Multipath Interference in High-Speed PAM4 Transmission

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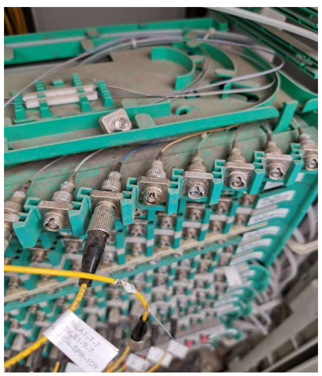
MPI challenges in access networks

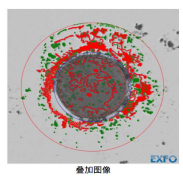
- PAM4 Ethernet modules have widely been deployed in access layer of SPN/MTN **since 2019**, especially **50GBASE-LR/ER**.
- Many link failure cases have been reported that **high packet loss ratio happened with normal link budgets and sufficient received power at Rx sides**.
- Connectors in outdoor cross connecting cabinets are **easily been affected by external environment, which is inevitable**.

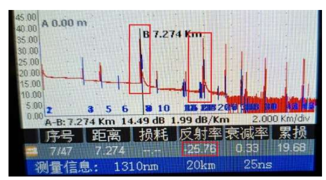


Environment factors:

- dust
- sand
- Moisture
- …

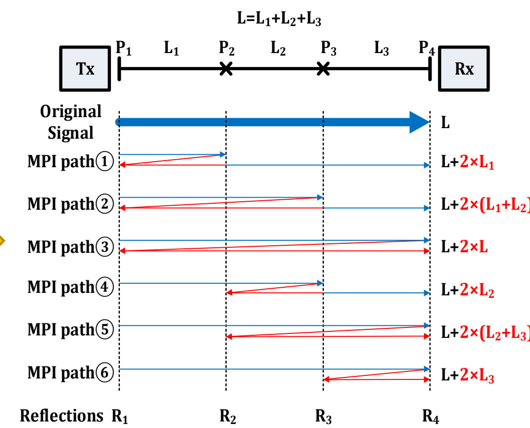
Dirty fiber end face





OTDR measurement in deployed 50GBASE-LR Link

Reflections of some connectors>**-20dB**

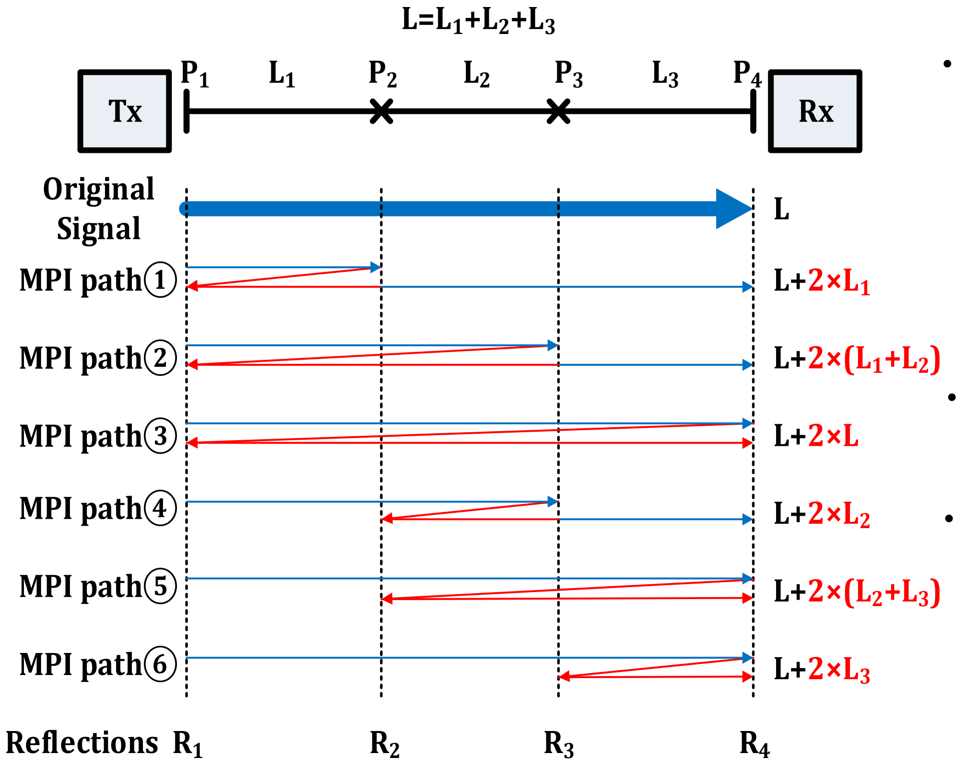


Multiple-path Interference

Could not be compensated by **simply increase launch power**

Multipath Interference

- Multiple reflections from fiber connectors, transmitter and receiver interfaces create multipath interference (MPI) in fiber optic links.
- MPI converts phase noise to **relative intensity noise (RIN)** and imposed a severe limit on high-speed PAMn transmission with direct detection.



- For a system with two connectors (including connections between link and modules), typically the length between two connectors is far longer than the coherent length of DML/EML, MPI induced RIN:

$$RIN(f)=\frac{4R^2}{\pi}\left[\frac{\Delta v}{f^2+\Delta v^2}\right]=\frac{4\alpha^2 R_1 R_2}{\pi}\left[\frac{\Delta v}{f^2+\Delta v^2}\right]$$

- Δv is the 3-dB bandwidth of EML/DML, $R_1$and R_2 are return loss of connectors, α is fiber attenuation.
- For a system with multiple connectors, MPI induced RIN:

$$RIN(f)=\frac{4}{\pi}\left[\frac{\Delta v}{f^2+\Delta v^2}\right]\sum_{i=2}^{N}\sum_{j=1}^{i-1}R_{ij}^2$$

$$=\frac{4}{\pi}\left[\frac{\Delta v}{f^2+\Delta v^2}\right]\sum_{i=2}^{N}\sum_{j=1}^{i-1}\alpha_{ij}^2 R_i R_j$$

$$ERI=\sum_{i=2}^{N}\sum_{j=1}^{i-1}\alpha_{ij}^2 R_i R_j$$

Effective reflectance index (ERI)

MPI Issue

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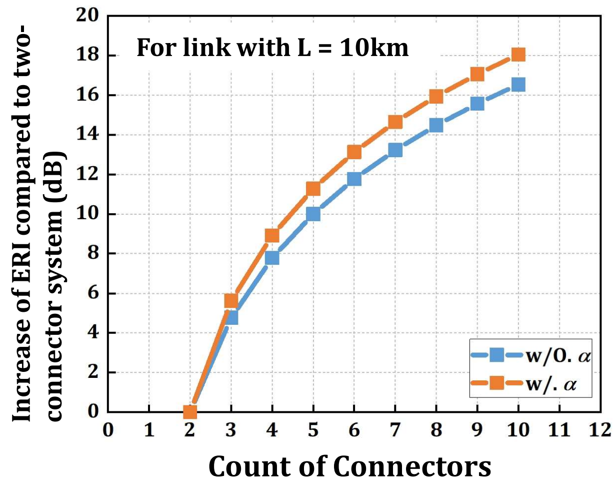

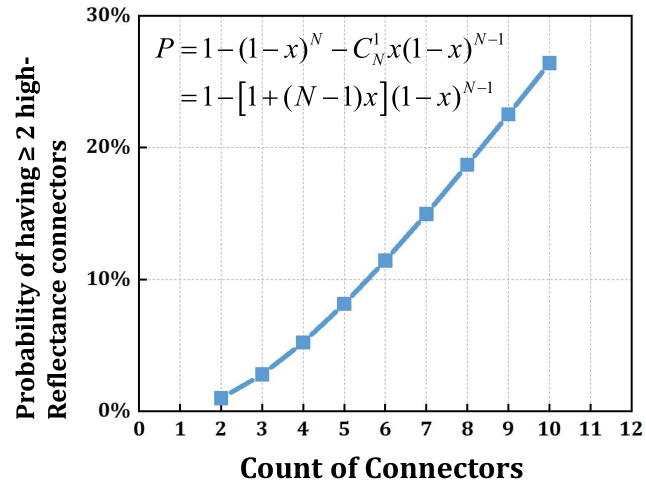

- There are one connector every 1~2km, and **5~10 connectors** in most links. FC/UPC, LC/UPC or SC/UPC connectors are all used in the networks. **The more connectors, the higher risks.**
- The return loss of fiber connectors, according to frequently used GR-326-CORE, is ≤ **-40 dB**. MPI has limited effect if these specifications are met.
- In real deployment, the return loss of fiber connectors degrades over time -> MPI

OTDR Trace Example

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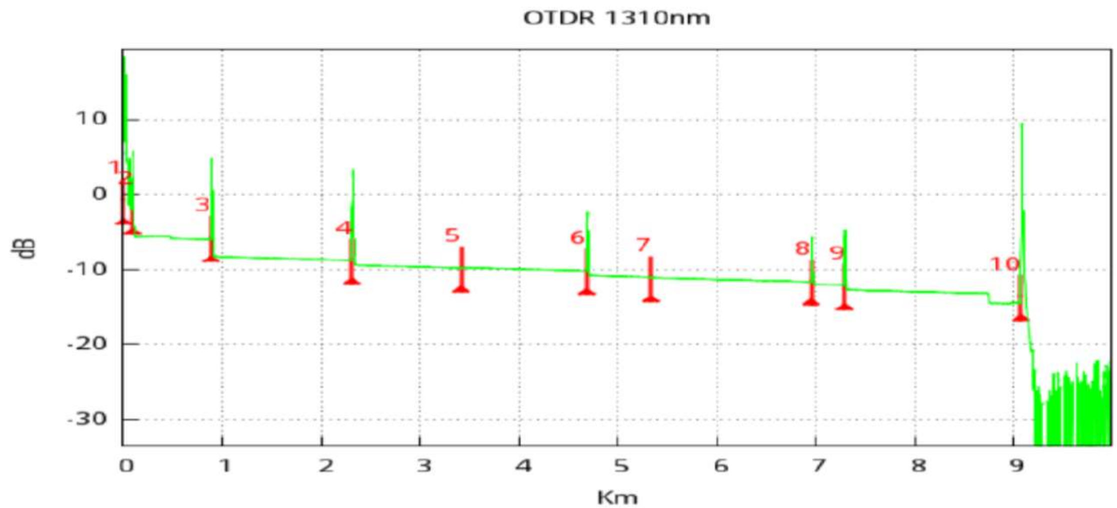

Event		Distance	Loss	Reflection	Slope	Section	Total loss
		Km	dB	dB	dB/km	Km	dB
1		0.000	0.007	-22.64		0.000	0.000
2		0.090	3.573	-44.05		0.090	5.572
3		0.883	2.230	-37.57	0.619	0.793	8.293
4		2.310	0.666	-35.23	0.340	1.427	9.444
5		3.412	-0.066		0.327	1.102	9.738
6		4.682	0.682	-43.80	0.336	1.270	10.846
7		5.334	0.069		0.346	0.652	11.142
8		6.952	0.342	-47.81	0.325	1.618	12.010
9		7.291	0.278	-44.77	0.300	0.339	12.390
10		9.076		-11.45	0.978	1.785	14.136

A link failure example measured in a deployed network in Beijing:

- Link length: 13.98km
- With packet continuously lost after FEC
- Pre-FEC BER = 2.264E-5
- Cal. ERI = -33.15dB

Statistics of Fiber Connectors in a Deployed Network

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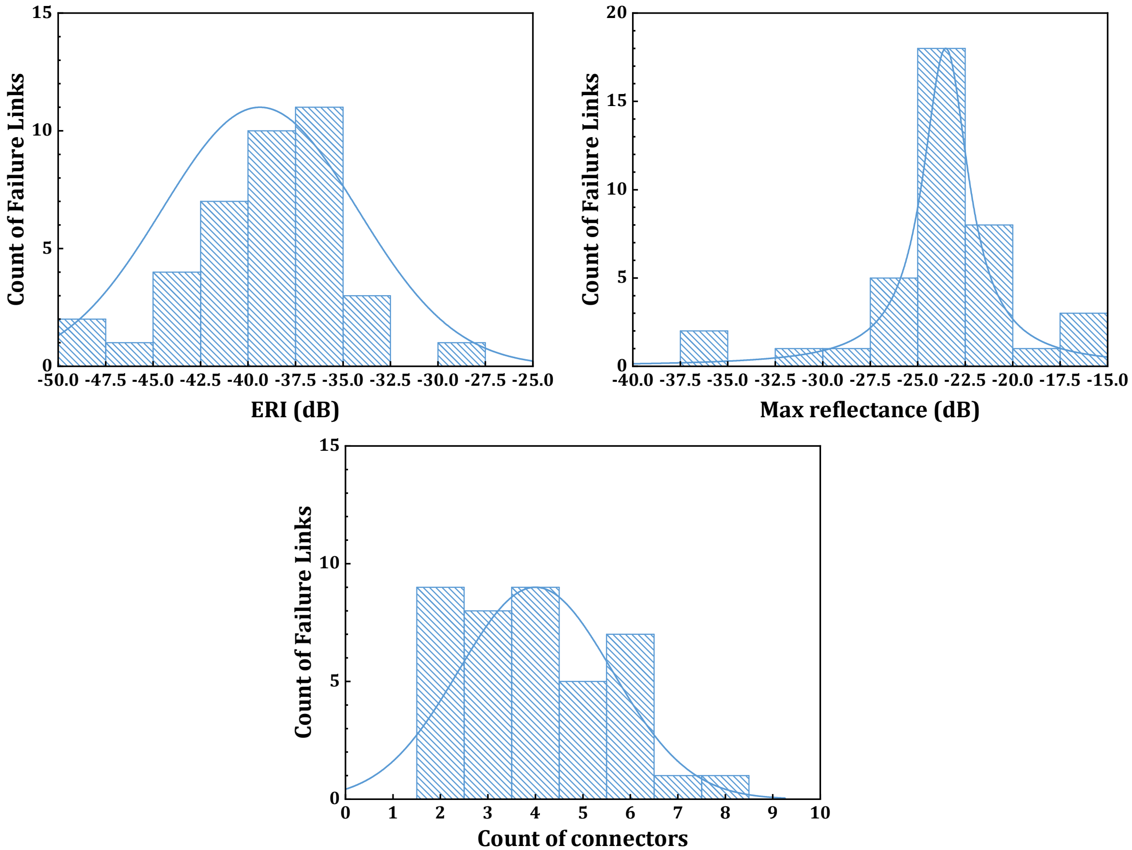
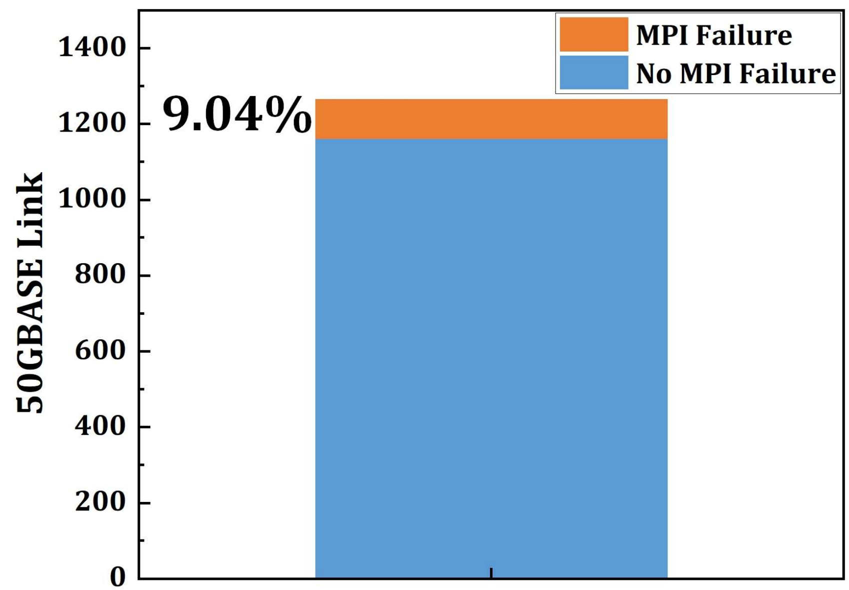


- Statistics of 40 failure links in a deployed network



9.04% links experienced MPI failure among thousands of 5G midhaul/backhauls using 50GBASE deployed in Province S, China.

Conclusions

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- MPI is a major issue for PAMn modules, especially when these modules are used in access networks with multiple connectors, rather than splicing points.
- Expecting suppress MPI by frequently cleaning connectors is not realistic for network operators when millions of them are deployed.
- Methods that can suppress MPI impact in non-ideal link conditions are preferred.

Thanks