10 Mb/s Single Twisted Pair Ethernet
PCS Layer Ideas

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Common PCS Layer

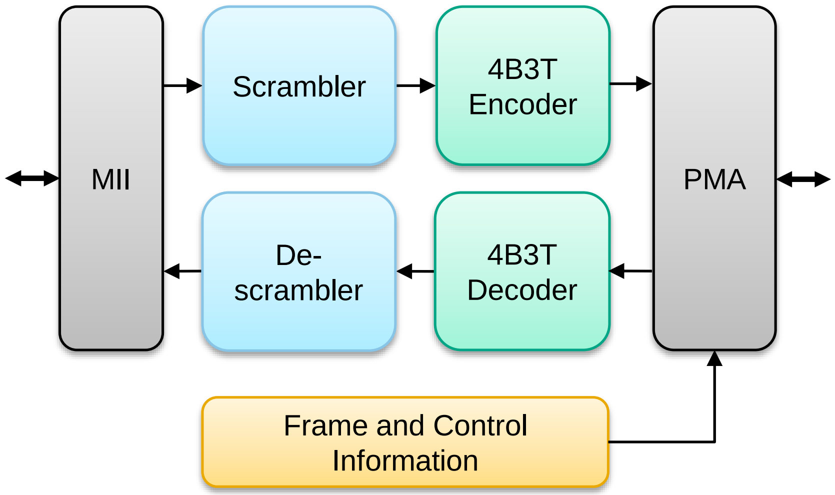
- As the 802.3cg PHY project is targeting a short and a long distance PHY, the idea is to keep as much of the implementation identical for the two different PHYs and to only implement changes in the PMA, but not in the PCS layer.
- Keeping the PCS layer the same, it is important, that already the binary bit stream, generated within the PCS layer out of the MII data stream, has the ability to transparently add control information before encoding this binary bit stream.

- The current 4B3T encoding adds the control information after encoding the bit stream into ternary symbols and therefore the coding of the control information is being bound to the line code.
- Therefore it would not be possible, to easily exchange the PMA layer for going to a simpler modulation, when creating a PHY for a short distance link.

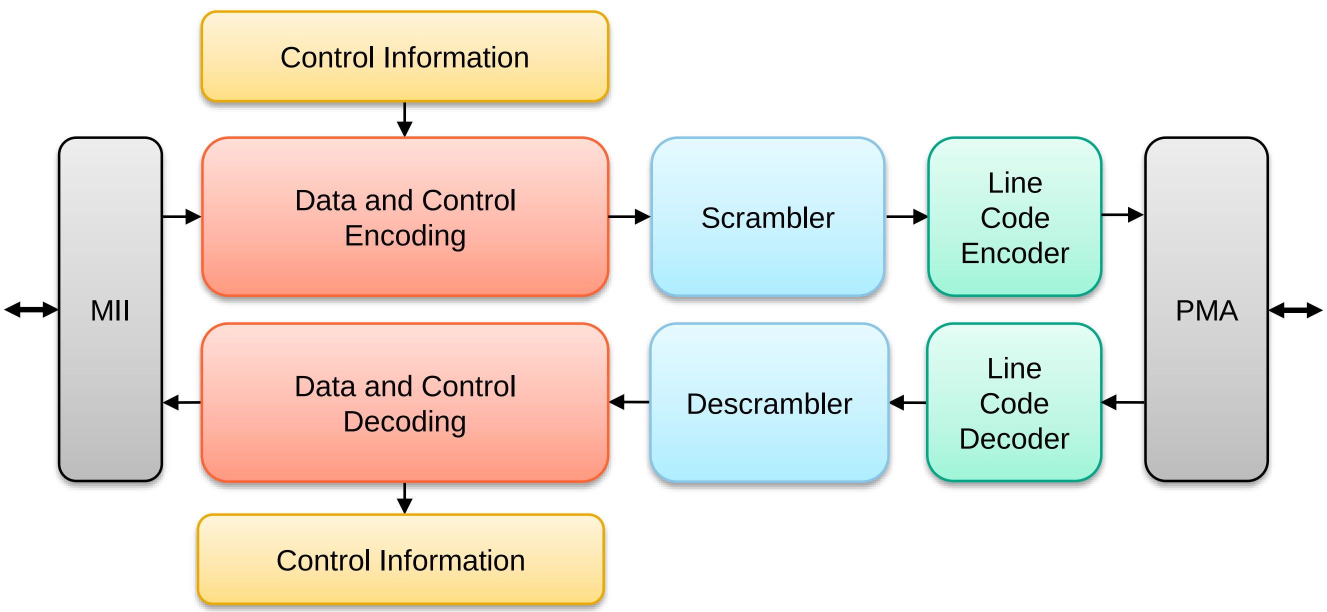
- If we decide, that we want to keep the PHY design for the short and the long distance PHY as near as possible, then a common PCS layer makes sense.

- For this it is important to separate the coding of the data/control stream and the line code.

PCS Layer Structure



Current PCS layer with self-synchronizing scrambler and 4B3T encoder.



Principle new PCS layer.

PCS Layer Requirements

- There are different requirements for the PCS layer, which have to be fulfilled:
  - Data and control information should be included into the same binary data stream.
  - As there is likely no FEC code, there is a need for a defined start of a data or control packet, so that a single bit error does not destroy the data stream for a longer duration.
  - The lower frequency content of the communication signal needs to be limited to allow an acceptable size of the power coupling inductors and the signal coupling capacitors.
  - The maximum BLW of the communication signal needs to be limited, not to run into the diode clamping of the inductors needed for intrinsically safe segments.
  - There needs to be an efficient line code to convert the binary signal into PAM-3 symbols.
- On the following slides the different requirements are explained in more detail.

Encoding of Data and Control Information

- Currently there are two different efficient encoder types for encoding the data and control information into a common binary data stream being used in the field of Ethernet:
  - 64B/66B or 128B/130B (or similar) encoders, which need 2 bit overhead, additionally to the payload data.
    - A “01” transition at the beginning of a packet signalizes a data packet.
    - A „10“ transition at the beginning of a packet signalizes a control packet.
    - „00“ and „11“ are not allowed and cause a receive error.
  - 64B/65B or 80B/81B (or similar) encoders, which need 1 bit overhead additionally to the payload data
    - A single „0“ at the beginning of a packet signalizes a data packet.
    - A single „1“ at the beginning of a packet signalizes a control packet.
  - While a code with only one bit for distinguishing between a data and a control packet provides a lower coding overhead, such codes typically require an additional error correcting code (e.g. RS or LDPC), because otherwise flipping of this single bit could have a significant impact on the PHY receive side.
- The longer the data block is, the less coding overhead is necessary.
- On the other side, the longer the data block gets, the latency of the PHY is also being increased.
- Therefore a 64B/66B encoding (or even using smaller packets) could be a good compromise.

64B/66B Encoding

- A 64B/66B adds a 2 bit header depending, if a pure data packet is being transmitted or, if a control packet/combined control and data packet is being transmitted:

0	**1**	**64 bit scrambled data**

1	**0**	**8 bit type**	**56 bit scrambled combined control/data**

- „00“ or „11“ headers are seen as code errors, so that the decoder outputs an error.

- At the beginning and the end of an Ethernet data packet transmission a combined control/data packet containing the start and termination symbols is being transmitted, within an Ethernet data frame pure data packets are being transmitted.
- During the idle phase control packets containing the idle code are being transmitted.

Scrambler/Descrambler

- Within the 64B/66B encoder the data and control information are being scrambled before adding the header.
- In the 64B/66B decoder the header is being removed and afterwards the data or control information are descrambled.
- From the topology self synchronizing scramblers are being used.

- As scrambler polynomial for the master device $x^{58} + x^{39} + 1$ could be used.
- As scrambler polynomial for the slave device $x^{58} + x^{19} + 1$ could be used.

- The use of two different scrambler polynomials is important, to allow an independent training of the echo canceller and equalizer.

Limitation of lower Corner Frequency

- The lower corner frequency of the PHY receive input path is currently approx. 200 kHz.
- This is a good compromise between cutting of low frequency disturbers, but not cutting of too much signal energy.

- While the high pass filter corner frequency of the receiver is in the range of 200 kHz, allowing for component tolerances the lower communication signal frequency part should be in the range of 250 kHz or above.
- For the current 4B3T encoding a maximum of 5 consecutive „+1“ or „-1“ can occur, which would be equivalent to a trapezoidal signal with a frequency of 750 kHz.
- From the 4B3T coding rules also a sequence of “… |−0+|+++|+0−|−−−|−0+|+++|+0−|−−−| …” is possible, which has a period of 12 symbols, leading to a minimum signal frequency of 625 kHz.

- Depending on the chosen coupling network for providing energy to the link segment, using two times 500 µH inductors in combination with 200 nF capacitors, the 200 kHz high pass filter allows for a power supply noise tolerance (excluding the coupling network) of up to 100 mV_{pp} assuming 10 mV_{pp} in-band noise.
- Going to a lower high pass filter frequency would cause a need for higher inductance values or would cause a reduced power supply noise tolerance.

Limitation of maximum allowed BLW

- The coupling circuit intended to be used for intrinsically safe applications, will contain several clamping diodes, which have an influence on the communication signal.
- The higher the BLW is, the higher the influence of the clamping diodes will be, especially at higher temperatures.
- The maximum BLW should not exceed approx. 10 % to prevent an unintended clamping of the communication signal.
- As the specified, maximum allowed BER is 10^{-9}, the probability for a BLW of more than 10 % should be below 10^{-11}, to have some safety margin.

Line Codes

- Depending on the PMA layer different line codes can be used in combination with the same PCS layer.
- E.g. for the short distance PHY a 2-PAM with DME encoding could be used.
- E.g. for the long distance PHY a 3-PAM with a 4B3T code (which produces very low BLW), a 3B2T code (which produces excessive BLW) or something in between (which limits the BLW and the lower frequency content of the communication signal on one side and has a better coding efficiency on the other side), but which is not yet designed, could be used.
- The line code mainly depends on the physical properties of the link segment.
- For a short link segment a line code with only two PAM levels working at a higher symbol rate makes sense, as it keeps the size of the coupling network components smaller and the communication frequency is in a range, where less disturbances occur within e.g. an electrical vehicle.
- For a long distance link segment a line code with three PAM levels makes more sense to keep the signal frequency down, but this increases the size of the coupling network components.
- Nevertheless the lower communication signal frequency is important to allow for the long reach.
- For intrinsically safe applications, it is important to keep the BLW low (typ. not more than 10 % to allow the clamping of the coupling inductors using silicon diodes).
- For the long distance link segment it is also important to limit the lower corner frequency of the communication signal to be able to suppress disturbers in the lower frequency band.

Line Codes

- While for the short distance link a DME encoding seems to be suitable, as it provides for a baseband system a high communication signal frequency (being outside the main disturbers frequency range within a vehicle) and also allows for small inductor sizes within the coupling network, this modulation is not suitable for the long reach PHY, as it is a very inefficient encoding, which is suitable mainly for short links with a low insertion loss.

- The following table shows the needed symbol rate for a transmission of 10 Mbit/s using different line codes in combination with a 64B/66B coding or a comma sequence within the inter-frame gap for the control information:

Line Code	Control Encoding	Approx. Symbol Rate	Approx. Nyquist Frequency	IL @ Nyquist Freq.
3-PAM	64B/66B Encoding	6.506463 MS/s	3.2532315 MHz	23.98 dB
4B3T	Comma Sequence	7.500000 MS/s	3.7500000 MHz	25.61 dB
4B3T	64B/66B	7.734375 MS/s	3.8671875 MHz	25.99 dB
3B2T	Comma Sequence	6.666667 MS/s	3.3333333 MHz	24.25 dB
3B2T	64B/66B	6.875000 MS/s	3.4375000 MHz	24.60 dB
DME	64B/66B	10.312500 MS/s	10.3125000 MHz	41.80 dB

- Channel Model: IL [dB] = 10 * (1.23 * SQRT(f/MHz) + 0.01 * f/MHz + 0.2 / SQRT(f/MHz)) +
  10 * 0.02 * SQRT(f/MHz)

Line Codes

- As it can easily be seen, the DME coding is not suitable for a long reach link segment, because the insertion loss is significantly too high, but seems to be suitable for shorter link segments.
- Having a closer look at the 3-PAM line codes, as shown in the first line of the table an insertion loss of 24 dB is the theoretically minimal possible insertion loss, assuming a 64B/66B coding for the control and data information, but no line code at all.
- More interesting is the comparison between the 4B3T line code with additional 66B/64B encoding and the currently implemented 4B3T line code using a comma sequence.
- The additional insertion loss at Nyquist frequency, when keeping the 4B3T line code and just increasing the symbol rate, is approx. **0.4 dB**.
- The additional loss in SNR assuming an AWGN channel is even lower and can be approx. calculated to:

$$\Delta SNR_{dB} = \frac{1}{f_{Nyquist} - f_{HP}} \cdot \int_{f_{HP}}^{f_{Nyquist}} IL(f)\, df - \frac{1}{\frac{66}{64} \cdot f_{Nyquist} - f_{HP}} \cdot \int_{f_{HP}}^{\frac{66}{64} \cdot f_{Nyquist}} IL(f) df$$

- Setting the Nyquist frequency to 3.75 MHz, the high pass filter frequency to 200 kHz and using the insertion loss model of the 1000 m link segment calculates an additional loss in SNR of:

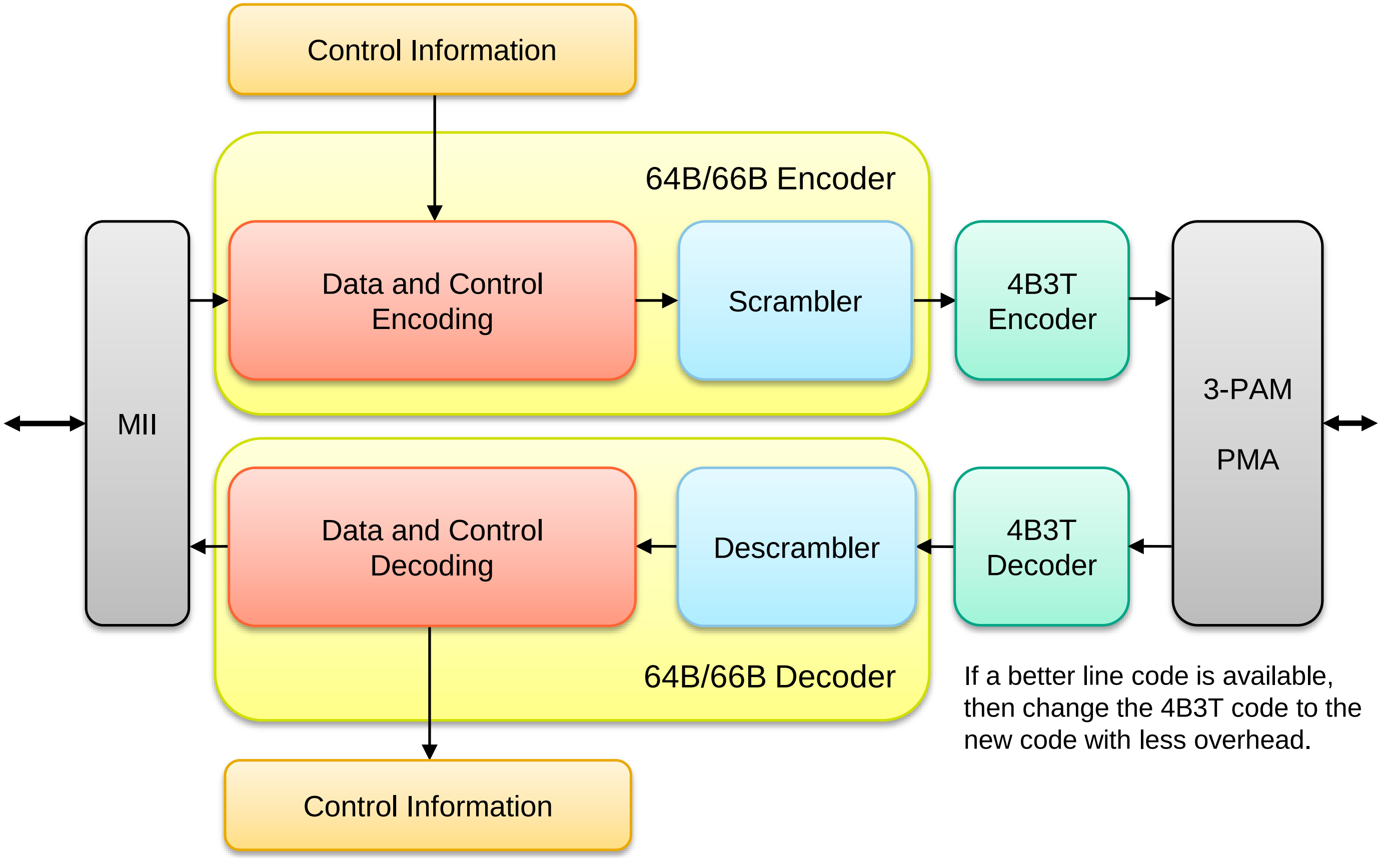
$$|\Delta SNR_{dB}| = |18.71\, dB - 18.94\, dB| = \mathbf{0.23\, dB}$$

Line Codes

- Comparing the 4B3T line code in combination with a 64B/66B coding, which tightly controls the BLW with a 3B2T line code also in combination with a 64B/66B coding, which has no BLW control at all, the additional insertion loss at Nyquist frequency is approx. **1.4 dB**.
- The additional loss in SNR, using the same calculation as on the slide before, is about **0.85 dB**.
- While the 4B3T line code marks the upper bandwidth needs, as additional information are needed to tightly control the BLW, the 3B2T marks the lower bandwidth needs in a practical implementation.
- A line code, which provides a compromise between needed bandwidth and BLW control, is expected to be somewhere in between these two codes.

Long Distance PCS Layer Idea

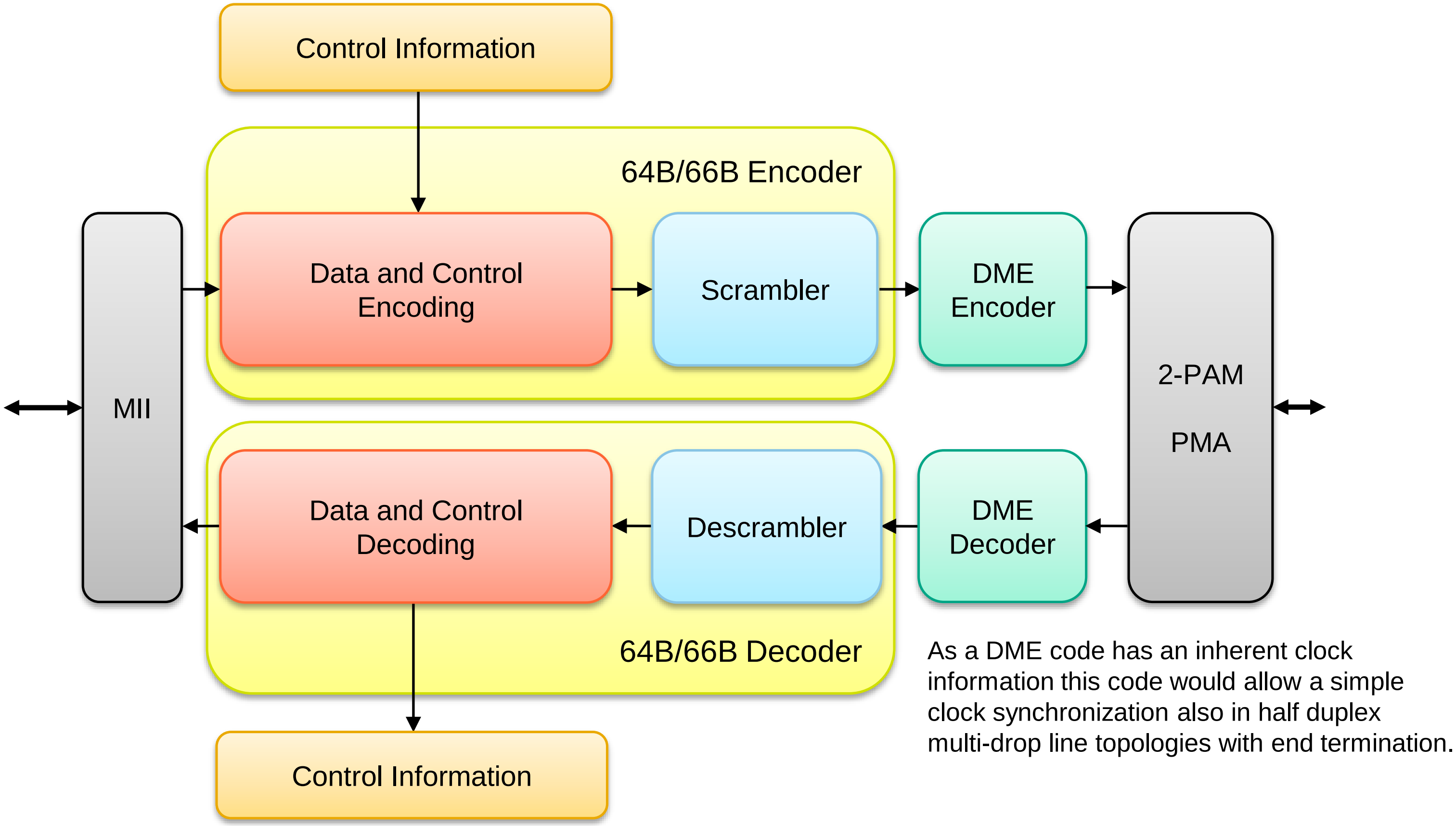
- Usage of a 64B/66B Encoder in the PCS layer and 4B3T as line code as a first step:



- The symbol rate would be 7.734375 MS/s (10 MHz * 99 / 128) instead of 7.5 MS/s.
- The additional loss in SNR added by the 64B/66B coding is about 0.23 dB.
- The additional IL of 0.4 dB equals to a cable length of approx. 15 m assuming a 1000 m link segment.

Short Distance PCS Layer Idea

- Usage of a 64B/66B Encoder in the PCS layer and DME as line code as a first step:



- The symbol rate would be 10.3125 MS/s (10 MHz * 66 / 64), which allows the usage of small inductors and capacitors in the coupling network.
- Only suitable for shorter reach link segments as insertion loss is too high for the long reach link segment.

Comparison Table

- The following table provides an overview about the properties of different PCS layer implementations:

Line Code and Control Coding	Symbol Rate	BLW	Coupling Network Size	Digital Simplicity	Analog Simplicity	Latency	Long/Short Distance PCS Integration
4B3T	+	++	o	++	+	+	-
4B3T with 64B/66B	o	++	o	+	+	o	++
3B2T with 64B/66B	++	--	-	+	-	o	++
New Code with 64B/66B	+/++	o/+	o/-	o/+	o/+	o/-	++

- Thinking about a new line code for the long distance PCS layer, the properties of this line code likely will be somewhere in between the 4B3T code and the 3B2T code.
- When developing such a line code, a good trade off between symbol rate, BLW and size of the coupling network needs to be found.
- It is important to keep the lower corner frequency of the communication signal as high as possible to also keep the coupling network size in an acceptable range.
- A 64B/66B encoding provides an independent control information coding, which helps to keep the PCS layer identical for the short and the long reach PHY, but also adds up an additional latency compared to the simple 4B3T code of approx. 64 bit times within the PHY.

Conclusion

- When trying to keep the development of the long and short distances PHY as close as possible, a common PCS layer makes sense.
- A 64B/66B coding adds some overhead and some complexity, but allows for an exchange of the PMA layer independently from the rest of the PHY IC.

- Important for the long reach link is to find a good line code.
- One approach could be to just use 4B3T as line code and live with the additional overhead of the 64B/66B encoding, slightly increasing the symbol rate.
- This will lead to an additional loss in SNR of 0.23 dB, but, due to the short pulse lengths and therefore relatively high lower corner frequency of the communication signal, will have several benefits related to BLW, droop and coupling network size and due to the short code length also latency.

- If the group has good ideas for a new line code, the 4B3T line code could be easily exchanged by the new line code afterwards.
- This line code needs to provide a good compromise between coding efficiency, BLW limitation, power coupling network size and code length.

Thank You