Update to oFEC-based single lambda baseline for 10km and 40km objectives

A baseline proposal

Tom Williams - Cisco
Gary Nicholl – Cisco
Mike Sluyski - Cisco
Weiqiang Cheng - China Mobile
Gert Sarlet - Coherent

Supporters

- Jörg-Peter Elbers, Adtran/ADVA
- Chen Zhu, Baidu
- John Johnson, Broadcom
- Vasu Parthasarathy, Broadcom
- Haojie Wang, China Mobile
- James Xing Jiang, Cisco
- Ray Nering, Cisco
- Markus Weber, Cisco
- Brian Welsh, Cisco
- John DeAndrea, Coherent
- Vipul Bhatt, Coherent
- Roberto Rodes, Coherent
- Roberto Marcoccia, Effect Photonics
- Ted Schmidt, Effect Photonics
- Xue Wang, H3C
- Yu Zhu, Hengtong Group
- Yanjun Zhu, Hisense
- Greg LeCheminant, Keysight Technologies
- Ernest Muhigana, Lumentum
- Ming Wang Mao, Meituan
- Kumi Omori, NEC
- Atul Srivastava, NTT
- Yann Loussouarn, Orange
- Erwan Pincemin, Orange
- Zhan Su, Ruijie Networks
- ChiYuan Chen, Spirent
- Shaohui Zhang, Tencent
- Sam Sambasivan, Verizon
- Huijun Sha, Viavi
- Aihua Liu, ZTE
- Chengbin Wu, ZTE
- Jeff Maki, Juniper Networks*
- Frank Chang, Source Photonics*

*Supports proposal for 40km only

Introduction

- williams_3dj_01a_230206.pdf provided an overview of the 10km and 40km market landscape
  - 800G LR unit volumes likely an order of magnitude lower than DR/FR and <2x ZR/ZR+
  - Comparison of relative cost of tunability
- Following the ad hoc straw poll after the nowell_3dj_optx_adhoc_01b_230222 and cole_3dj_optx_adhoc_01b_230222 presentations, there is strong support to split the 10km objectives into two
  - A 4 wavelength objective based on IMDD
  - A 1 wavelength objective based on coherent
- Based on the market analysis presented for both the IMDD and coherent proposals, it should be clear that both of these 10km objectives should leverage the development efforts of higher volume adjacent applications

Possible 800GBASE-LRx Approaches

- IMDD with concatenated FEC – KP4+Hamming(128,120)
  - See rodes_3df_01a_2211.pdf
  - Targets lowest potential cost structure
- Coherent using segmented oFEC-based FEC as in 800ZR DSPs
  - **Highly leverages industry investment using a common, interoperable implementation for LR, ER and ZR**
  - Higher coding gain at lower baud rate
  - Extra link margin and/or better manufacturing yield
  - Alignment of the development will result in a broader component supply chain
- OIF 800LR - KP4+BCH(126,110)
  - Lower latency for applications inside the data center with 100G AUI
    - Target applications not driven by traditional LR
  - Doesn't leverage development of higher volume interfaces
    - Different baud rate, framing and timing architecture
  - O-band is adopted in OIF and not well-suited for 40km

We believe that an IMDD standard and an oFEC based coherent standard will result in the broadest supply base supporting a wide range of LR use cases while maintaining rational industry investment

Alignment Requirement of 10/40/80km

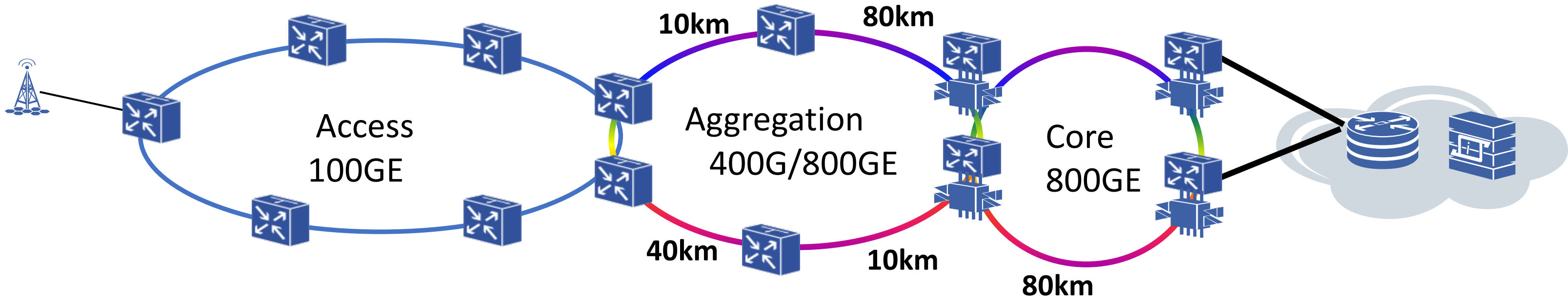
Keeping technical consistency in 10/40/80km is quite necessary in view of telecom operators

- **As 5G and metro applications extend quickly, IP network urgently requires 800GE**. For one example, in a Fixed broadband access network, 30000 subscribers now share one BRAS. The average access rate is more than 270Mbps and the uplink speeds are already reaching 800Gb/s in aggregate.

- Currently, telecom operators deploy 100GE in metro network, where **the link distributions** are shown in the table below. **800GE interfaces** is expected to be used in the same link scenario, which **is extremely likely to result in the same usage statistics 100GE**

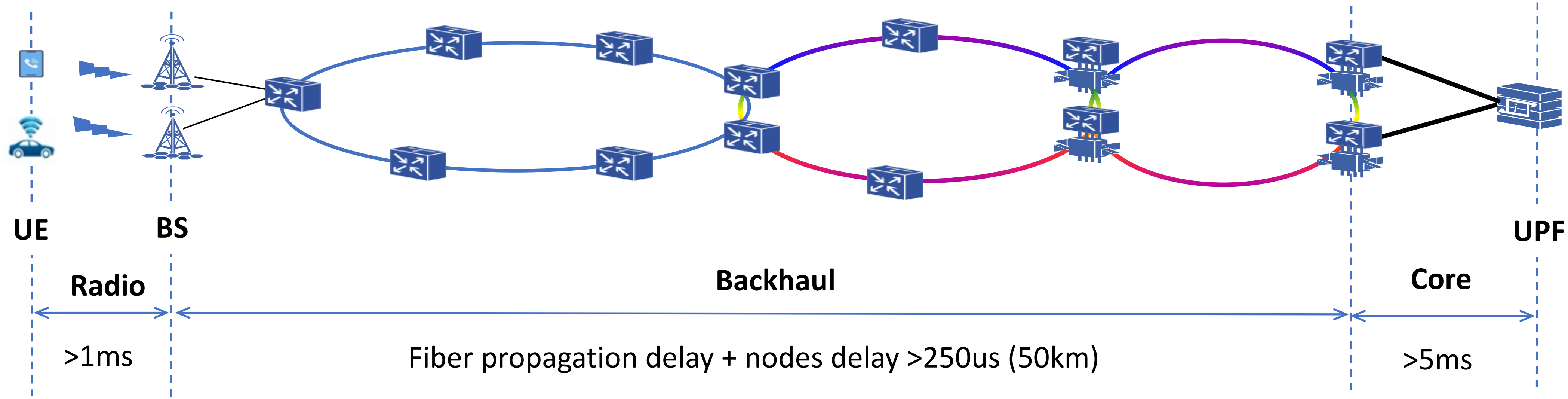
Transmission Distance	<2km	**10km**	**40km**	**80km**
10GE distribution	0.28%	44.46%	44.05%	11.20%
100GE distribution	0	56.43%	34.59%	8.97%

- As mentioned above, 800GE at metro may be randomly deployed in different distance, such as 10km, 40km and 80km. Thus, **the interoperation is required and the technical compatibility between them** will bring a significant advantage in supply and spare parts.



Delay analysis of 800GE in Metro-network

Here we take 5G as an example, it can provide three significant services including eMBB, mMTC and uRLLC; **uRLLC** Services are dedicated to 5G Low Latency Enhancements.



Generally, The latency for 5G UE to UPF involves radio interface, backhaul and core network.

- According to the technical specification in “**3GPP TR 38.834 v16.0.0**”, one-way propagation delay of radio interface is targeted within **1 ms**, while in practice, the vaule is much more than **1 ms**, even up to **5 ms** based on our tests
- For the backhaul, the average scope is within about **50 km**, where the corresponding fiber propagation delay is about **250 us**; additionally considering the node delays, the unidirectional backhaul delay is over **250 us**
- At the core network, the UPF processing delay is above 5 ms.

Combining the aforementioned three aspects, the entire end-to-end delay exceeds 6.25ms, thus **the module delays of microsecond level impact little on the uRLLC services, and can be negligible.**

Considerations in Coherent LR1 Implementation Selection

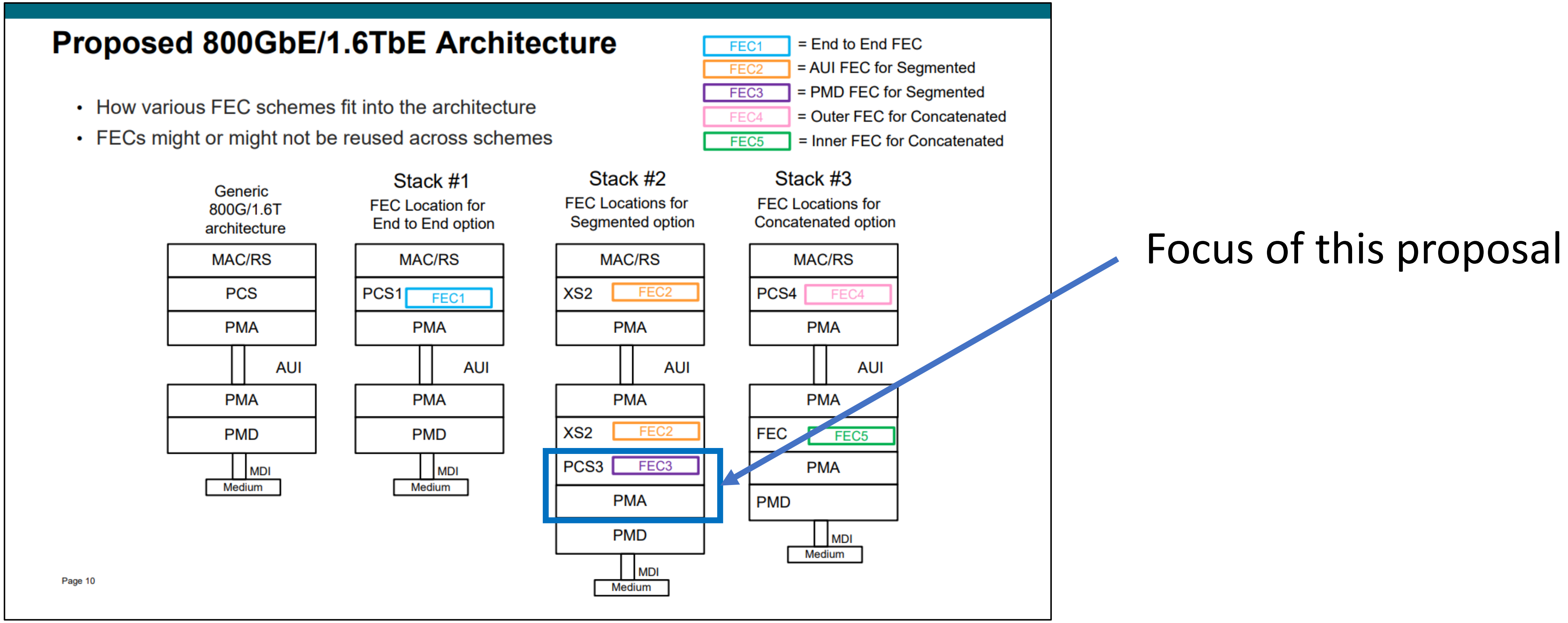
- Market Size
  - As demonstrated in williams_3dj_01a_230206.pdf the LR market is best served by leveraging investment in adjacent applications
  - The OIF approach isn't just a different FEC, it's a completely different data path
- Overhead
  - The OIF LR operates at **123.6Gbaud** overhead to achieve **~1e-2 FEC** threshold
  - oFEC operates at **118.2Gbaud** with a FEC threshold of **~2e-2**
  - An oFEC-based implementation will have a broader supply base and **>1.5dB (or 5km)** better sensitivity performance that can be used for either additional manufacturing or link margin
- Optical Band
  - OIF has selected O-band
  - IEEE is better served to align on C-band with 10/40km interop
- Latency
  - The majority of10/40km applications are not latency sensitive, particularly in the use cases where coherent offers the most value
  - SYNCE and IEEE 1588 PTP Class C/D can be achieved using GMP mapping and OFEC. Deterministic latency, is key requirement
  - Where lowest latency is required, the IMDD LR4 implementation is the better choice

Logic Architecture Goals

- Leverage industry investment with a common logic baseline (FEC) supporting LR, ER and ZR
- Build upon the ongoing work in 802.cw (400GBASE-ZR) to define an 802.3 PHY documentation structure for a coherent interface
- Support both 800GAUI-8 (100G/lane) and 800GAUI-4 (200G/lane)
- Separate FEC for electrical and optical interfaces (“segmented FEC”)
  - Decouples the AUI and PMD developments (simpler and lower risk)
- Strong FEC performance
- Tradeoff between latency and performance
  - Optimized for the different reaches (but with common FEC engine)
- Protocol aware monitoring and signaling
  - fault detection, fault isolation, and fault protection

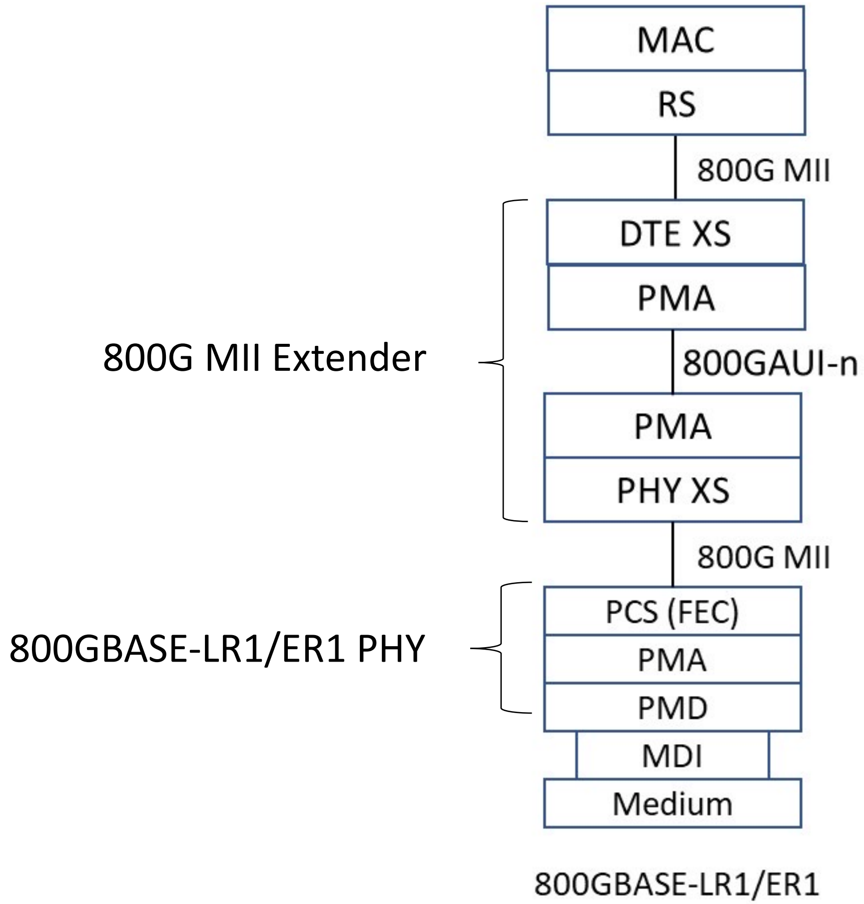
Fit into the adopted logic architecture

This proposal fits within the adopted 802.3dj logic architecture



From: gustlin_3df_01a_220517

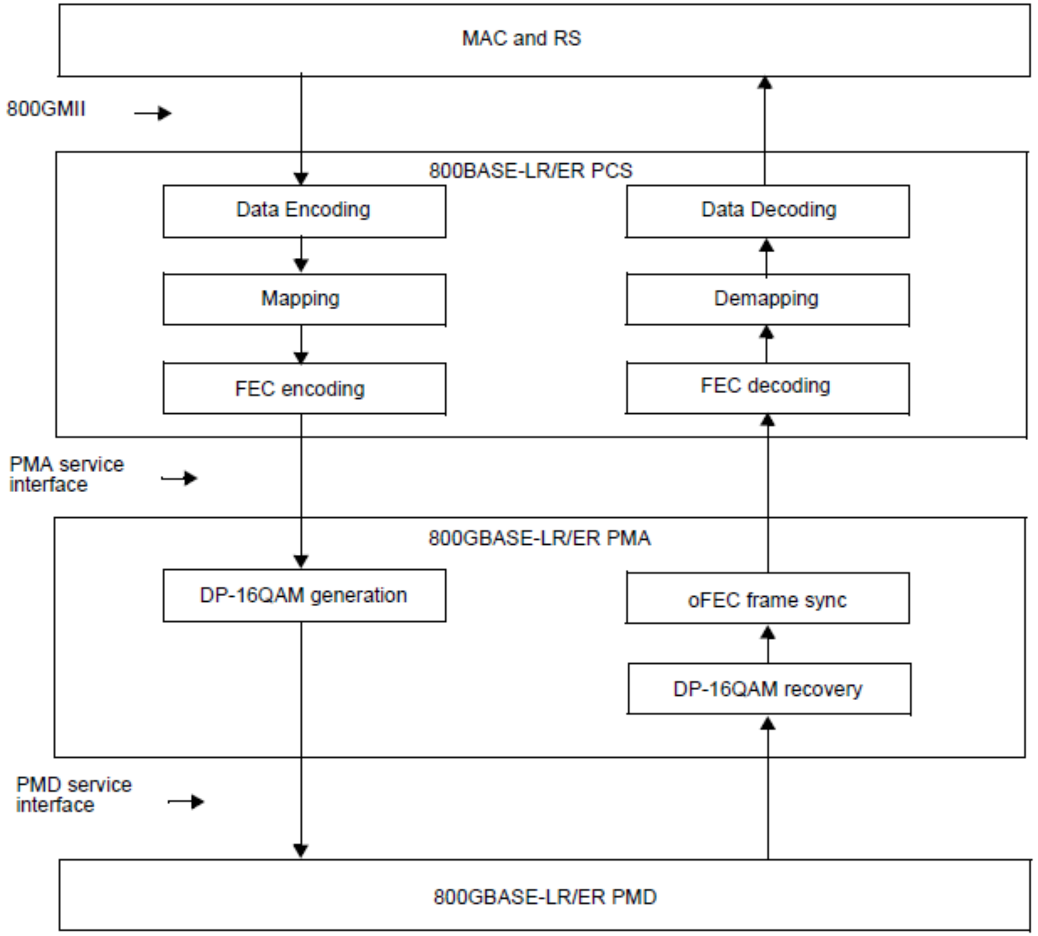
Logic Architecture Overview



- Based on a Type 3 FEC/PHY scheme ("segmented FEC") as described in brown_3dj_optx_adhoc_01a_230222
  - Same architecture as 400GBASE-ZR (3cw)
- The 800GBASE-LR1/ER1 PHY only covers the optical links
  - No optional AUIs are supported by the PHY
- AUIs (if required) are supported with the 800GMII Extender
  - 800GAUI-8 defined in 802.3df (already done)
  - 800GAUI-4 will be defined in 802.3dj

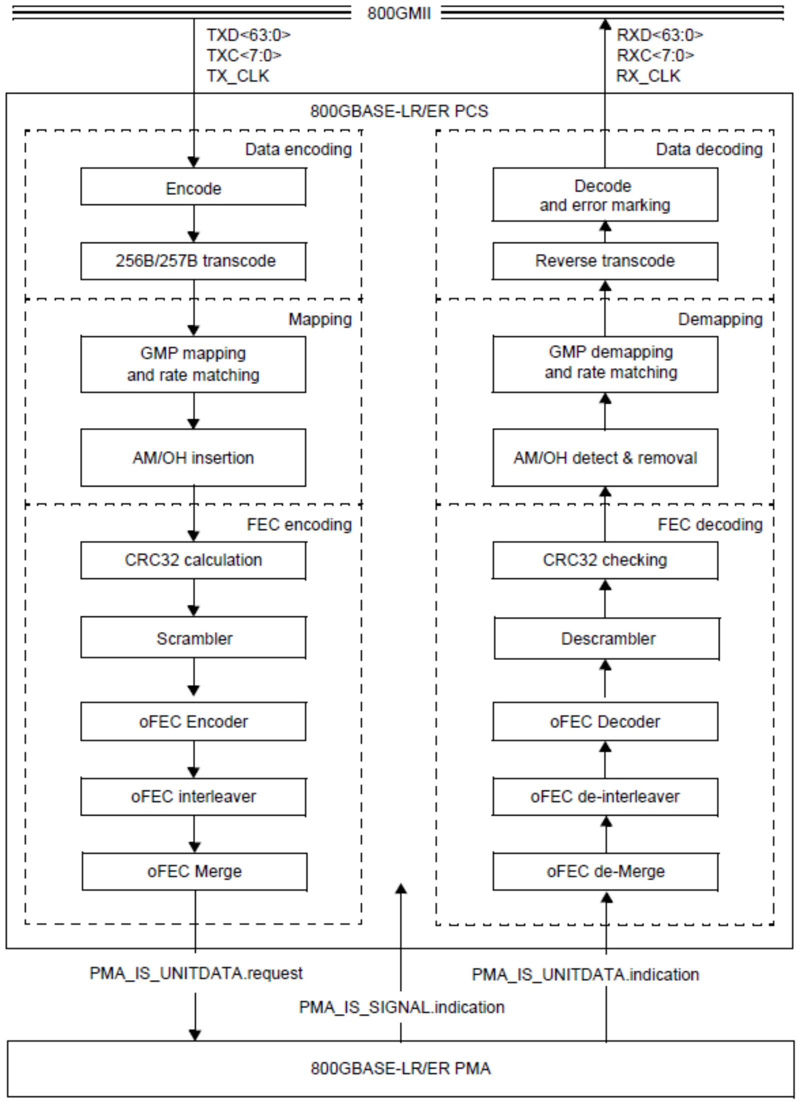
This baseline proposal only addresses the 800GBASE-LR1/ER1 PHY

800GBASE-LR1/ER1 PHY Overview



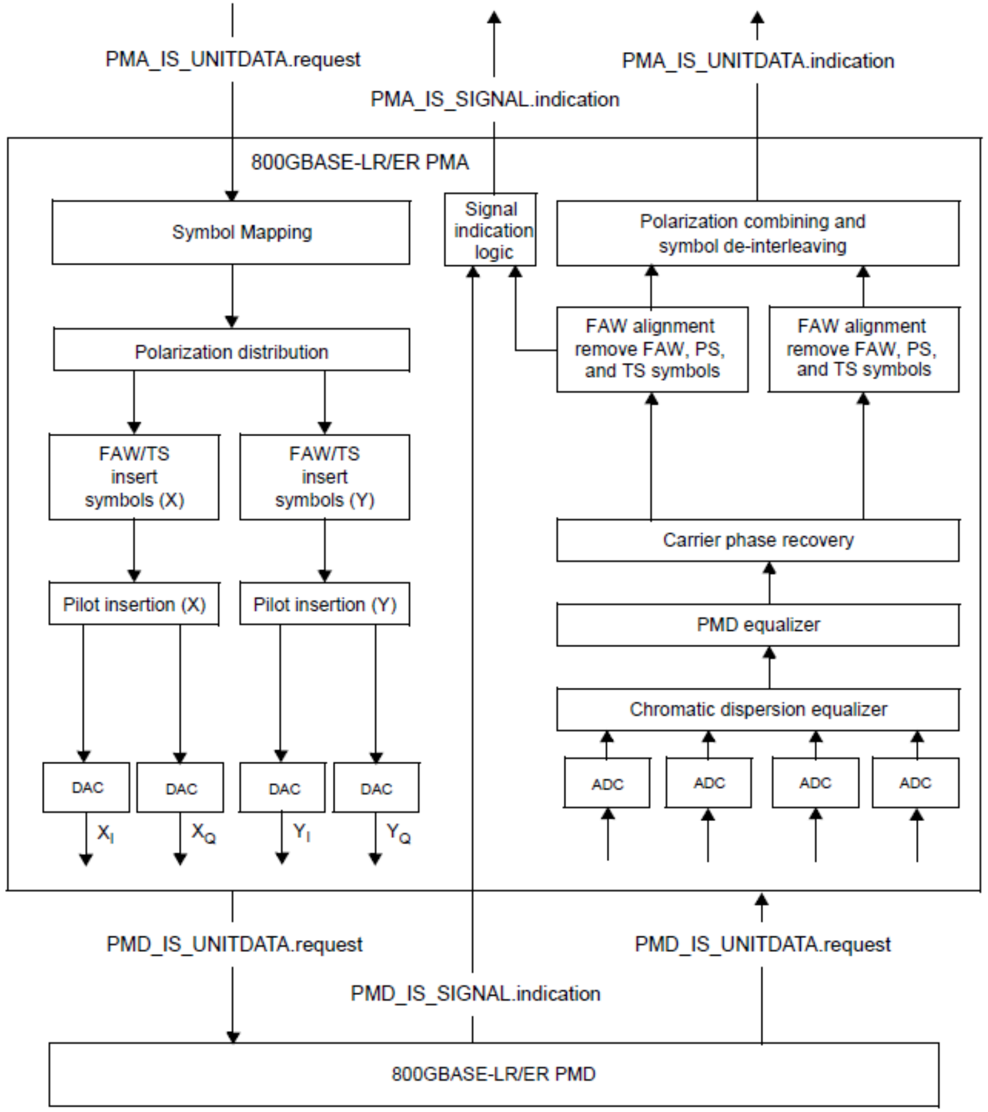
- Leverages the extensive ongoing efforts in 802.3cw to define an 802.3 PHY documentation structure to support a coherent optical interface
  - Split of functionality between PCS, PMA and PMD
  - Definition of PMA and PMD services interfaces
- PCS
  - 256/257b data encoding/decoding
  - GMP mapping
  - FEC encoding/decoding (based on oFEC defined for 800ZR)
- PMA
  - DP-16QAM generation/recovery

PCS Overview



- Leverage efforts from 802.3cw and OIF 400ZR for the 800GBASE-LR/ER PCS.
- Leverage ongoing efforts from OIF 800ZR; Open ROADM FlexO-Xe, and ITU-T SG15 Q11 B400G.
  - GMP mapped
  - ZR Frame Alignment Marking (AM).
  - CRC32 per IEEE 802.3 Clause 3.2.9 – addresses MTTFPA.
  - 15% OH oFEC (~118GBaud)
  - ZR adaption to oFEC/ZR DSP frame structure.

PMA Overview



- Leverage ongoing efforts from OIF 800ZR, Open ROADM, and ITU-T SG15 Q11 for 800GBASE-LR/ER PMA
  - DP-16QAM Symbol mapping and polarization distribution (XI/XQ/YI/YQ)
  - DSP framing - FAW, TS, PS
    - Pilot spacing every 64 symbols
    - 84 blocks of oFEC aligned to DSP super frame structure.
    - 175,104 16-QAM Symbols

Logic Architecture Summary

- 800GBASE-LR1/ER1 logic baseline is based on a Type 3 PHY (“segmented FEC”) scheme as defined in brown_3dj_optx_adhoc_01a_230222
- The proposal builds upon the ongoing efforts in 802.3cw to define an 802.3 PHY documentation structure to support a coherent optical interface
- Common FEC solution to address LR, ER and ZR
  - Strong performance
  - Trade off between performance and latency for the different reaches

800GBASE-LR1 and ER1 Laser definition

- Propose 1550nm based laser
  - Consistent with ZR
  - Avoids excessive loss in ER1 application
  - Supports 18km reach when using same link budget as 10km O-band
  - Enables interop between LR1 <-> ER1 <-> ZR
- Tunable laser for ZR as defined by OIF – fully tunable, DWDM capable
- ER1 Transmitter – single fixed λ, temp controlled laser (e.g. DFB), amplifier
  - Reduced performance specs vs ZR
  - SOA or µEDFA amplifier
- LR1 Transmitter – single fixed λ, temp controlled laser (e.g. DFB)
  - No amplification required to close LR link

Relaxed laser specs and **reduced testing** requirements for ER/LR compared to ZR DWDM

Transmitter Specifications

Description	800G-LR1	800G-ER1	Unit
Signaling rate	118.2	118.2	Gbd
Modulation format	DP-16QAM	DP-16QAM	
Channel frequency (Nominal)	**193.7**	**193.7**	THz
Channel frequency accuracy (+/-)	+/- 1.8	+/- 1.8	GHz
Average launch power (min)	-10	-2	dBm
Average launch power (max)	-6	2	dBm
Average launch power of OFF transmitter (max)	-20	-20	dBm
Laser linewidth (max)	**1.0**	**1.0**	MHz
I/Q phase error (+/-)	5	5	Deg
I/Q quadrature skew (max)	0.75	0.75	Ps
I/Q amplitude imbalance (mean)	1	1	dB
Transmitter EVM	12	12	%

Parameters in blue represent spec relaxations compared to ZR optics

Transmitter Specifications (cont.)

Description	800G-LR1	800G-ER1	Unit
Transmitter OSNR	35	35	dB
Power difference between X and Y polarizations (max)	1.0	1.0	dB
Skew between X and Y polarizations (max)	5	5	ps
Transmitter reflectance (max)	-20	-20	dB
RIN average	-145	-145	dBc/Hz
RIN peak	-140	-140	dBc/Hz

Receiver Specifications

Description	800G-LR1	800G-ER1	Unit
Modulation format	PM-16QAM	PM-16QAM	
Frequency offset between received carrier and local oscillator	+/-3.6	+/-3.6	GHz
Receive sensitivity	-17.3	-17	dBm
Average receive input power (max)	+3	+3	dBm
CD tolerance (max)	200	800	ps/nm
Peak PDL tolerance	1.5	1.5	dB
DGD	5	10	ps
SOP tolerance	5	5	krad/s

Illustrative Link Budgets

Parameter	800G-LR1	800G-ER1	Unit
Power budget	7.3	15	dB
Operating distance	10	40	Km
Channel insertion loss	5.0	14	dB
Allocation for penalties	0.5	1.0	dB
Additional insertion loss	1.8	0	dB

Summary

- The industry will benefit from alignment of both IMDD and coherent specifications leveraging investments in adjacent applications
  - A coherent implementation based on oFEC can support LR, ER and ZR enabling cost optimization for the lower volume applications through technology reuse and simplified testing
  - Coherent LR1 should focus on a robust specification with unallocated margin that can provide extra protection against unknown fiber impairments or reaches exceeding 10km
  - An oFEC-based solution offers >1.5dB better sensitivity performance that can be used for manufacturing or link margin