	Threshold Umum	Referensi Standar
Throughput	Laju data maksimum yang berhasil diterima (RX) tanpa terjadi kehilangan frame. Diukur dalam Mbps.	≥ 95% dari CIR (Committed Information Rate)	ITU-T Y.1564 (Service Activation) RFC 2544
Frame Loss Rate / Count	Jumlah/persentase frame yang hilang selama transmisi (tidak sampai tujuan).	≤ 0.1% (Carrier-grade), idealnya 0%	ITU-T Y.1564 Clause 8. MEF 10.3.1 Clause 5.6
Jitter (Delay Variation)	Variasi delay antar frame yang berurutan saat diterima. Disebut juga Frame Delay Variation (FDV).	< 10 ms (untuk data), < 1 ms (untuk SCADA/VoIP)	MEF 10.3.1 Clause 5.5 ◆ ITU-T Y.1541
Out-of Sequence Rate / Count	Jumlah atau persentase frame yang diterima tidak dalam urutan pengiriman.	≤ 0.002% (carrier-class)	ITU-T Y.1564 Clause 8.4 RFC 2889

1) ITU-T Y.1564 – Service Activation Test, used for end-to-end testing of throughput, delay, frame loss, and jitter[8].
2) RFC 2544 – Used for benchmarking multiplexer and switch network devices.
3) MEF 10.3.1 – Metro Ethernet Forum standard for performance testing of Carrier Ethernet services.
4) ITU-T Y.1541 – Provides maximum delay and jitter limits for real-time networks such as SCADA and VoIP.

These parameters represent the minimum quality of service that must be met by communication systems that serve the protection, control, and monitoring processes in the electricity system.

3. Results and Discussion

3.1. Normal Operation Test Scheme

This scheme represents the normal operating conditions of the network, where all paths in the loop topology are active and free from physical disruption. Under these conditions, no protective switching occurs because traffic flows through the main path according to the network design, as detailed below.

Table 2: Resume Schema 1

Parameter	Treshold (Standar)	Hasil	Status
Throughput	≥ 95% dari CIR	49,999 Mbps	PASS
Frame Loss	0% (Carrier-grade)	0.0E-00	PASS
Jitter	< 1 ms	0,233 ms	PASS
Latency	< 10 ms	0,989 ms	PASS
Out-of-Sequence	≤ 0.002%	0	PASS
Verdict Y.1564	Parameter memenuhi SLA	PASS	PASS

Kondisi normal operasi menunjukkan performa jaringan yang sangat stabil, tidak ditemukan alarm maupun *error* pada layer fisik maupun layer *Ethernet*, seperti *Loss of Signal (LOS), Link Down,* atau *error frame*

SUMMARY

Results Summary

Test Status	
Service Configuration Test Status	Completed, Pass
Service Performance Test Status	Completed, Pass
Pass/Fail Verdict	PASS
Start Time	12/17/2025 02:16:54 PM
Duration	00d:00:10:39
Test Recovery	0

EtherSAM

Services Summary

	Service Name	Service Configuration Test	Service Performance Test
1	Service 1	PASS	PASS

Service Configuration Summary

	Service Name	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Max Throughput (Mbit/s)	Service Verdict
1	Service 1	0.0E-00	0.25033	0.98111	49.999	PASS

Service Performance Summary

	Service Name	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Avg Throughput (Mbit/s)	Service Verdict
1	Service 1	0.0E-00	0.2336C	0.98892	49.999	PASS

Fig 4: Shows PASS test results

Alarms/Errors

Alarms/Errors List	
Active/Historical Alarms/Errors	None

Fig 5: Alarm & Errors Display

Detailed EtherSAM Results

Service Configuration Test

Service 1 : Service 1

Committed Steps

Committed Step	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Verdict	Avg Throughput (Mbit/s)
1-50%CIR	0.0E-00	0.24950	0.97058	PASS	24.999
2-75%CIR	0.0E-00	0.25021	0.97663	PASS	37.500
3-90%CIR	0.0E-00	0.25033	0.97814	PASS	44.997
CIR	0.0E-00	0.23380	0.98111	PASS	49.999

Service Performance Test

Service 1 : Service 1

	Average	Minimum	Maximum	Estimate
Throughput (Mbit/s)	49.999	49.985	50.008	N/A
Jitter (ms)	0.09252	< 0.00001	0.23380	0.09473
Latency (ms)	0.83640	0.72785	0.98892	N/A
	Seconds	**Count**	**Rate**	
Frame Loss	0	0	0.0E00	
Out-of-Sequence	0	0	0.0E00	

Fig 6: Test Result

LOGGER

ID	Start Time	Event	Duration	Details
1	12/17 02:16:54 PM	Test Started		2025-12-17
2	12/17 02:16:58 PM	Service Configuration test started		2025-12-17
3	12/17 02:17:32 PM	Service Performance test started		2025-12-17
4	12/17 02:27:33 PM	Test Stopped		PASS

Fig 7: Test Logger

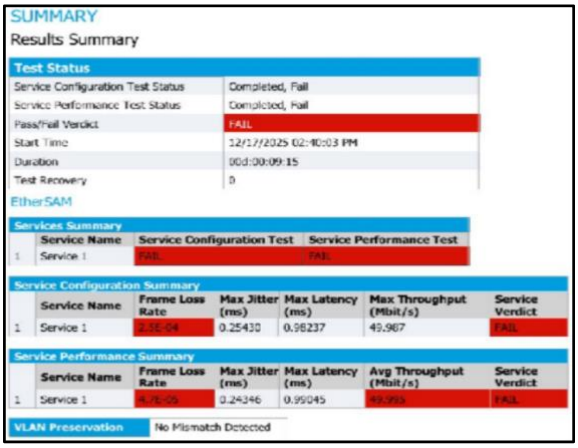
The test results show that the Loop Protect Multiplexer is able to meet all Service Level Agreement (SLA) parameters when the network is operating under ideal conditions, with jitter and latency values at very low levels (<1 ms) thus indicating that the network is feasible and reliable to support critical services. Based on these findings, it can be concluded that the network architecture and Multiplexer configuration are appropriate and functioning well; therefore, the disturbances that occur in the field are not caused by normal network operating conditions, but are triggered by abnormal conditions related to failures in the transmission path, especially when the switching process is not completely seamless according to the ITU-T Y.1564 standard[8].

3.2 Single-Lane Break Condition Test Scheme

This diagram illustrates a single outage scenario, where one path in a loop topology is interrupted, while the other path continues to function as a redundant path. In such a situation, an automatic switching mechanism is expected to effectively redirect traffic to maintain service continuity and prevent significant disruption to network performance.

Table 3: Resume Skema 2

Parameter	Treshold (Standar)	Hasil	Status
Throughput	≥ 95% dari CIR 0%	49,995 Mbps	PASS
Frame Loss	(Carrier-grade)	4,7E-05	FAIL
Jitter Latency	< 1 ms	0,243 ms	PASS
Out-of-	< 10 ms	0,990 ms	PASS
Sequence Verdict Y.1564	≤ 0.002%	0	PASS FAIL
	Parameter memenuhi SLA	FAIL	



SUMMARY

Results Summary

Test Status	
Service Configuration Test Status	Completed, Fail
Service Performance Test Status	Completed, Fail
Pass/Fail Verdict	FAIL
Start Time	12/17/2025 02:40:03 PM
Duration	00d:00:09:15
Test Recovery	0

EtherSAM

Services Summary

	Service Name	Service Configuration Test	Service Performance Test
1	Service 1	FAIL	FAIL

Service Configuration Summary

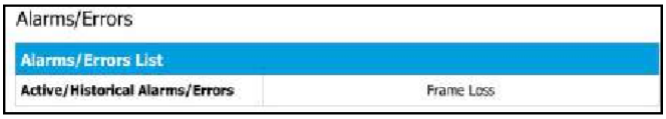
	Service Name	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Max Throughput (Mbit/s)	Service Verdict
1	Service 1	2.5E-04	0.25430	0.98237	49.987	FAIL

Service Performance Summary

	Service Name	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Avg Throughput (Mbit/s)	Service Verdict
1	Service 1	4.7E-05	0.24346	0.99045	49.995	FAIL

VLAN Preservation	No Mismatch Detected

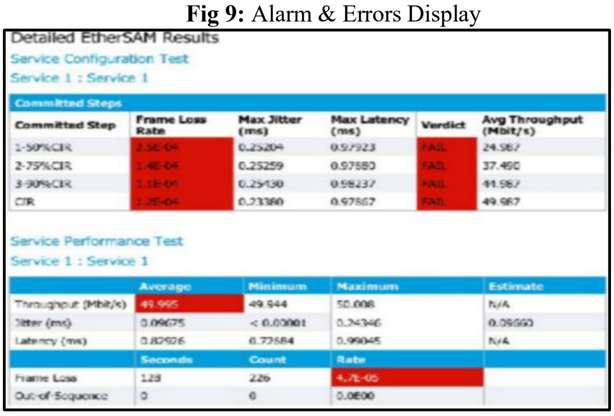
Fig 8: Shows FAIL test result



Alarms/Errors

Alarms/Errors List	
Active/Historical Alarms/Errors	Frame Loss

Fig 9: Alarm & Errors Display



Detailed EtherSAM Results

Service Configuration Test

Service 1 : Service 1

Committed Steps

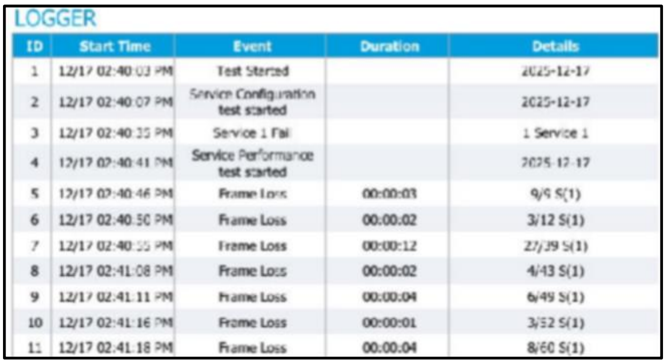
Committed Step	Frame Loss Rate	Max Jitter (ms)	Max Latency (ms)	Verdict	Avg Throughput (Mbit/s)
1-50%CIR	2.5E-04	0.25204	0.97923	FAIL	24.987
2-75%CIR	1.4E-04	0.25259	0.97880	FAIL	37.490
3-90%CIR	[illegible]	0.25430	0.98237	FAIL	44.987
CIR	1.2E-04	0.23380	0.97867	FAIL	49.987

Service Performance Test

Service 1 : Service 1

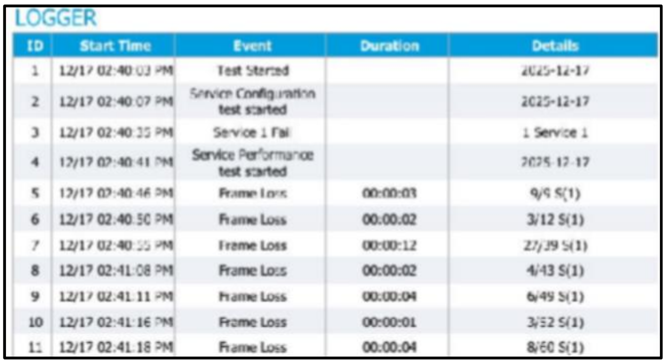
	Average	Minimum	Maximum	Estimate
Throughput (Mbit/s)	49.995	49.944	50.008	N/A
Jitter (ms)	0.09675	< 0.00001	0.24346	0.09660
Latency (ms)	0.82926	0.72684	0.99045	N/A
	Seconds	**Count**	**Rate**	
Frame Loss	128	226	4.7E-05	
Out-of-Sequence	0	0	0.0E00	

Fig 10: Test Result



LOGGER

ID	Start Time	Event	Duration	Details
1	12/17 02:40:03 PM	Test Started		2025-12-17
2	12/17 02:40:07 PM	Service Configuration test started		2025-12-17
3	12/17 02:40:35 PM	Service 1 Fail		1 Service 1
4	12/17 02:40:41 PM	Service Performance test started		2025-12-17
5	12/17 02:40:46 PM	Frame Loss	00:00:03	9/9 S(1)
6	12/17 02:40:50 PM	Frame Loss	00:00:02	3/12 S(1)
7	12/17 02:40:55 PM	Frame Loss	00:00:12	27/39 S(1)
8	12/17 02:41:08 PM	Frame Loss	00:00:02	4/43 S(1)
9	12/17 02:41:11 PM	Frame Loss	00:00:04	6/49 S(1)
10	12/17 02:41:16 PM	Frame Loss	00:00:01	3/52 S(1)
11	12/17 02:41:18 PM	Frame Loss	00:00:04	8/60 S(1)



LOGGER

ID	Start Time	Event	Duration	Details
1	12/17 02:40:03 PM	Test Started		2025-12-17
2	12/17 02:40:07 PM	Service Configuration test started		2025-12-17
3	12/17 02:40:35 PM	Service 1 Fail		1 Service 1
4	12/17 02:40:41 PM	Service Performance test started		2025-12-17
5	12/17 02:40:46 PM	Frame Loss	00:00:03	9/9 S(1)
6	12/17 02:40:50 PM	Frame Loss	00:00:02	3/12 S(1)
7	12/17 02:40:55 PM	Frame Loss	00:00:12	27/39 S(1)
8	12/17 02:41:08 PM	Frame Loss	00:00:02	4/43 S(1)
9	12/17 02:41:11 PM	Frame Loss	00:00:04	6/49 S(1)
10	12/17 02:41:16 PM	Frame Loss	00:00:01	3/52 S(1)
11	12/17 02:41:18 PM	Frame Loss	00:00:04	8/60 S(1)

Fig 11: Test *Logger*

Although the throughput value is still relatively stable and close to the Committed Information Rate (CIR), the system is still categorized as a failure due to consistent frame loss during the switching process that does not meet the Service Level Agreement (SLA) requirements based on the ITU-T Y.1564 standard, where the frame loss value is required to be zero. This condition indicates that the switching mechanism in the Loop Protect Multiplexer is not yet completely seamless, because even though the network has redundant paths, the traffic switching process still causes temporary packet loss which is technically sufficient to cause service failure when evaluated based on carrier-grade standards.

3.3 Root Cause Analysis Root Cause Analysis

Based on the test results for both schemes, it appears that the Loop Protect Multiplexer network performance exhibits significant differences in characteristics between normal and fault conditions. Under normal conditions, all service quality parameters meet established standards, indicating that network capacity, transmission media quality, and basic device configuration are optimal. However, in the event of a single-path outage, performance degradation occurs, directly impacting service continuity, although not always accompanied by a significant decrease in throughput. To clarify the differences in performance characteristics under each condition, the test results are summarized in the following table:

Table 4: Comparison of test results

Parameter Utama	Normal	Putus 1 Jalur
Throughput	Stabil ≈ CIR	Stabil ≈ CIR
Frame Loss Rate	0	≠ 0 (saat switching)
Jitter	Rendah	Rendah
Latency	Rendah	Rendah
Out-of-Sequence	Tidak ada	Tidak ada
Status SLA Y.1564	PASS	Gagal
Kontinuitas Layanan	Terjaga	Terganggu sesaat
Throughput	Stabil ≈ CIR	Stabil ≈ CIR

Test findings show that in a single-path outage scheme, the average throughput value remains close to the Committed Information Rate (CIR). This indicates that bandwidth and transmission media are physically available. However, the service is still deemed a failure based on the ITU-T Y.1564 standard due to detected frame loss and, in some cases, out-of-sequence frames.

This confirms that in Service Performance Test-based service evaluations, throughput cannot be the sole indicator of service success. Although the network still has backup paths, the switching process is not seamless. During the disruption detection and path switching phase, transient frame loss occurs, resulting in failure to meet SLAs, even though jitter and latency remain within acceptable limits. [7]

Figure 4.9 of the RCPS shows a root cause analysis of service failures during a disruption to a single network in a loop topology. The causes of the disruption are grouped into five main factors: configuration errors, failure to detect disruptions, physical problems with the backup path, SDH device failures, and limitations of traditional switching technology. Configuration and disruption detection factors can cause the failover process to fail optimally, while physical and device problems can potentially exacerbate service degradation. However, based on performance testing results, the most dominant root cause of the problem lies in the reactive switching mechanism, which still results in frame loss during path transitions. This indicates that the existing redundancy system is not yet completely seamless in maintaining service continuity.[9]

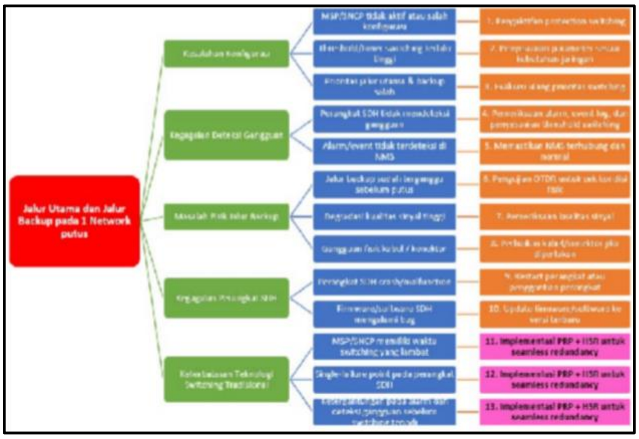


Fig 12: RCPS

3.4 Service Implications

Failure of the switching mechanism in the Loop Protect Multiplexer has implications for all services running on it. The backbone network, in this context, serves as a critical transport layer, connecting the substation nodes, the Control Center, and the monitoring system end-to-end. Therefore, performance degradation in the transport layer not only impacts a single application but also the entire integrated service ecosystem. Conceptually, a switching failure in the Loop Protect Multiplexer backbone has multi-layered implications:

3.3.1. Physical Layer → Frame loss & switching delay
3.3.2. Transport Layer → IP connectivity instability
3.3.3. Application Layer → Disruption of NMS, VoIP, and SCADA communications

These findings indicate that the reliability of integrated services is not solely determined by the quality of the application or endpoint, but is highly dependent on the characteristics of the redundancy mechanisms in the transport layer. Thus, in mission-critical power systems, reactive switching mechanisms that result in even the slightest frame loss can have a disproportionate impact on the continuity of operational services.

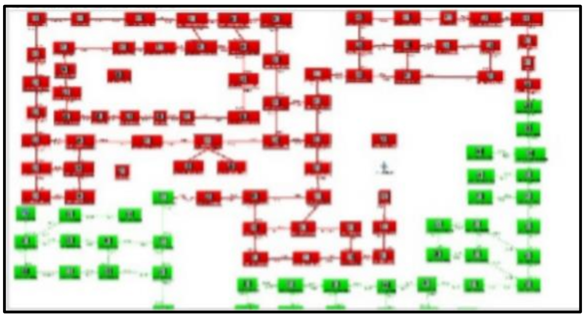


Fig 13: Monitoring HSR

Fig 14: Monitoring Spectrum SCADA

Fig 15: Monitoring VoIP UC

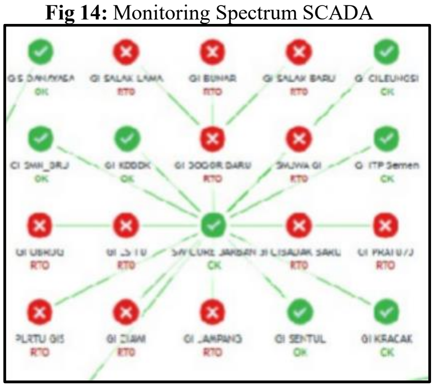


Fig 16: Monitoring WAN-TI

Conceptually, this condition indicates a cross-layer dependency, where failures in the transport layer can escalate into disruptions in the application layer, impacting the operation of the electric power system. Therefore, in the context of critical infrastructure such as that managed by PT. PLN (Persero), redundancy mechanisms are not sufficient to only guarantee the availability of alternative paths, but must also be able to ensure transmission continuity without frame loss during the transition process. This implication emphasizes that improving system reliability requires not only optimizing device configurations, but also implementing a more seamless and parallel redundancy approach to support the real-time communication needs of modern electric power systems.

4. Conclusion

Based on the test results on two operational schemes, it can be concluded that the Loop Protect Multiplexer performance is in optimal condition when the network is operating normally, where all Service Level Agreement (SLA) parameters based on the ITU-T Y.1564 standard are met with stable throughput values approaching CIR, 0% frame loss, and very low jitter and latency. This indicates that the network architecture and device configuration have been well designed and are capable of supporting critical services. However, in the single-path disconnection scheme, although the throughput remains stable and bandwidth capacity is still available, the system is declared to fail due to frame loss during the switching process, thus failing to meet the carrier-grade standard that requires zero frame loss. This finding confirms that the applied redundancy mechanism is still reactive and not completely seamless, resulting in transient disruptions during path transitions. Conceptually, this failure indicates a cross-layer impact, where disruptions in the transport layer can escalate to the application layer and affect critical services such as SCADA, NMS, and operational communications in the electricity infrastructure managed by PT. PLN (Persero). Therefore, improving system reliability requires not only configuration optimization, but also the implementation of more parallel and truly seamless redundancy mechanisms to ensure real-time service continuity without losing frames during the switching process.

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