Multipath interference penalties for P802.3dj

John Johnson, Broadcom

Supporters

- Mike Dudek, Marvell
- Roberto Rodes, Coherent
- Vipul Bhatt, Coherent
- Matt Traverso, Marvell
- Ali Ghiasi, Ghiasi Quantum
- Hai-Feng Liu, HG Genuine
- Mark Kimber, Semtech
- Peter Stassar, Huawei
- Chris Cole, Coherent

Multipath interference (MPI) penalty

- Comments against P802.3dj D1.2 and D1.3 called into question the validity of assumptions behind the MPI penalty allocations and how to treat them in the power budgets. (See ghiasi_3dj_02_2501)
- MPI is a random process – there is no single "right" answer. The probability of the MPI penalty exceeding a given allocation is governed by statistical confidence levels. MPI random variables include:
  - Fiber cabling: the number and types of connectors in the link, and fiber length between them.
  - Connectors: the optical reflectance and insertion loss of fiber connectors
  - Optical phase: the optical phase between reflections varies rapidly in time
- The MPI penalty allocations in 3dj D1.4 were carried over unchanged from P802.3bs/cd clauses with similar fiber cabling.
- This presentation takes a step back to look at those prior assumptions and approximations and discusses their validity for 200G per lane PMDs.

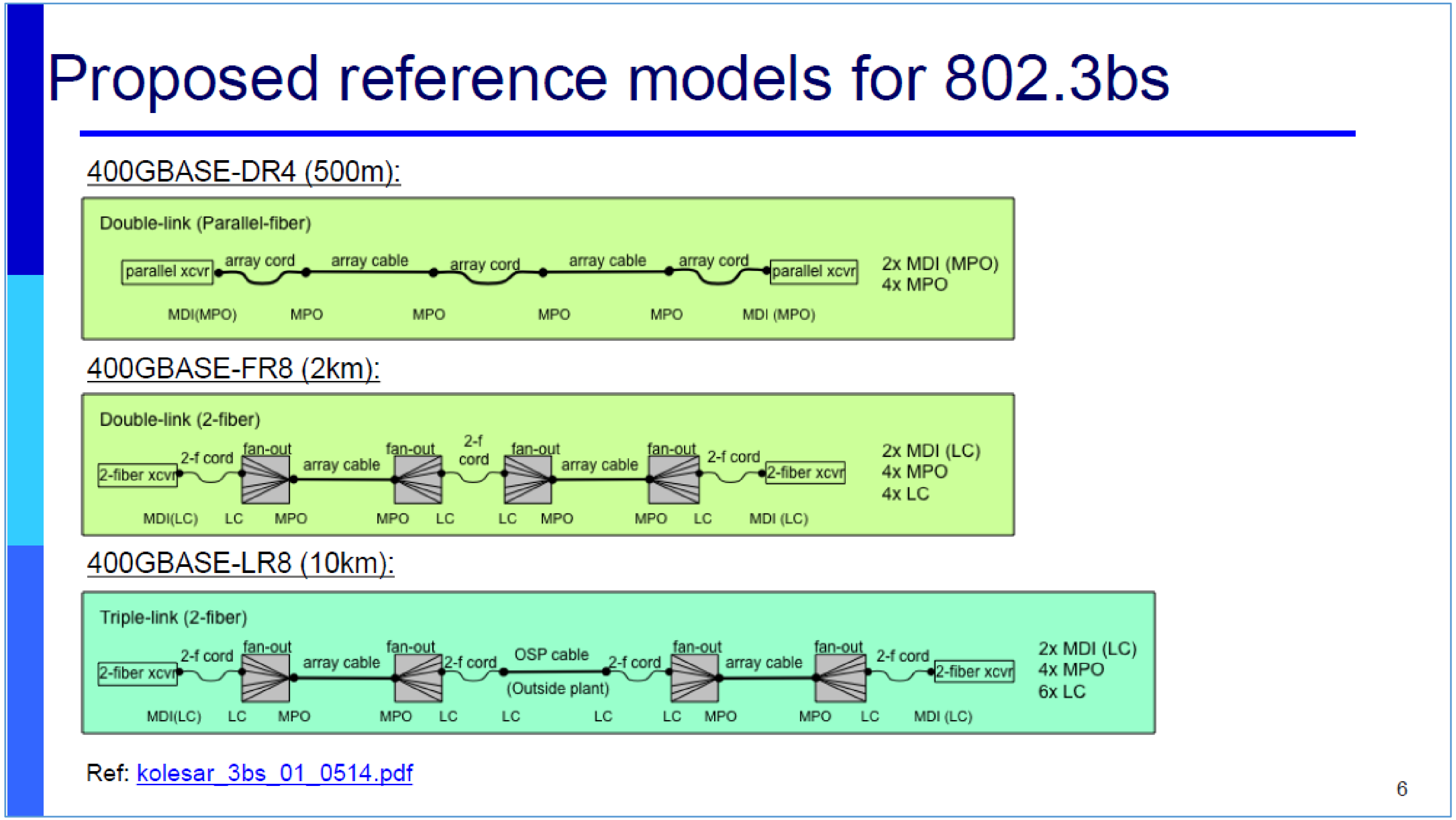
P802.3bs/cd MPI references

- Kolesar_3bs_01_0514 proposed models for fiber cabling and channel insertion loss. Nicholl_3bs_01a_0316 presented fiber cabling models that were adopted during 3bs comment resolution.
  - For DR4: double link, parallel fiber
  - For FR8: double link, duplex fiber (also used for DR in traverso_3cd_01_0317)
  - For LR8: triple link, duplex fiber
- king_01a_0116_smf presented the details of MPI calculations and provided an Excel spreadsheet-based Monte Carlo model to explore various scenarios.
  - Phases between reflections are random, but reflections and losses are fixed
  - Analyses the histograms of the vertical sub-eye openings to estimate Q and BER
- liu_3bs_01a_0316 presented the MPI analyses and penalties for 400GBASE-DR4/FR8/LR8 that were adopted during 3bs comment resolution.
  - The power budget allocation for MPI penalty is constant and the connector reflectance varies with the number of connectors (see Table 121-15 and Table 122-19)
- traverso_3cd_01_0317 presented the MPI analysis and penalties that were adopted for 100GBASE-DR during 3cd comment resolution.
  - The result is a power budget that trades insertion loss for MPI penalty (see Table 140-13).

P802.3bs/cd MPI assumptions

- "Baseline" BER = 2.4e-4 (host RS FEC)
  - The equivalent for 3dj FECo PMDs would be similar, 2.28e-4.
  - FECi PMDs would nominally use 4.8e-3, resulting in lower MPI penalty for the same cabling.
- Extinction ratio = 4.5 to 5 dB (> 1 dB margin to minimum)
  - A lower value may be more representative at 200G and will result in higher MPI penalty.
- Confidence level = 1e-6 (random reflection phases)
  - This is conservative since an MPI "failure" requires the joint probability of both worst-case fiber cabling and modules.
  - We could consider using a higher probability by taking this into account, as was considered in the statistical analysis of CD.
- Channel insertion loss:
  - Some 3bs contributions used half of the max channel IL at the middle of the link, but the adopted values were calculated with an assumption of the max IL at the far end of the link from the RX.
  - This is both a non-physical distribution of loss and is also not the worst case, which is IL = 0dB.
  - Using a random or typical per-connector loss may be a more realistic way to model MPI, at least for 500m and 2km PMDs.
- Connector return loss:
  - Worst case TX and RX (MDI) reflectance= -26 dB. This term dominates MPI calculations – is it overly pessimistic?
  - -35dB is assumed for the LC connectors in duplex fiber patch cords. (IEC-61753-1 RL Grade 3)
  - -45dB is assumed for the angled MPO connectors in parallel fiber cables for DR4 (IEC-61753-1 RL Grade 2)
  - -55dB is assumed for the angled MPO connectors in FR4/LR4 duplex fiber cabling (IEC-61753-1 RL Grade 1)
  - Should 3dj use random variables for the connector reflectivity, rather than worst cases?

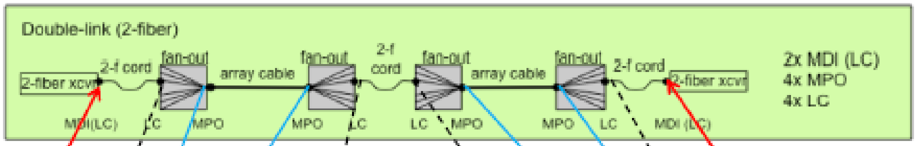
Fiber cabling models adopted by P802.3bs
(Nicholl_3bs_01a_0316)



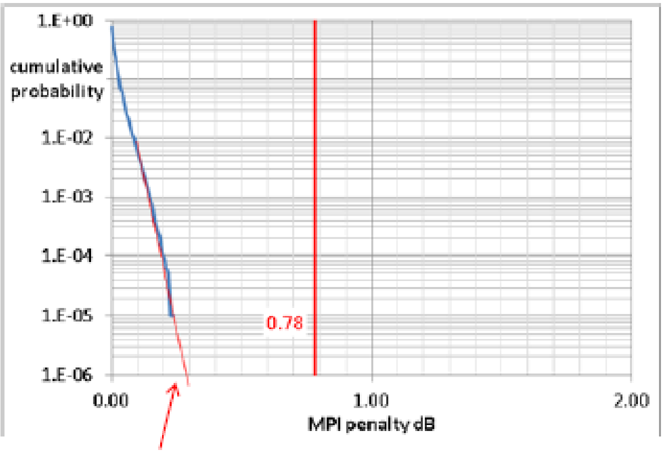
Example MPI penalty calculation
(liu_3bs_01a_0316)

400GBASE-FR8 (2km)

Simulation Parameters:
Link model: Double link (2-fiber)
Simulation model: king_02a_0116_smf.7z
Runs: 100k
BER: 2e-4
ER: 4.5 dB
Confidence: 1e-6
Tx/Rx MDI: 26 dB
LC: 35 dB
Angle polished MPO: 55 dB
Loss: 4 dB at end of link



	PMD											PMD
ER	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12
4.5	Rpmd	RconF	RconG	RconG	RconH	RconK	RconK	RconH	RconG	RconG	RconF	Rpmd
Reflection level inputs->	-26	-35	-55	-55	-35	-1000	-1000	-35	-55	-55	-35	-26
IL dB	0	0	0	0	0	0	0	0	0	0	4	



Recommend to include 0.3 dB MPI penalty into the link budget.

8

Using the nominal fiber cabling models and reflectance values, Hai-Feng proposed the following MPI penalty allocations for the 802.3bs power budgets:

400GBASE-DR4: 0.1 dB
400GBASE-FR8: 0.3 dB
400GBASE-LR8: 0.5 dB

Specification Method 1: Fixed MPI penalty

- Max MPI penalty is calculated for the nominal number of connectors and nominal max reflectance.
- The max discrete reflectance spec is then adjusted for cases with different number of connectors to give no worse MPI penalty than the nominal case.
- Pros:
  - The MPI penalty allocation, link power budget and max channel insertion loss are all constants.
- Cons:
  - The connector reflectances given aren't standard grades, so it's impractical to implement in this way.

Table 121–15—Maximum value of each discrete reflectance

Number of discrete reflectances above –55 dB	Maximum value for each discrete reflectance
1	–37 dB
2	–42 dB
4	–45 dB (nominal)
6	–47 dB
8	–48 dB
10	–49 dB

Table 122–19—Maximum value of each discrete reflectance

Number of discrete reflectances above –55 dB	Maximum value for each discrete reflectance		
	200GBASE-FR4 or 400GBASE-FR8	200GBASE-LR4 or 400GBASE-LR8	200GBASE-ER4 or 400GBASE-ER8
1	–25 dB	–22 dB	–19 dB
2	–31 dB	–29 dB	–27 dB
4	–35 dB	–33 dB	–32 dB
6	–38 dB	–35 dB	–35 dB
8	–40 dB	–37 dB	–37 dB
10	–41 dB	–39 dB	–39 dB

Specification Method 2: Variable MPI penalty

- MPI penalty is calculated over a broad range of cable models.
- As MPI penalty increases, link power budget is shifted from channel insertion loss to penalties.
- Pros:
  - Link power budget is a constant.
  - Channel IL is easily measured.
  - More connectors can be accommodated by procuring lower loss connectors and cables.
- Cons:
  - Channel IL is not a constant, complicating network design.

Table 140–13—100GBASE-DR maximum channel insertion loss versus number of discrete reflectances

MPO connectors

Maximum channel insertion loss (dB)		Number of discrete reflectances > –55 dB and ≤ –45 dB								
		0	1	2	3	4	5	6	7	8
LC connectors Number of discrete reflectances > –45 dB and ≤ –35 dB	0	3	3	3	3	3	3	3	3	3
	1	3	3	3	3	3	3	3	3	3
	2	3	3	3	2.9	2.9	2.9	2.9	2.9	2.9
	3	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	—[a]
	4	2.8	2.8	2.8	2.8	2.7	2.7	2.7	—[a]	—[a]
	5	2.8	2.8	2.7	2.7	2.7	2.6	—[a]	—[a]	—[a]
	6	2.6	2.6	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]

[a]The indicated combination of reflectances does not provide a supported maximum channel insertion loss.

No adjustment for MPI penalty < 0.15 dB

Double link, duplex fiber case

-35dB and -45dB are used in the simulations, even though these are the worst cases for each class of connector.

Discussion

- P802.3dj D1.4 reuses the same MPI assumptions as P802.3bs/cd. The Task Force needs to make two separate decisions:
  - If MPI penalties should be re-calculated with new assumptions for 200G PMDs.
  - How revised MPI penalties either change the power budget and TX/RX specs, or change the max channel insertion loss (as in Cl. 140).
- Consider for example the different assumptions used in ghiasi_3dj_02_2501:
  - Target BER values specific to P802.3dj (2.28e-4 and 4.8e-3 vs. 2.4e-4)
  - Connector reflectivities of -35 and -45 dB (same as 3bs/cd)
    - These are worst case values. Should we treat them as random variables in the MC analysis?
  - Reduced extinction ratio (3.5 dB vs. 4.5 dB)
    - Maybe 4 dB is a better typical value for 200G TX?
  - Half of the maximum IL at the midpoint of the link (vs. max IL at end)
    - Both "lumped loss" choices are rather arbitrary and not very physical, especially the far-end case.
    - Should we use nominal per-connector losses, or include them as random variables in the MC analysis?
  - Reduced confidence level (1e-5 vs. 1e-6).
    - Given that only marginal modules on worst-case channels will fail when the MPI allocation is exceeded, the use confidence level could be significantly smaller. Similar argument was used to support Q = 1e-4 for channel CD.
    - A 1e-6 confidence level may be more appropriate when a full statistical treatment of connector losses and reflectances is made.

Thank You