Modulation wars: How to steer through uncertainty

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Introduction

- This is not a proposal of a modulation scheme
  - We are still in study group phase – too early for that
  - But discussions about modulation for 400 Gb/s/lane are ongoing for a long time
- It looks like discussion of modulation is imminent
  - This is not the first time we are in this situation
  - “Those who don’t remember the past are condemned to repeat it” (George Santayana)
- This presentation is intended to provoke thoughts related to this discussion
  - Without a clear bottom line

Simplistic/theoretical view

- Assuming the BASE-R encoding with RS(544,514) at the PCS (6.25% PCS/FEC overhead), the baseline transmitted bit rate for 400GPL is 400*17/16=425 Gb/s
- This can be accomplished by
  - PAM2 aka NRZ: 1 bit/symbol ➔ 425 GBd, Nyquist frequency = 212. 5 GHz
  - PAM4: 2 bits/symbol ➔ 212.5 GBd, Nyquist frequency = 106.25 GHz
  - PAM6: ~2.5 bits/symbol ➔ 170 GBd, Nyquist frequency = 85 GHz
  - PAM8: 3 bits/symbol ➔ 141.6… GBd, Nyquist frequency = 70.83… GHz
  - And others
- Depending on available channel bandwidth

What is the available channel bandwidth?

- Depends on the medium and the endpoints
- For some optical media, it may be considered unlimited
  - Endpoints are the bottleneck
  - 106.25 GHz (required for PAM4) is commonly considered feasible
- In electrical media there are harder bandwidth limits
  - Sufficiently high SNR
  - Reasonable group delay variation
  - Reasonably resonance free
  - Reasonably mode-conversion free
  - 106.25 GHz looks very challenging!
- With limited output swing, increasing modulation depth carries an SNR penalty
  - Crosstalk, Tx noise, Rx noise hurt more
  - Stronger FEC may be needed (“coding gain”)

We've been here before

A recent example (not the first) is Clause 94, 100GBASE-KP4

- In development of IEEE 802.3bj-2014 there were similar concerns
  - The relevant objective was 100 Gb/s over 4 backplane lanes
  - Initial electrical channels contributed to the project suggested that "NRZ" was not feasible, thus PAM4 was proposed
  - A "modulation war" ensued
  - Eventually we defined two backplane PMDs – Clause 93, 100GBASE-KR4 (PAM2) and Clause 94, 100GBASE-KP4 (PAM4) – with considerable effort
  - 802.3bj took 3.5 years to complete
- Optical PMDs were not defined by 802.3bj but were part of the discussion
  - 802.3bm followed with an optical PMD and AUIs
- Eventually the market clearly chose one solution
  - Improved channel technology became available
  - 25 GBd NRZ was prevalent, 100GBASE-KP4 had no significant adoption
  - Was it a mistake?

Why Clause 94 wasn't a mistake

1. New modulation required new tools. We developed:
   - A modulation-aware channel metric (COM)
   - Modulation-aware transmitter specifications (SNDR, RLM)
   - RS-FEC, and specifically RS(544,514) for PAM4
   - 1/(1+D) Precoding
   - PRBS13Q and PRBS31Q as standard test patterns

   These tools have been used in multiple subsequent projects that defined 50, 100, and 200 Gb/s/lane (electrical and optical PMDs) – enabling faster development of 802.3bs and subsequent projects
2. Experience gathered in design, T&M, system modeling
3. Future technology was unknown – we hedged our bet!

… Back to the future

- Do we believe we will have electrical channels with sufficient bandwidth for PAM4 modulation (Nyquist frequency = 106.25 GHz) available at, or closely after, the completion of the project?
- If so, we can assume PAM4 signaling for electrical interfaces…
  - We can re-use existing architectural building blocks, e.g. SM-PMA, and spec methods
  - Significant overlap in DSP solutions for electrical and optical
  - Non-fully-retimed solutions may be possible in the future
  - Mostly ”known unknowns” – parameter values, loss budgets, reference receiver, inner FEC or not (which?)
  - The project can complete relatively quickly (2029?)
- If not, we should assume a higher-order modulation, e.g. PAM6
  - We will need new PMAs, maybe combining modulation and coding
  - We will need new specification tools (all Tx specs)
  - Larger difference between optical and electrical DSPs
  - Fully retimed optics only
  - New unknown unknowns
  - Longer time to project completion (203x?)

Should we do both again?

- Implications
  - Larger effort in the standard, even longer time to completion
  - Uncertainty in the industry
  - Likely one solution will win, the other will be seen – in hindsight – as a waste of time
  - Endpoints supporting two modulations take more time to develop, and are less optimal than single modulation ones
- But
  - We hedge our bet
  - We may dodge the modulation war
  - We lay the ground for the next generation technology (right around the corner!)

Summary

- Optical signaling in 802.3dv will likely use PAM4
- For electrical interfaces we should decide
  - Likely either PAM4, PAM6, or both
  - The longer we take to make the decision, the longer we delay project completion
- Bottom line: ~~~~~~~~~~~~~~~~~~~~~~

That’s all!

Questions?