Alignment of 800GBASE-LR1 and 800GBASE-ER1 with OIF800ZR Implementations

A baseline proposal

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*Supports proposal for 40km only

Topics

- 800G LR & ER
  - Market Considerations
  - Technical Approaches
  - Baseline Proposal

Cost is driven by reach, fiber capacity and volume

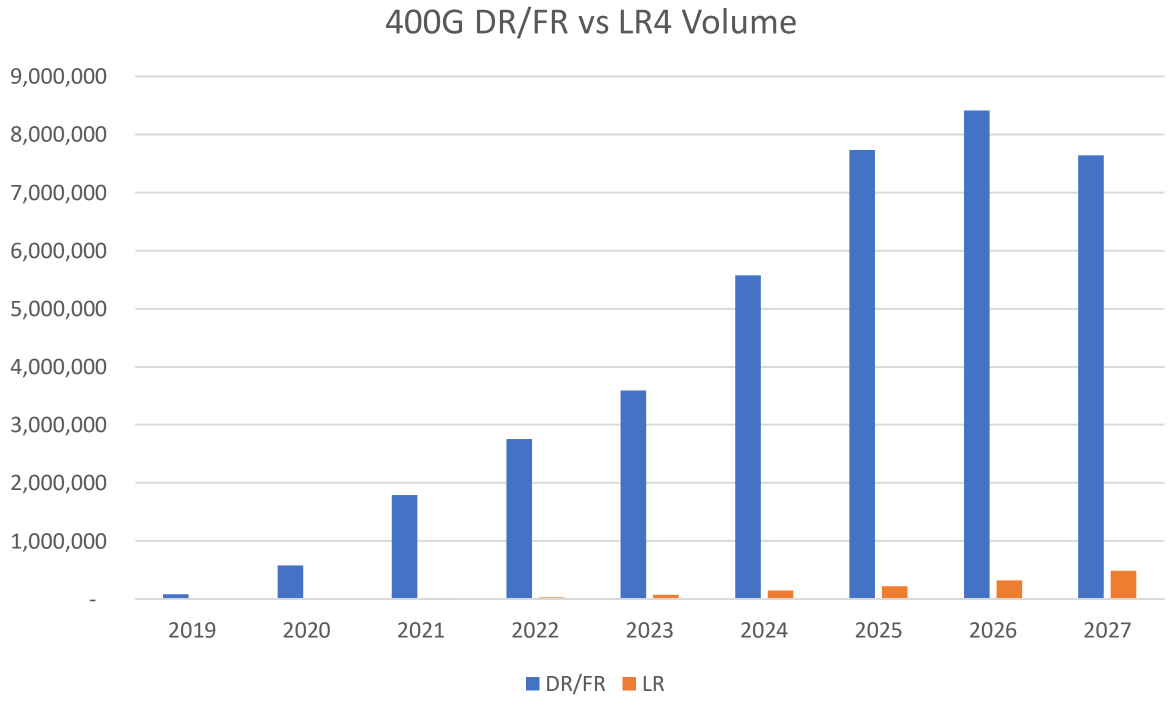
≤ 2km | **10 km** | **40 km** | **80 km** | **DWDM (tunable) 120km**

Next few slides will consider relative volume and cost for these different interfaces at 400G and 10G. The reason to look at 10G is because all of these interfaces are IMDD at 10G.

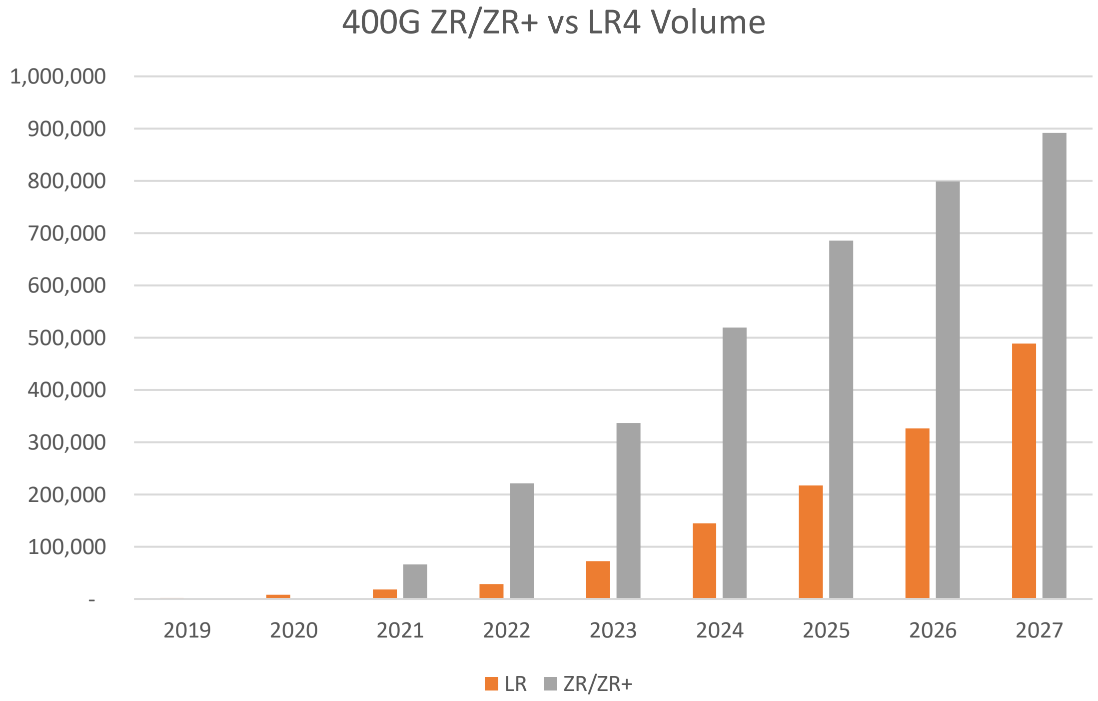
At 10G, this is referred to as ZR

At 400G, this is referred to as ZR

400G Volume Comparison



Source: LightCounting Optical Components Market Forecast, Oct 2022.



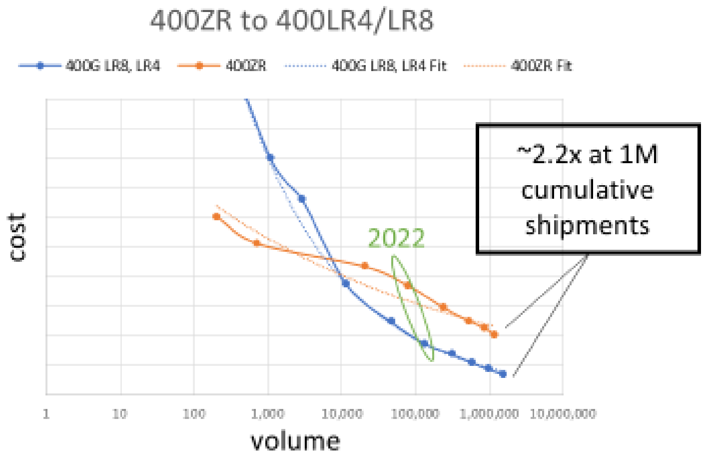
Source: LightCounting Optical Components Market Forecast, Oct 2022.

DR/FR volumes much higher than LR

ZR/ZR+ volumes > 2x compared to LR

400G Relative Cost Comparison

Using 400G coherent vs IMDD cost comparison to gain insights into 800G



Source: LightCounting, October 2021 Market Forecast report

Note: Any particular implementor's costs may vary

- Looking at LightCounting's report on 400G module data
- Complexity drives initial cost and manufacturing improvements and volume drive the reduction over time
- At 400G, a 100km DWDM 400ZR module is projected to only have a 2.2x cost difference at comparable volumes with 400G 10km IMDD
- Predicting what an 800G equivalent curve would look like:
  - Coherent complexity reduces
  - IMDD complexity increases
  - Volume of IMDD less leverage from 2km
  - Coherent volume increases (if adopted by 802.3df) with leverage from 40km

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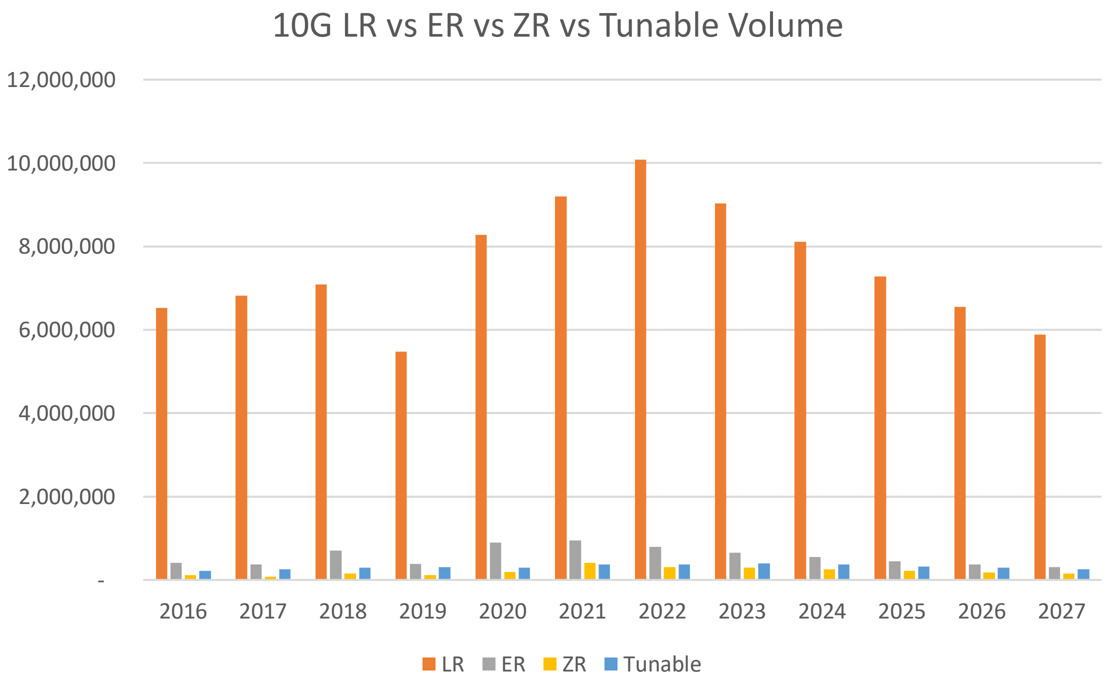
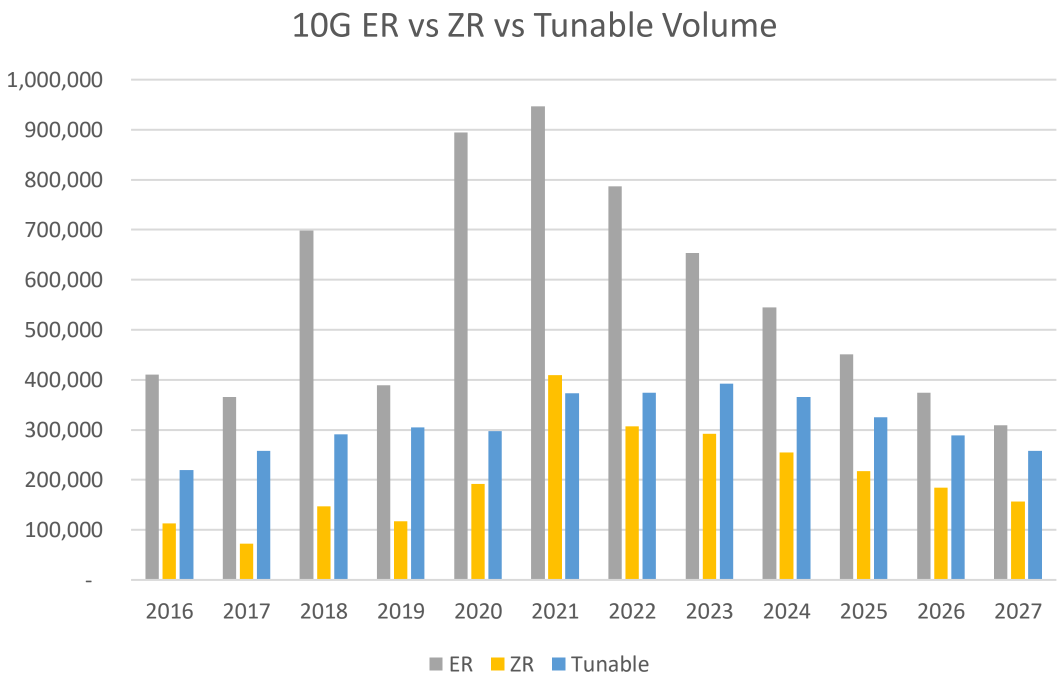
Relative Volumes at 10G



Source: LightCounting Optical Components Market Forecast, Oct 2022.



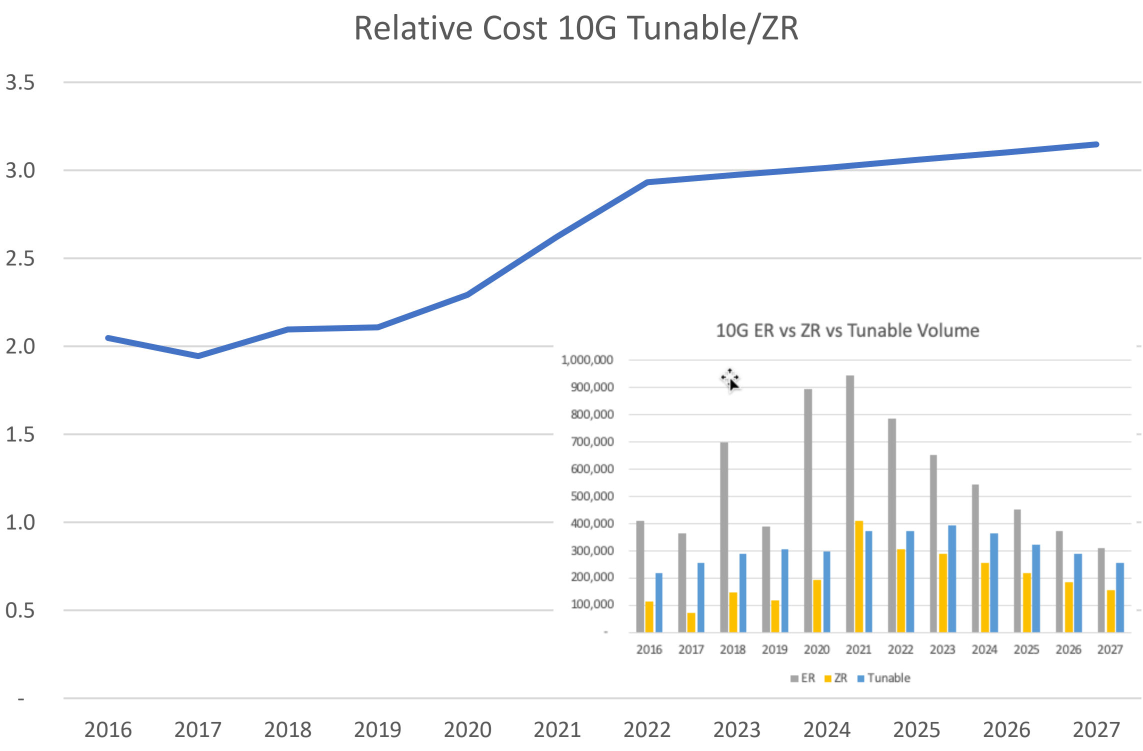
Source: LightCounting Optical Components Market Forecast, Oct 2022.

No DR/FR, so LR volumes dominate

Tunable volume comparable to ZR

Relative Cost of Tunability

Example 10G Tunable vs 10G ZR



Note: Any particular implemetor’s costs may vary

Source: LightCounting Optical Components Market Forecast, Oct 2022.

- Tunable DWDM drives a higher relative cost
- Comparable volumes, but tunable is 2-3x higher relative cost than ZR
  - Higher relative cost laser technology
  - Higher relative cost test stations
  - Longer test times
  - Lower yields

DWDM requirements drive higher relative cost whether based on IMDD or coherent

Summary of LR market assumptions

- With industry standardization of DR/FR solutions, the LR market is much smaller than earlier (i.e. 10G or 100G) generations
  - Order of magnitude lower than DR/FR and half the ZR/ZR+ volume at 400G
- The higher relative cost for tunable DWDM exists whether using IMDD or coherent technology
  - Tunable lasers are not required for coherent LR or ER interfaces in the scope of 802.3df
- The low volume for LR interfaces makes alignment with other industry investments critical
  - Alignment with DR/FR does offer the potential for lower relative cost, as observed at 400G
    - Important to avoid decisions that could burden the DR/FR implementations
    - More detail needed on the technical alignment of IMDD LR with DR/FR, particularly related to DSP development
  - Alignment with ZR/ZR+ offers the potential for a high-yielding implementation with minimal extra development
    - As ZR/ZR+ volumes have increased, this approach achieves some of the same benefits of scale

Possible 800GBASE-LRx Approaches

- IMDD with concatenated FEC – KP4+Hamming(128,120)
  - See rodes_3df_01a_2211.pdf
  - Robust interconnect based on high-yielding manufacturing specs?
- 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 for extra link margin and/or better manufacturing yield
    - Alternatively, coding gain can be reduced for improved power and latency
  - 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
  - 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 oFEC based standard will result in a high-yield solution with a broader supply base

Alignment Requirement of 10/40/80km

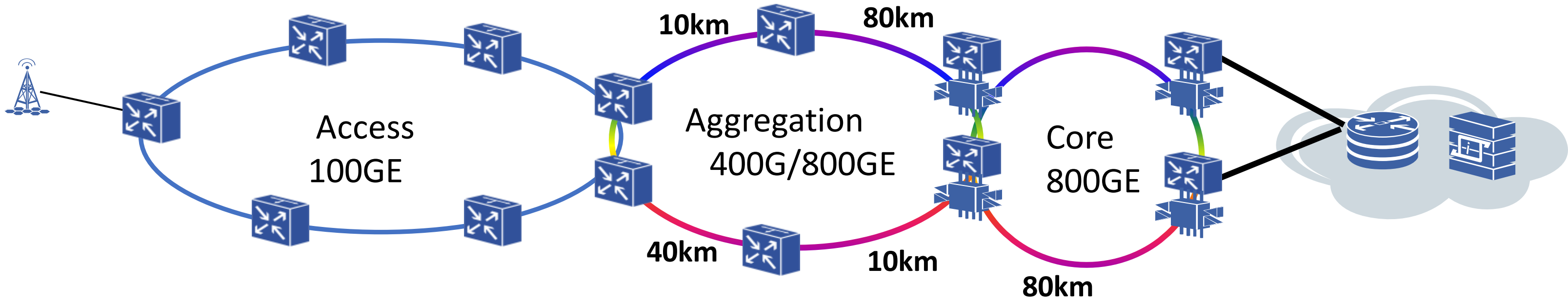
Keeping technical consistency in 10/40/80km is quite necessary in view of telecom operators

- **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.



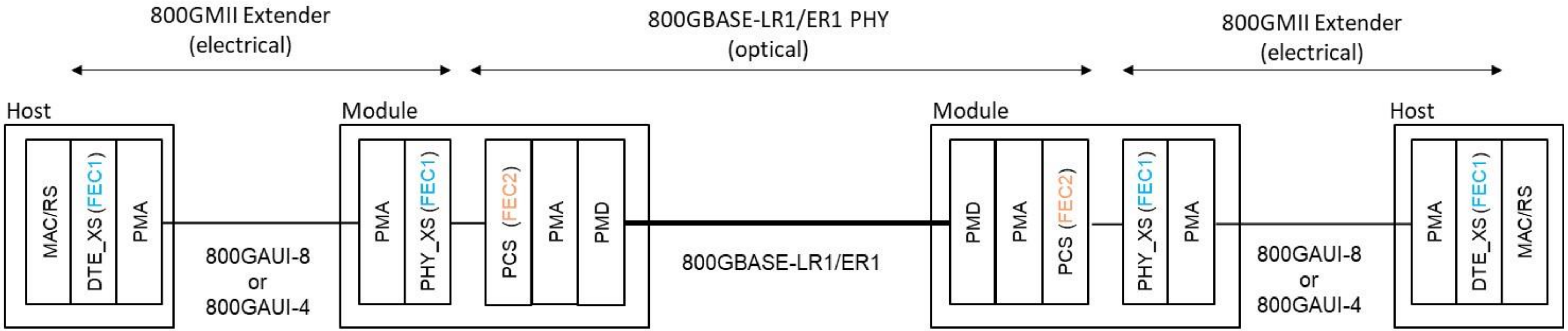
oFEC introduction and overview

- oFEC was standardized at 400G for ZR+ applications
  - Interoperability validated across multiple DSPs available today
    - oFEC is used in interoperable interfaces defined by Open ROADM, CableLabs, OpenZR+ and ITU
    - OIF has selected oFEC for 800ZR
  - Higher performance expanded the addressable market for ZR+ solutions
    - 11.6dB NCG (16QAM)
- Based on an iterative decoder
  - Existing oFEC standards assume 3 soft decision iterations
  - Implementations with fewer implementations can reduce power and latency by sacrificing some coding gain
    - The same encoder is used in both cases, so development effort and interoperability between implementations can be maintained

What about latency?

- 2-10 km of SMF fiber contributes ~10-50 µs of latency to the link
- Traditionally, some LR use cases have been based on additional loss elements in the link
  - Patch panels, optical switches, etc.
  - Fiber impairments (CD, PMD, etc.) for these applications may be less than 10km of SMF
  - Lower latency in these applications is beneficial, but robust operation and a broad supply base is primary consideration to users
- At 800G, new use cases are driving requirements for sub-1us latency
  - Is LR the right place to address these applications?
  - Will these applications drive substantially more LR volume?
    - If volume is smaller than LR, we need to be careful not to drive a costly solution
    - If volume is much larger than LR, we should optimize for this use case
    - No data has been provided on market potential

800GBASE-LR1/ER1 Logic Architecture



- Assumes a segmented FEC scheme (leveraging the work from 802.3cw)
  - Compatible with the architecture adopted in gustlin_3df_01a_220517
  - Separate FEC code for electrical and optical interfaces - decouples the AUI and PMD developments (simpler and lower risk)
  - Optical PMD specs guaranteed to be independent of host AUI speed
- 800GMII Extender provides the electrical interface (AUI)
  - 800GAUI-8: already defined in 802.3df (no additional work necessary)
  - 800GAUI-4: will be defined in 802.3dj

Note: "FEC2" in the above figure could be a concatenated FEC code.

800GBASE-LR1/ER1 PHY Architecture

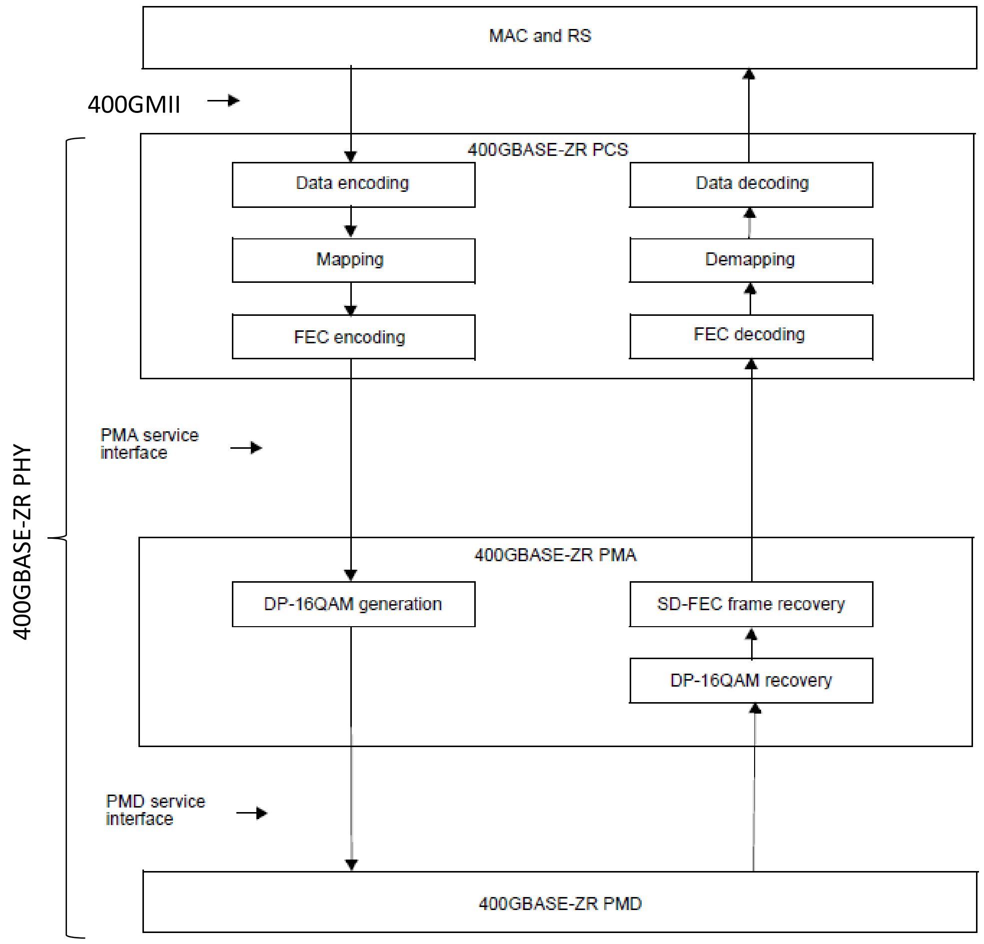


Figure 155–1—400GBASE-ZR PCS and PMA high level block diagram

Ref: new figure that is proposed to be added to 802.3cw, Clause 155

- 800GBASE-LR1/ER1 PHY only needs to support the optical interface
  - No optional physically instantiated AUI
  - AUI is provided by the 800GMII Extender
- 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
- Should be possible to define an 800GBASE-LR1/ER1 logic baseline fairly quickly (and independent from any activities on 200G/lane electrical interfaces)

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	6.8	15	dB
Operating distance	18	40	Km
Channel insertion loss	6.3	14	dB
Allocation for penalties	0.5	1.0	dB

Summary

- The industry will benefit from alignment of all coherent specifications using a common FEC enabling interoperable ZR, ER and LR
  - A coherent implementation based on oFEC can support all of these applications enabling cost optimization for the lower volume applications through technology reuse and simplified testing with higher manufacturing yields
  - Power/latency optimized implementations could also be supported
    - Reduced decoder iterations would maintain interop
    - Further latency reduction could be achieved by bypassing or modifying the interleaver
  - Robust specifications tolerant to existing fiber specs capable of supporting both datacom and telecom requirements