PHY/FEC architecture considerations V2

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Introduction

- Consideration of PHY/FEC schemes from IEEE architecture perspective.
- Exploration of impact of different FEC concatenation and segmentation choices.
- First version presented at 802.3dj Optical Ad Hoc meeting on 22 February 2023.
  https://www.ieee802.org/3/dj/public/adhoc/optics/0223_OPTX/brown_3dj_optx_adhoc_01a_230222.pdf

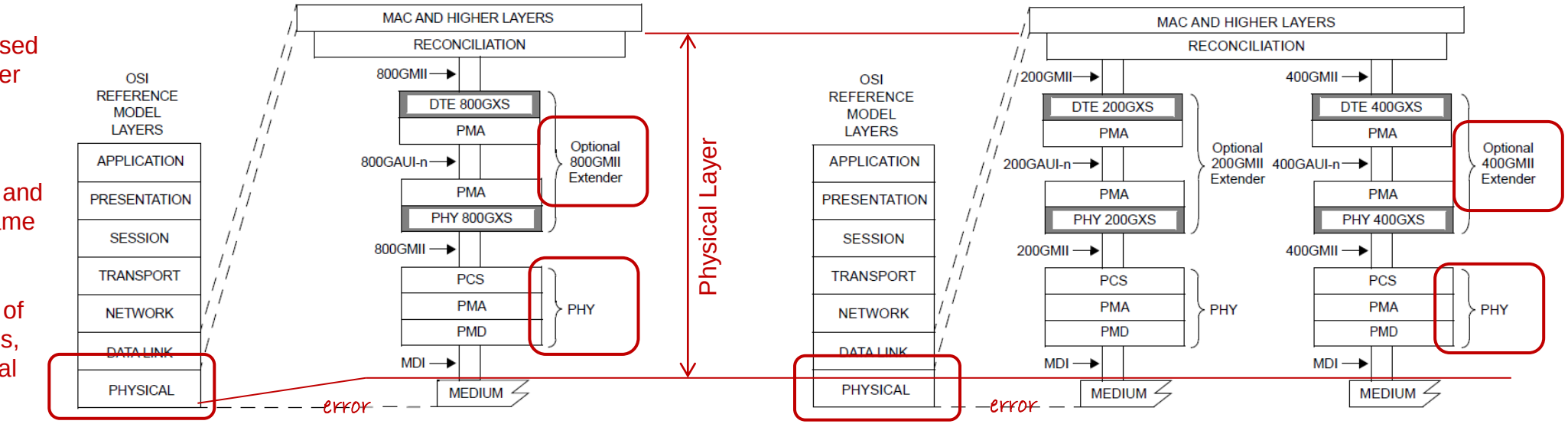
IEEE architecture terms

1.4.467 Physical Layer device (PHY): Within IEEE 802.3, the portion of the Physical Layer between the Medium Dependent Interface (MDI) and the media independent interface specific to the data rate (e.g., MII, GMII, XGMII). The PHY contains the functions that transmit, receive, and manage the encoded signals that are impressed on and recovered from the physical medium.

The physical layer is composed of the Reconciliation Sublayer (RS), optional MII Extender, PHY, and MDI.

PHY (physical layer device) and physical layer are not the same thing.

The MII extender is not part of the PHY. As its name implies, the MII Extender is a physical extension of the MAC/RS.



800GAUI-n = 800 Gb/s n-LANE ATTACHMENT UNIT INTERFACE
800GMII = 800 Gb/s MEDIA INDEPENDENT INTERFACE
800GXS = 800GMII EXTENDER SUBLAYER
DTE = DATA TERMINAL EQUIPMENT
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

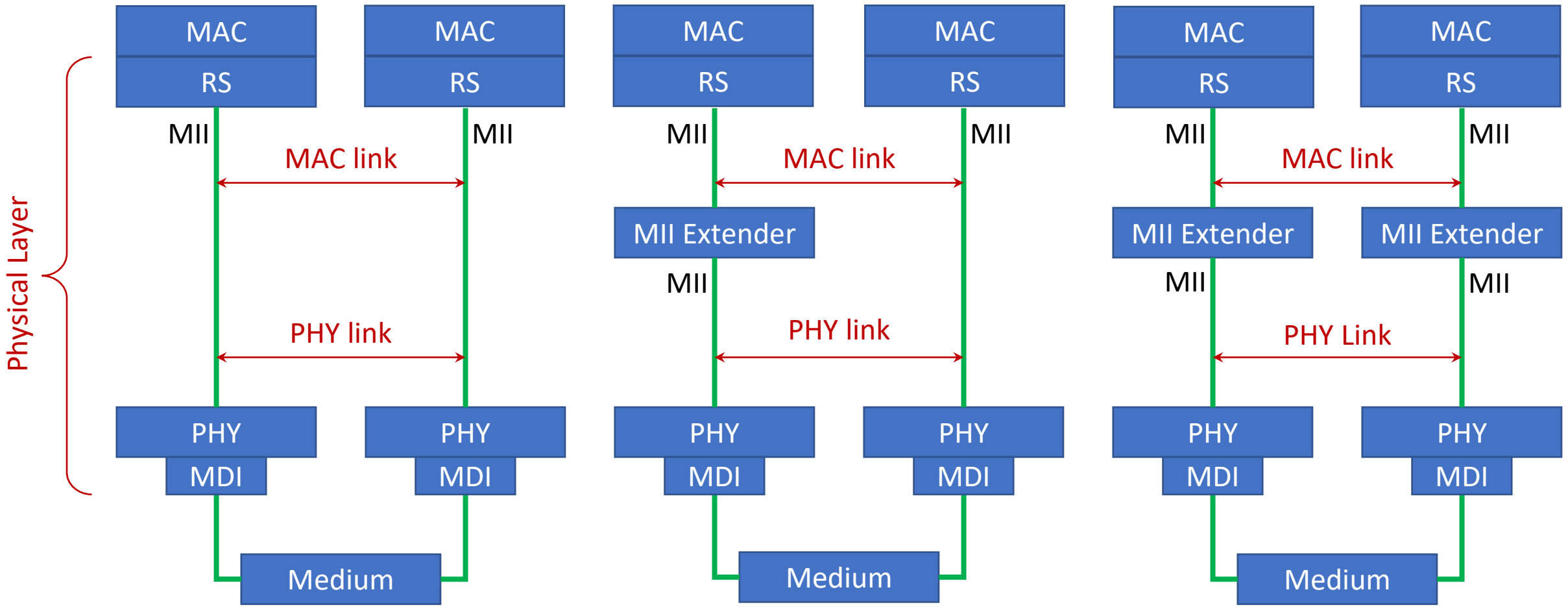
Figure 171–1—800GXS relationship to the ISO/IEC Open System Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

200GAUI-n = 200 Gb/s n-LANE ATTACHMENT UNIT INTERFACE
200GMII = 200 Gb/s MEDIA INDEPENDENT INTERFACE
200GXS = 200GMII EXTENDER SUBLAYER
400GAUI-n = 400 Gb/s n-LANE ATTACHMENT UNIT INTERFACE
400GMII = 400 Gb/s MEDIA INDEPENDENT INTERFACE
400GXS = 400GMII EXTENDER SUBLAYER
DTE = DATA TERMINAL EQUIPMENT
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 118–1—200GXS and 400GXS relationship to the ISO/IEC Open System Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

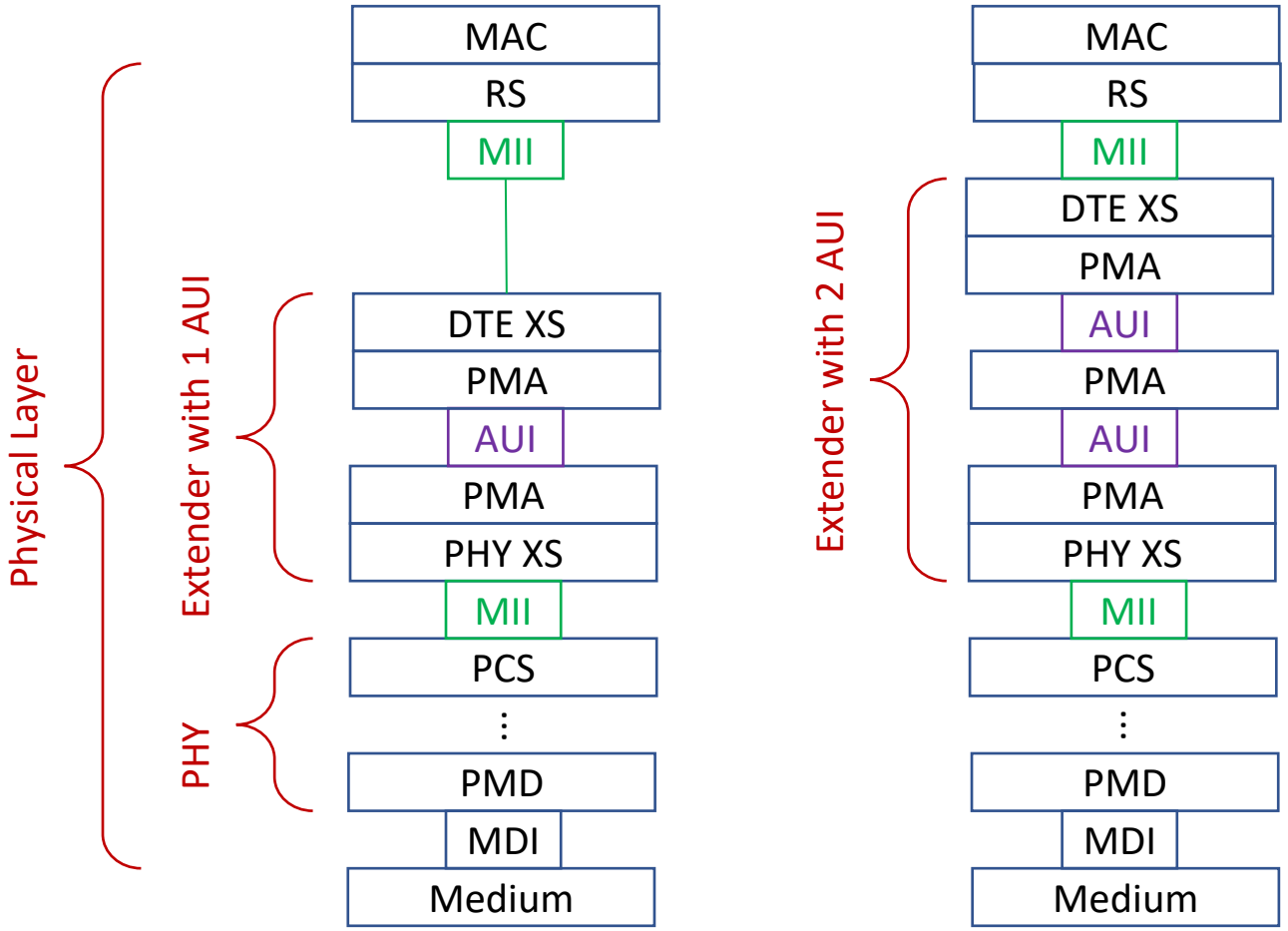
Ethernet Physical Layer View

RS here means “Reconciliation Sublayer”, not “Reed-Solomon”.

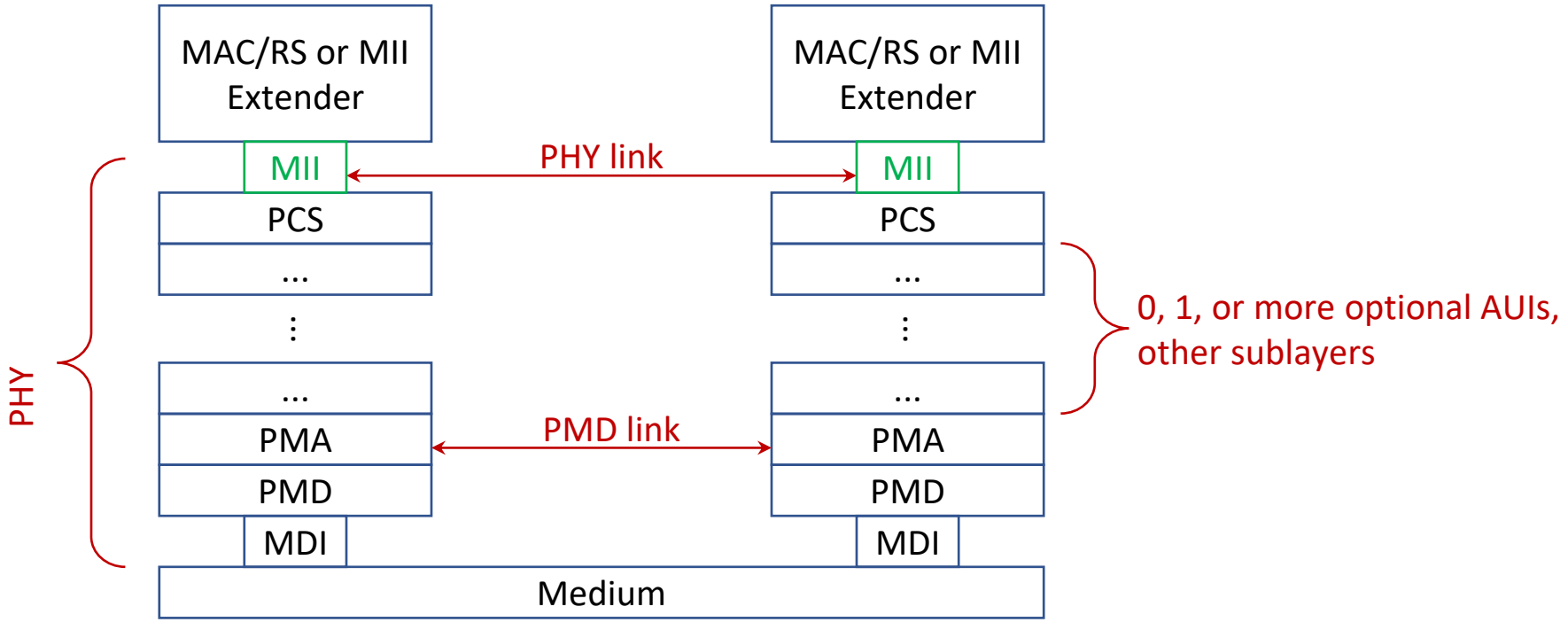


MAC link = path from MII below one MAC/RS to the MII below the other MAC/RS (i.e., MAC to MAC) – not IEEE term
PHY link = path from MII above one PHY to the MII above the other PHY – not IEEE term
If there are no MII Extenders then MAC link = PHY link (far left)

MII Extender



Ethernet PHY view

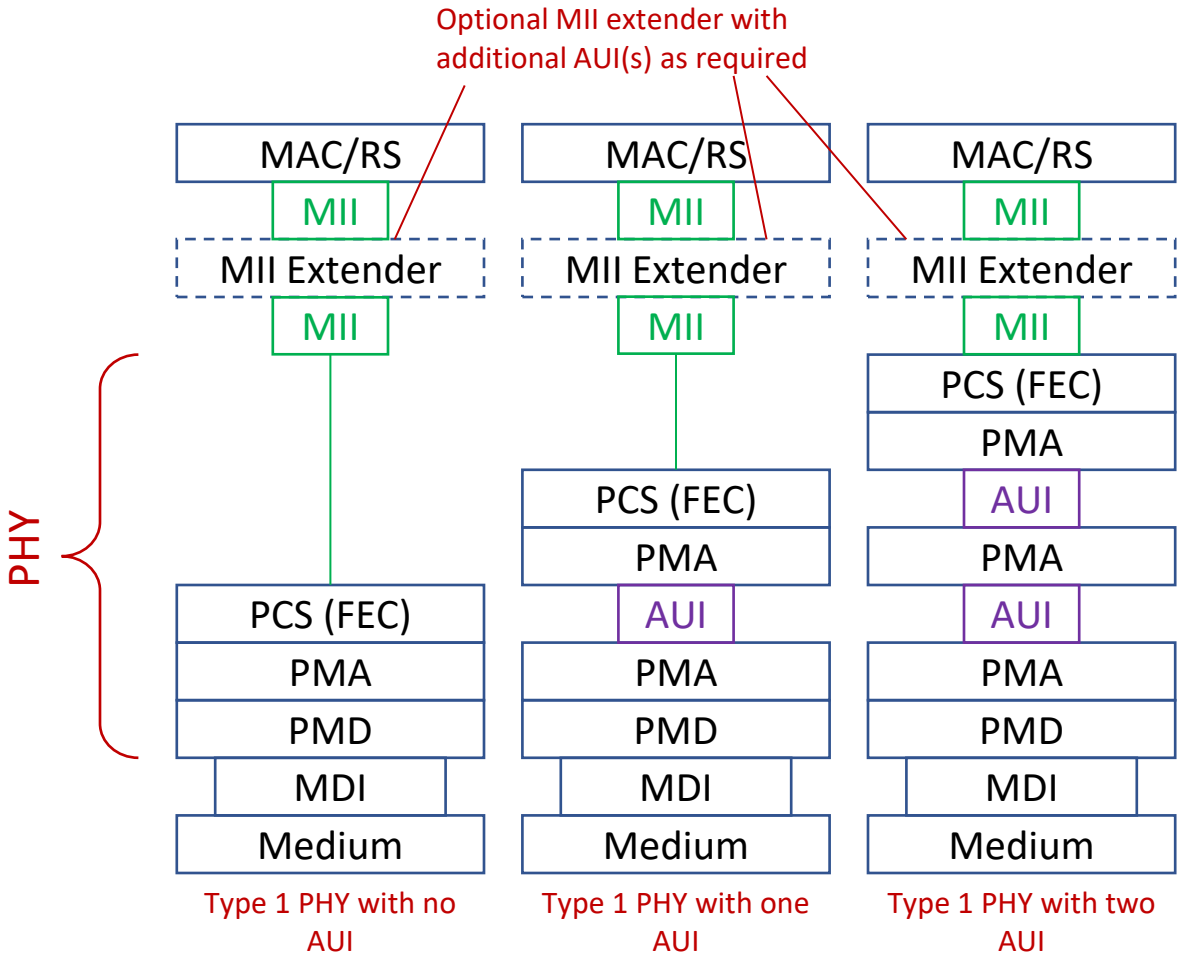


PMD link = path from PMD at one end to PMD at the other end (i.e., no AUIs) – not IEEE term
The PHY on each end of the PMD link is of the same Type: 1, 2, or 3 (see later slides)

PHY/FEC types

- Three PHY/FEC types are explored
- Type 1: single FEC spans multiple AUIs and the PMD link
  - sometimes referred to as “end-to-end FEC”
- Type 2: outer FEC spans multiple AUIs and the PMD link (like Type 1), additional inner FEC spans PMD link
  - sometimes referred to as “concatenated FEC”
- Type 3: FEC is dedicated to PMD link
  - sometimes referred to as “segmented FEC”

Type 1 PHY/FEC



- A single FEC spans the PHY link (PCS to PCS) which may include up to four AUIs.
- FEC corrects errors that are contributed by the PMD link and the AUIs.
- PMD and Medium characteristics are defined with AUI errors in mind.
- BER trade off between the AUIs and the PMD link.
- More AUIs may be added above the PHY using the optional MII Extender without affecting PHY performance.
- The following PHYs are Type 1 PHY/FEC:
  all 200GBASE-R in 802.3, 802.3ck, 802.3db
  all 400GBASE-R in 802.3, 802.3ck, 802.3db
  all 800GBASE-R in 802.3df

Type 1 BER Specification Example

From IEEE Std 802.3-2022

121. Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-DR4

121.1.1 Bit error ratio

The bit error ratio (BER) when processed according to Clause 120 shall be less than 2.4×10^{-4} provided that the error statistics are sufficiently random that this results in a frame loss ratio (see 1.4.344) of less than 1.7×10^{-12} for 64-octet frames with minimum interpacket gap when processed according to Clause 120 and then Clause 119. For a complete Physical Layer, the frame loss ratio may be degraded to 6.2×10^{-11} for 64-octet frames with minimum interpacket gap due to additional errors from the electrical interfaces.

If the error statistics are not sufficiently random to meet this requirement, then the BER shall be less than that required to give a frame loss ratio of less than 1.7×10^{-12} for 64-octet frames with minimum interpacket gap.

BER requirement for the PMD only.

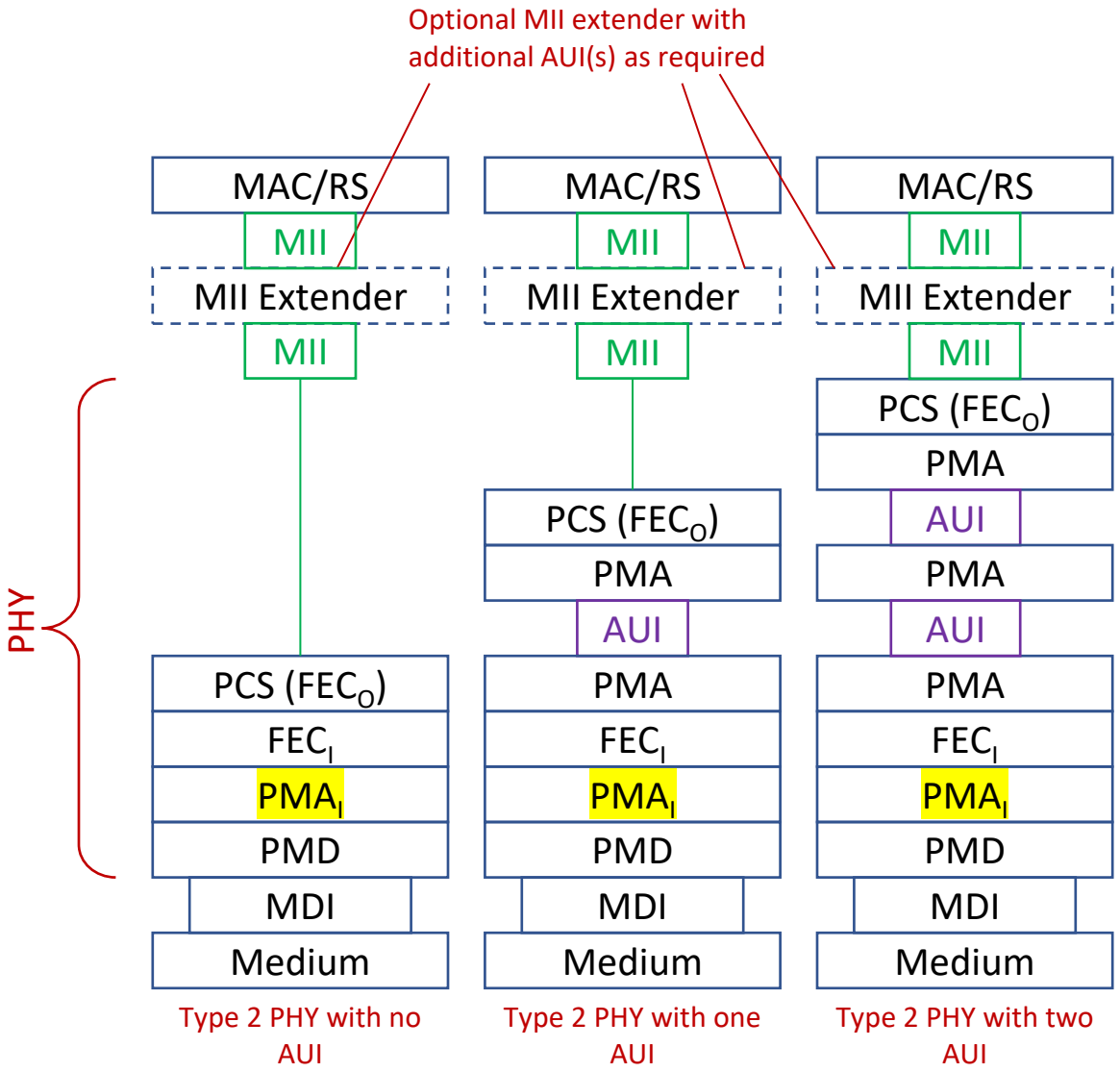
BER requirement for whole Physical Layer.

- 200GBASE-DR4 is a typical Type 1 optical PHY
- For the PMD link:
  - BER limited to 2.4E-4 (if random errors)
  - FLR limited to 1.7E-12
- For the PHY link:
  - FLR is limited to 6.2E-11

Type 1 PHY/FEC

- The intent of a Type 1 PHY/FEC is to provide minimum net latency, power, and complexity (gate count) due to FEC processing in the PHY link.
- Pro:
  - Latency limited to a single FEC encode-decode pair.
- Con:
  - PMD specifications must be tightened up to allow for errors introduced by AUI(s).

Type 2 PHY/FEC

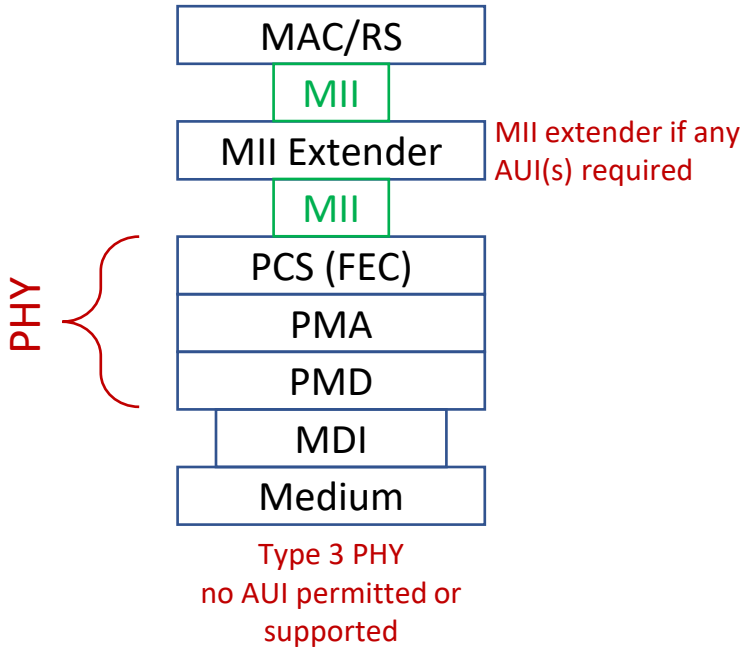


- An outer FEC (FEC$_O$) spans the PHY link (PCS to PCS) including up to four optional AUIs (like Type 1)
- An inner FEC (FEC$_I$) spans only the PMD link (PMD to PMD)
- The PMA below FEC$_I$ (PAM$_I$) is different from the PMAs above FECI.
- FEC$_I$ corrects “most” errors contributed by the PMD link
- FEC$_O$ corrects errors not corrected by FEC$_I$ and error contributed by the AUIs
- The combined effect of FEC$_I$ and FEC$_O$ results in the target frame loss ratio (FLR) for the PHY.
- FEC$_I$ and FEC$_O$ defined in conjunction with each other.
- PMD and Medium characteristics defined with AUI errors in mind.
- BER trade off between the AUIs and the PMD link.
- More AUIs may be added above the PHY using the MII Extender without affecting PHY performance.
- This PHY/FEC type is new for 802.3.

Type 2 PHY/FEC

- The intent of a Type 2 PHY/FEC is to provide a compromise with better performance than Type 1 and lower net latency, power, and complexity (gate count) than Type 3 for the PHY Link.
- Pros:
  - Provides extra FEC processing (allows for higher pre-FEC BER) for the PMD Link compared with smaller increment in latency, power, and complexity compared with Type 3.
  - Can permit higher AUI BER than Type 1.
  - Higher signaling rate due to enhanced FEC limited to just the PMD link and does not affect the AUI links.
  - Allows inner code to be collocated with the PMA/PMD so that soft decoding is an option.
- Cons:
  - For the same FEC encoding, PMD specifications must be tighter (compared to Type 3) to allow for errors introduced by AUI(s).
  - Careful consideration of combined effect of inner and outer FECs is required.

Type 3 PHY/FEC



- An FEC spans the PHY link (PCS to PCS) with no AUIs in either PHY.
- If one or more AUIs are required at either end, then an MII Extender is always required.
- The FEC corrects errors contributed ONLY by the PMD link.
- The FEC may take many forms, e.g., RS only, RS + Hamming/BCH (like Type 2), oFEC, etc.
- FEC may be defined independently of other encoding sublayers.
- PMD and Medium characteristics defined independent of AUI characteristics.
- No trade off between the AUIs and the PMD link is required.
- The following PHY is a Type 3 PHY/FEC:
  400GBASE-ZR in 802.3cw

Type 3 PHY/FEC

- The intent of Type 3 PHY/FEC is that the PMD FEC is optimized for and dedicated to the PMD link.
- Pros:
  - Errors created by AUI(s) are isolated from PMD link.
  - No interaction with other encoding sublayers.
  - A higher signaling rate (if needed) of enhanced FEC limited to just the PMD link and does not affect the AUI links.
- Cons:
  - Extra latency, power, complexity (gates) due to FEC processing (compared to Type 1 and Type 2) due to 3 FEC segments (3 encoders/decoders) to support AUIs at both ends.

Conclusion

- Three unique PHY/FEC types are explored.
- Each type has a set of advantages and disadvantages and uniquely impacts how the PMD and medium are specified.
- Use of terms like “end-to-end” and “segmented” to describe these schemes are ambiguous.

Appendix

Thanks