Considering 2 km and 10 km Architectural Alternatives

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Supporters

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- Sudeep Bhoja – Inphi
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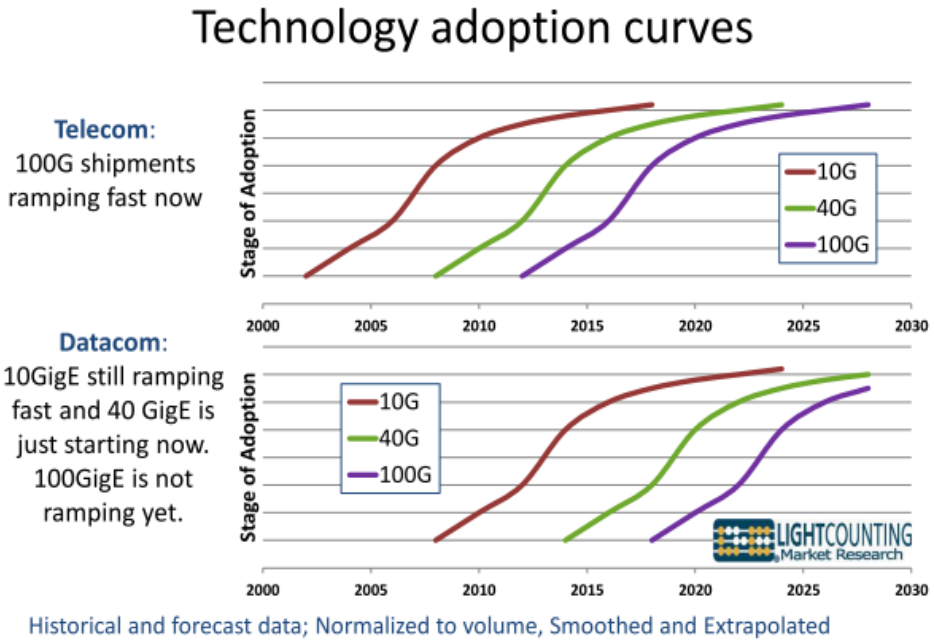
Outline

- Defining “Broad Market Potential” for 2 km and 10 km solutions
- Market View of “Relative Cost” for 2 km and 10 km solutions
- Evaluating “Technical Complexity” of 2 km and 10 km alternatives

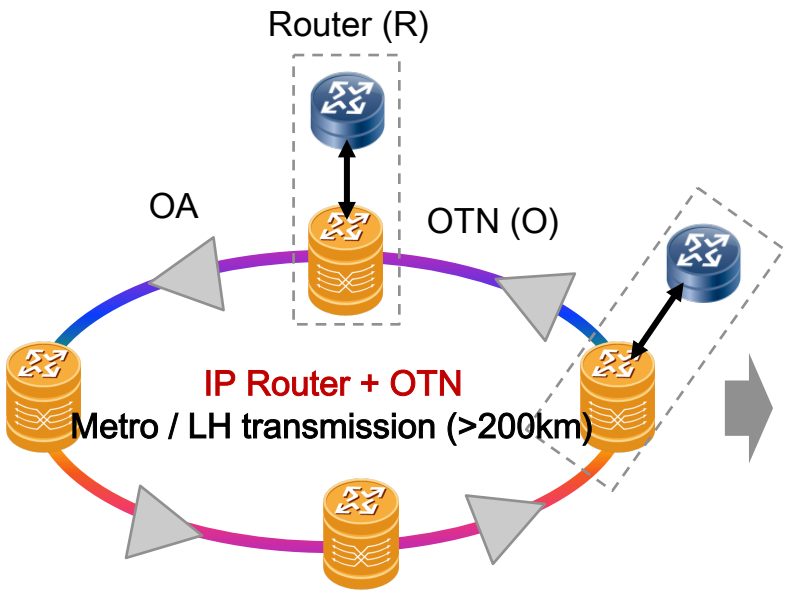
Broad Market Potential (for 2 km and 10 km solutions)

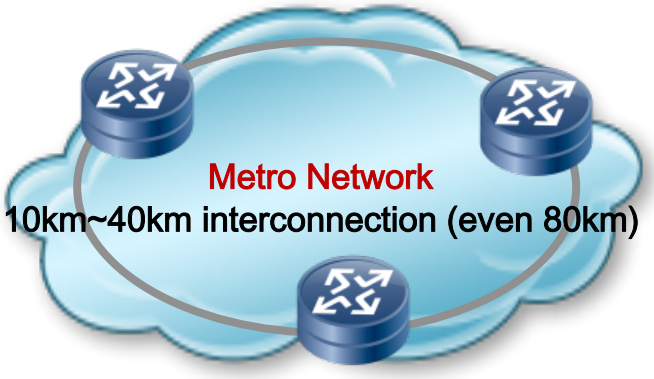
- The term “Broad Market Potential” has changed as Ethernet has evolved from a corporate edge solution into the data center and carrier core solution.
- Volume for a given technology is less important than where it fits into the market, and how many end users are ultimately served by it.
- For example, the volume of 400G router-OTN connections in the world will be much smaller than the volume of 400G data-center fabrics, but both are necessary to enable a broader market for Ethernet.
- However, when we further considered “what do we really want”, the “timing” question is very relevant, and this question needs to be reworded to “what do we really need and when”.
- According to the Lightcounting’s presentation at the previous 400GbE ad-hoc meeting, the overview of the need until about 2020, first needs will be in telecom and interconnection between datacenters and telecom.

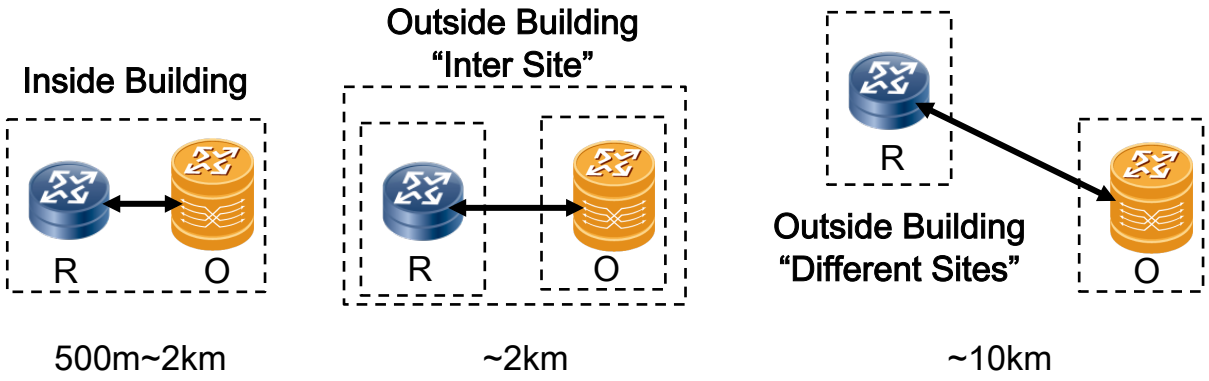


(1) ref: murray_app_01a_1013.

Broad Market Potential (for 2 km and 10 km solutions)







- ~70% of router-OTN connections will be served by a 2 km fiber PMD solution. (1)
- ~15% of router-OTN connections cannot be served by a 2 km fiber PMD but can be served by a 10 km PMD. (1)
- Based upon the current 10GbE situations, 10km can cover at least 60% of link requirements and 40km can cover 80%~90% of requirements. (1)

- Undoubtedly this application enables a "broader market" for Ethernet.
- Given the ratio of 2 km to 10 km market size, the relative cost of these two targets must be carefully considered.

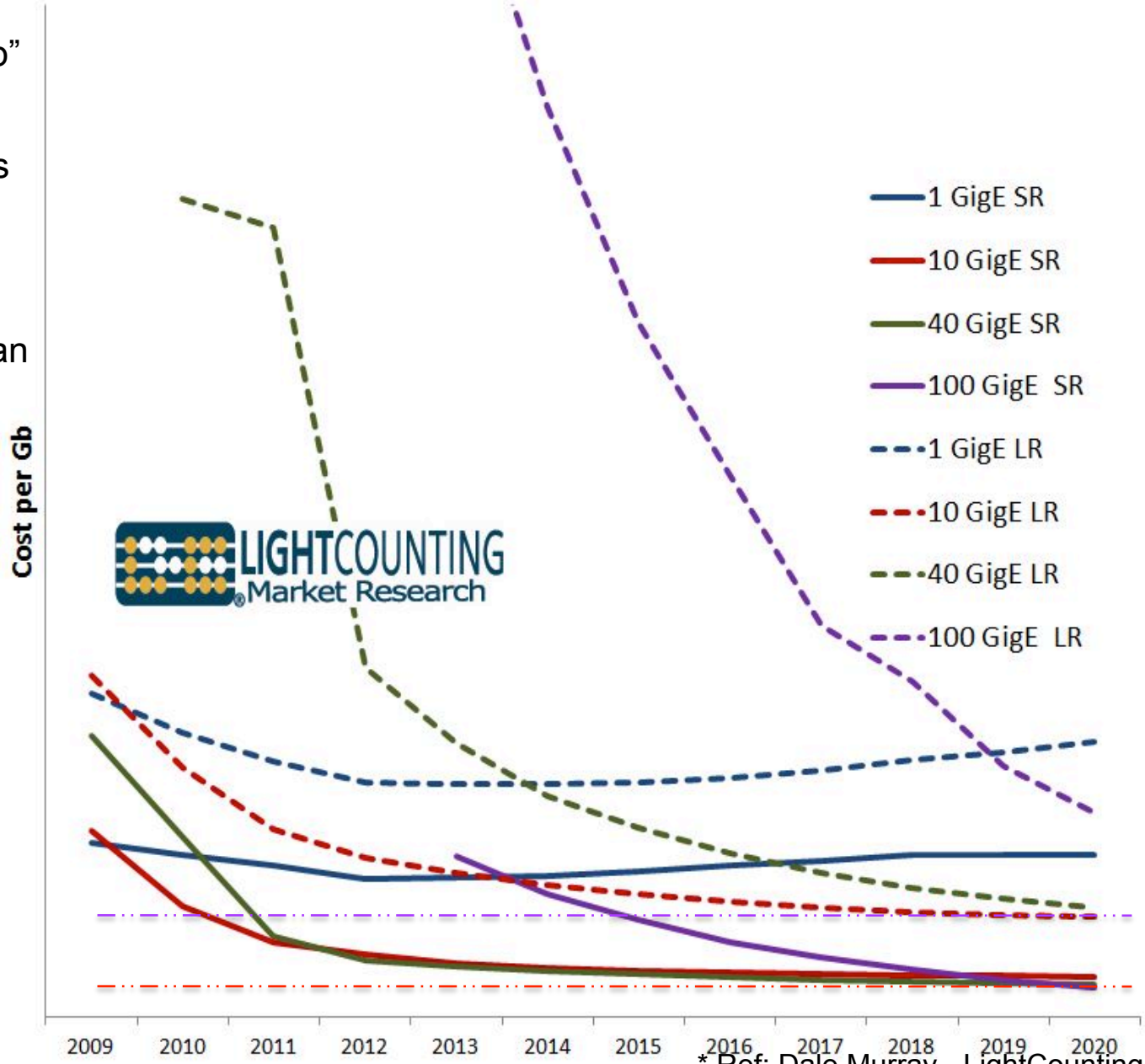
(1) ref: song_x_400_01a_1113.

Relative Cost (for 2 km and 10 km solution)

- Relative Cost requirements at the core are different than they are as they move toward the edge. For longer links, higher cost and complexity may be tolerated in the transceiver if it helps to achieve an overall reduction in system cost.
  - Per-port costs are often amortized over large numbers of users and thus a generic “10x the performance for 3x the cost” expectation does not necessarily make sense.
  - Comparing relative costs in the same application for given technology steps is a more practical approach.
  - Consideration of installed vs. new cabling is important because the cost of installation can be substantial in longer reach applications.
  - “One size fits all” solutions (i.e.: 10 km) can address short-term market needs, but long-term cost focus becomes more important for shorter reach applications.

Relative Cost (for 2 km and 10 km solution)

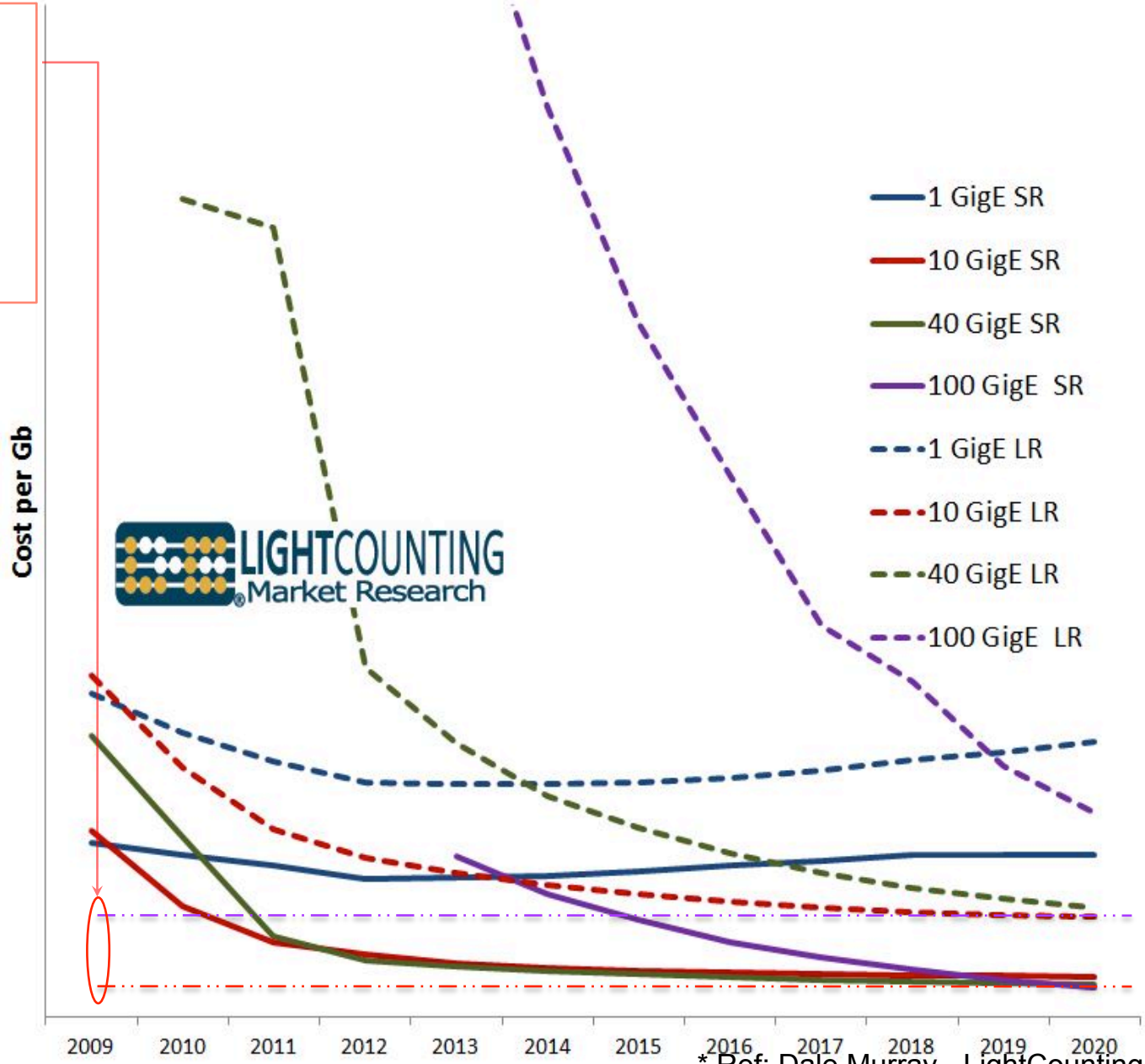
- Slide showing relative “Cost per Gb” actual and projected for various Ethernet transceiver technologies provided by Dale Murray, LightCounting
- A number of useful observations can be made from this slide.



* Ref: Dale Murray - LightCounting

Relative Cost (for 2 km and 10 km solution)

- Asymptotic “Cost” for Long Reach (10km) vs. Short Reach (<300m) shows that market can tolerate > 2x Cost per Gb Δ based on reach / application.



Relative Cost Asymptote

- Long Reach (10km)
- Short Reach (<300m)

* Ref: Dale Murray - LightCounting

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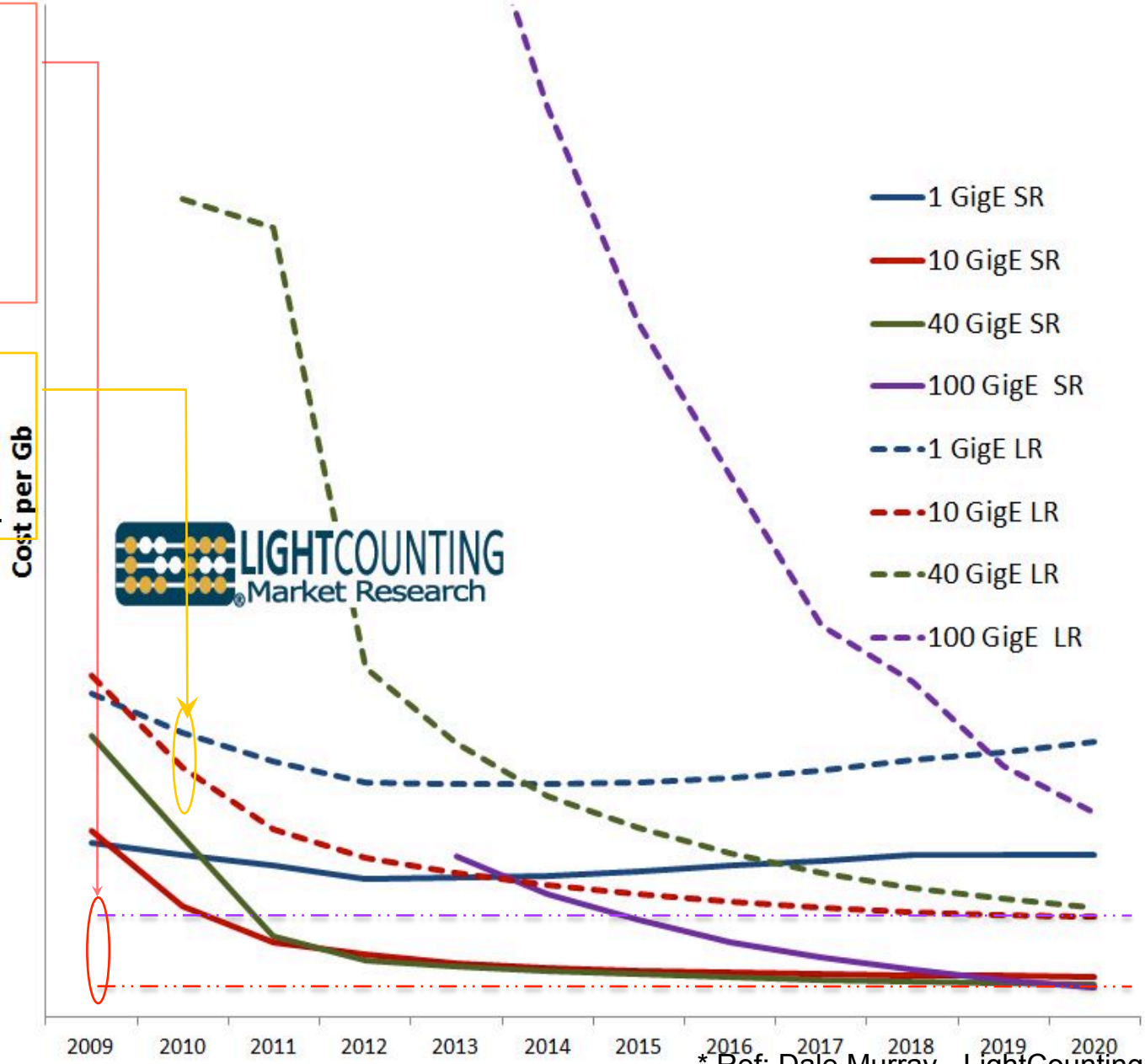
- Observe that as market matures, it is expected that "Cost per Gb" should be lower than prior speed.



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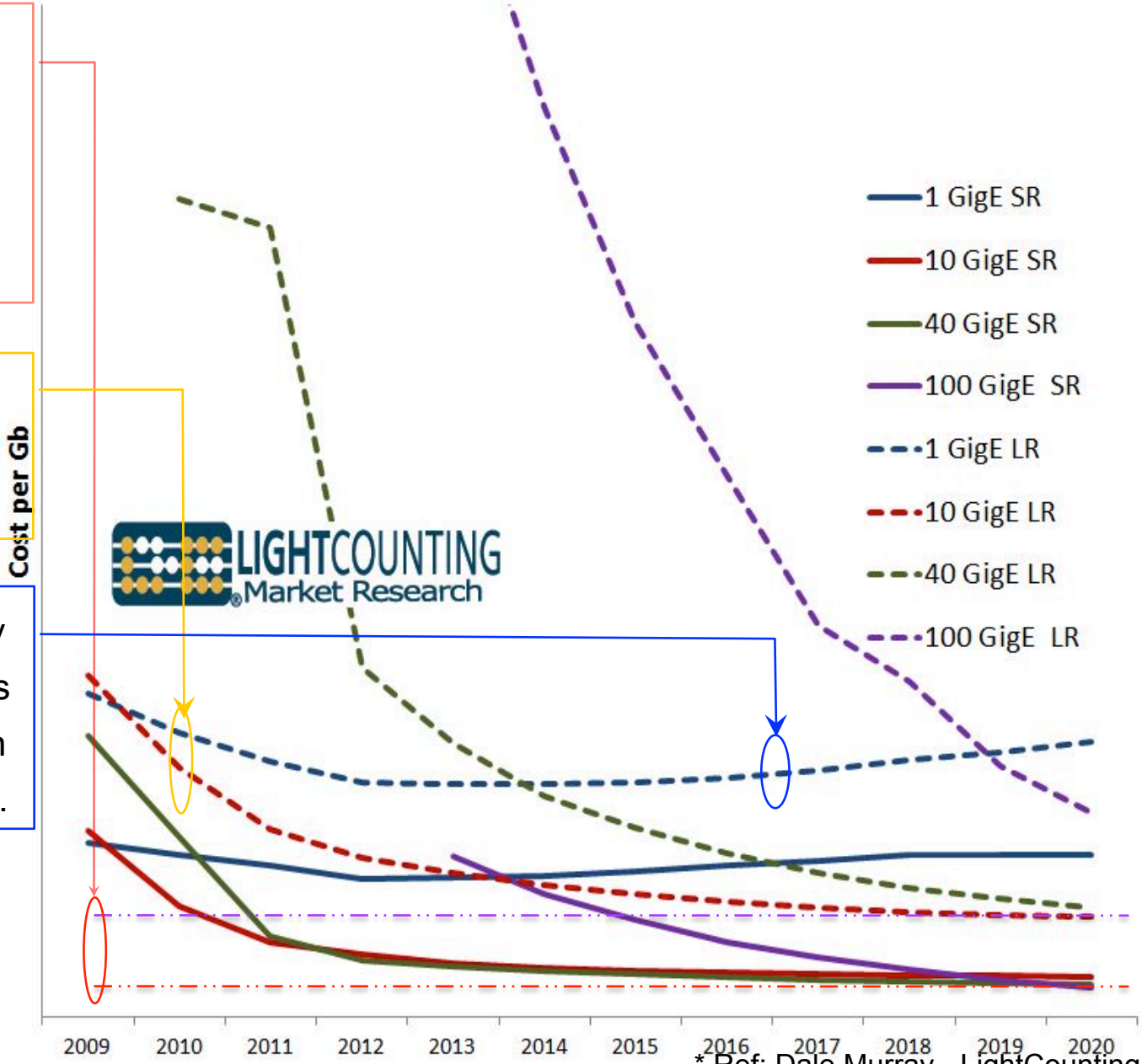
- Observe that as market matures, it is expected that "Cost per Gb" should be lower than prior speed.
- Observe that "Cost per Gb" actually increases for mature technologies as their use / volume is overtaken by newer and faster technologies.



Relative Cost Asymptote

- Long Reach (10km)
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Relative Cost Targets (by solution)

Table of relative cost targets as a function of reach/application (Cost/Gb).

Market	400GbE (projected)
DC Edge 3m~100m	0.8t
DC Fabric 100m~500m	1.2t
DC Core 2 km	1.5t
Carrier IP-Core 10 km	2t

- The value “1t” is approximately equal to cost of 100G DC “Short Reach” solution.
- Different applications require different cost points to achieve successful market adoption.

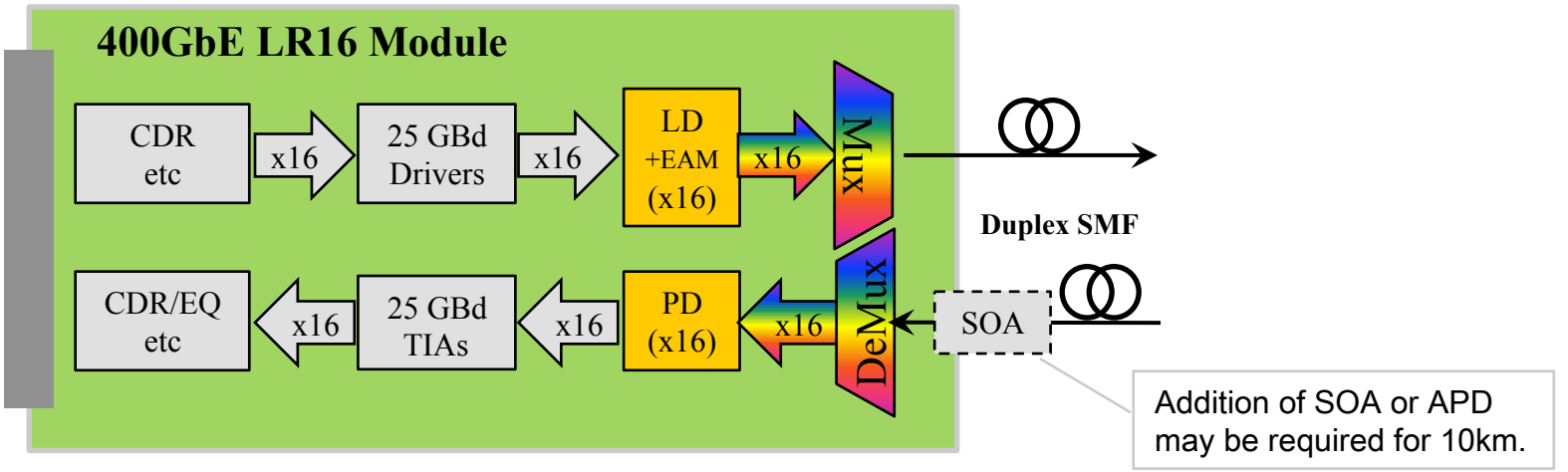
* Note – These are simplified extrapolations, not intended to be exact.

Relative Cost (likely technical alternatives - 2 km and 10 km)

- Lets explore song_400_01_0513 options
  - 16x25 GBd NRZ
  - 8x50 GBd NRZ
  - 8x25 GBd PAM4
  - 4x50 GBd PAM4
  - 4x100Gb/s HOM (>PAM4)

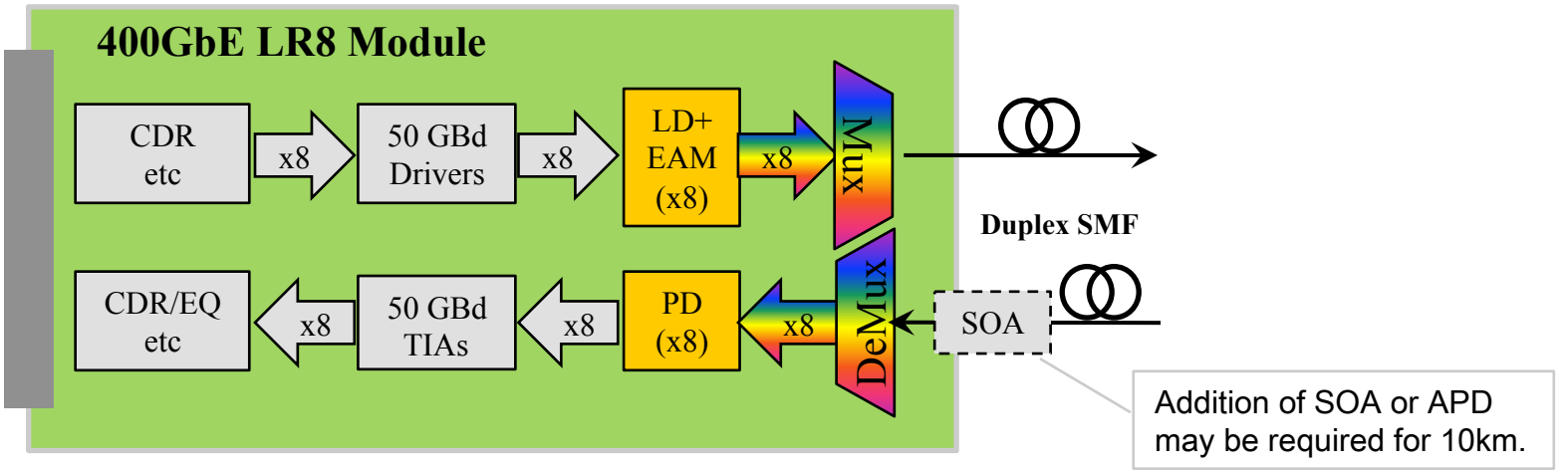
Technical Complexity (2 km and 10 km)

- 16x25 GBd NRZ
  - Laser & modulation straight-forward / low cost per unit but number of units – add cost
  - Tighter wavelength control required - adds cost
    - Or expanded grid (2~4*LWDM) increases dispersion penalty
  - Mux complexity and filter complexity higher - adds cost
    - 16-channel Mux and Demux increase loss (PLC platform)
  - More components, more power, more complex packaging – adds cost



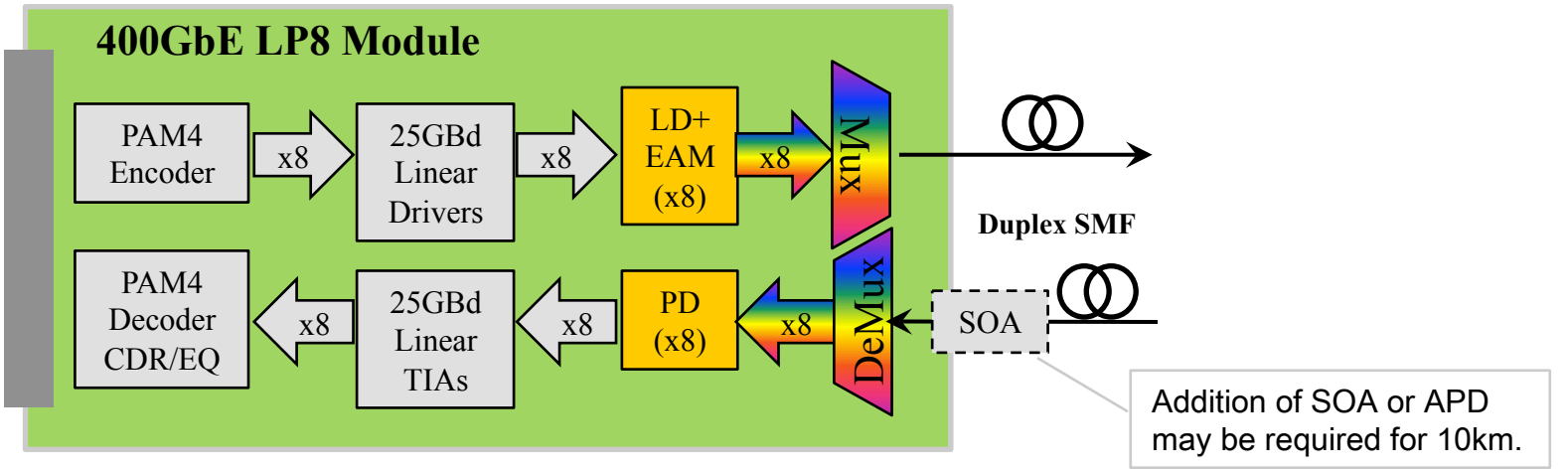
Technical Complexity (2 km and 10 km)

- 8x50 GBd NRZ
  - Lasers & modulation more complex, higher cost per unit but reduced number of units – cost TBD
  - Tight wavelength control required - adds cost
    - Or expanded grid (2*LWDM) increases dispersion penalty
  - Mux complexity and filter complexity high - adds cost
  - Many components, high power, more complex packaging – adds cost



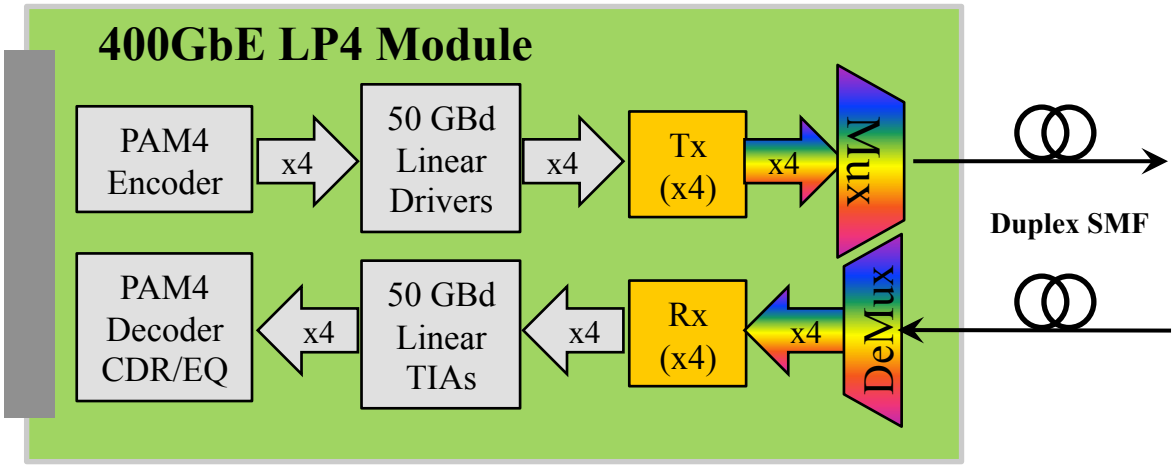
Technical Complexity (2 km and 10 km)

- 8x25 GBd PAM4
  - Commoditized Lasers, modulation more complex, balanced cost per unit but reduced number of units – cost TBD
  - Tight wavelength control required - adds cost
    - Or wider grid (2xLWDM) adds dispersion penalty
  - Mux complexity and filter complexity high - adds cost
  - Many components, high power, more complex packaging – adds cost
  - Balances Time-To-Market with Cost



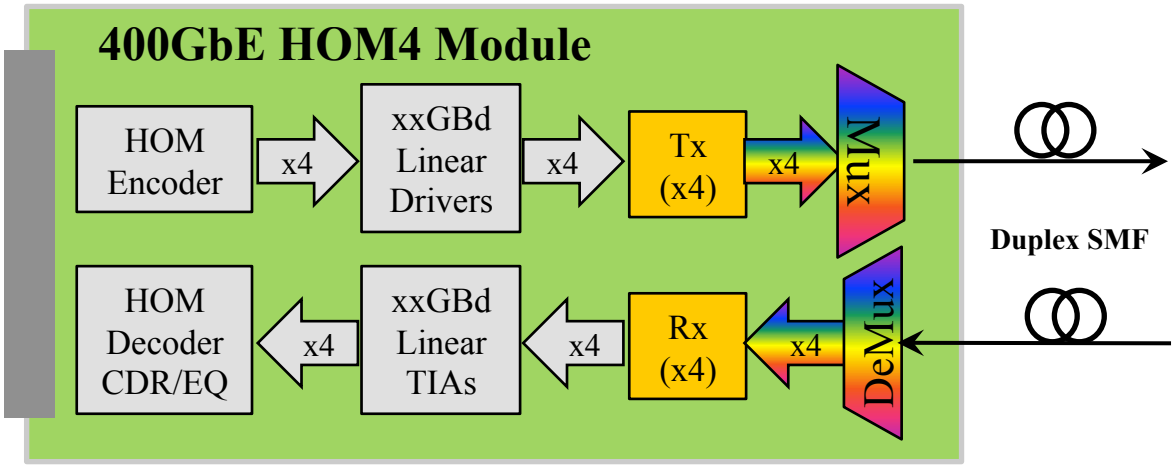
Technical Complexity (2 km only?)

- 4x50 GBd PAM4
  - Lasers & modulation more complex, higher cost per unit but substantially reduced number of units – saves cost
  - Less wavelength control required - saves cost
  - Mux complexity and filter complexity lower - saves cost
  - Fewer components, lower power, simpler packaging – saves cost
  - Time to market later, but ultimately lowest cost



Technical Complexity (2 km or 10 km)

- 4x100Gb/s HOM (>PAM4)
  - Lasers & modulation more complex, higher cost per unit but substantially reduced number of units – saves cost
  - Less wavelength control required – saves cost
  - Mux complexity and filter complexity lower – saves cost
  - Fewer optical components, lower power, but bigger digital components and power – may challenge packaging
  - Time to market late, complexity needs to be understood



Technical Complexity & Cost Balance (2 km)

Solutions	4x25 GBd NRZ	16x25 GBd NRZ	8x25 GBd PAM4	8x50 GBd NRZ	4x50 GBd PAM4
Relative Cost of TOSA	1.0	3.0	1.9	2.9	1.5
Relative Cost of ROSA	1.0	3.0	2.0	2.9	1.7
Relative Cost of IC	1.0	4.0	2.6	4.0	3.0
Relative Total Cost	1.0	3.1	2.0	3.0	1.8

- 8x25 GBd PAM4 solution achieves Technical Complexity (Time-To-Market) balance with lowest cost.
- 4x50 GBd PAM4 solution achieves lowest cost in the longer term.

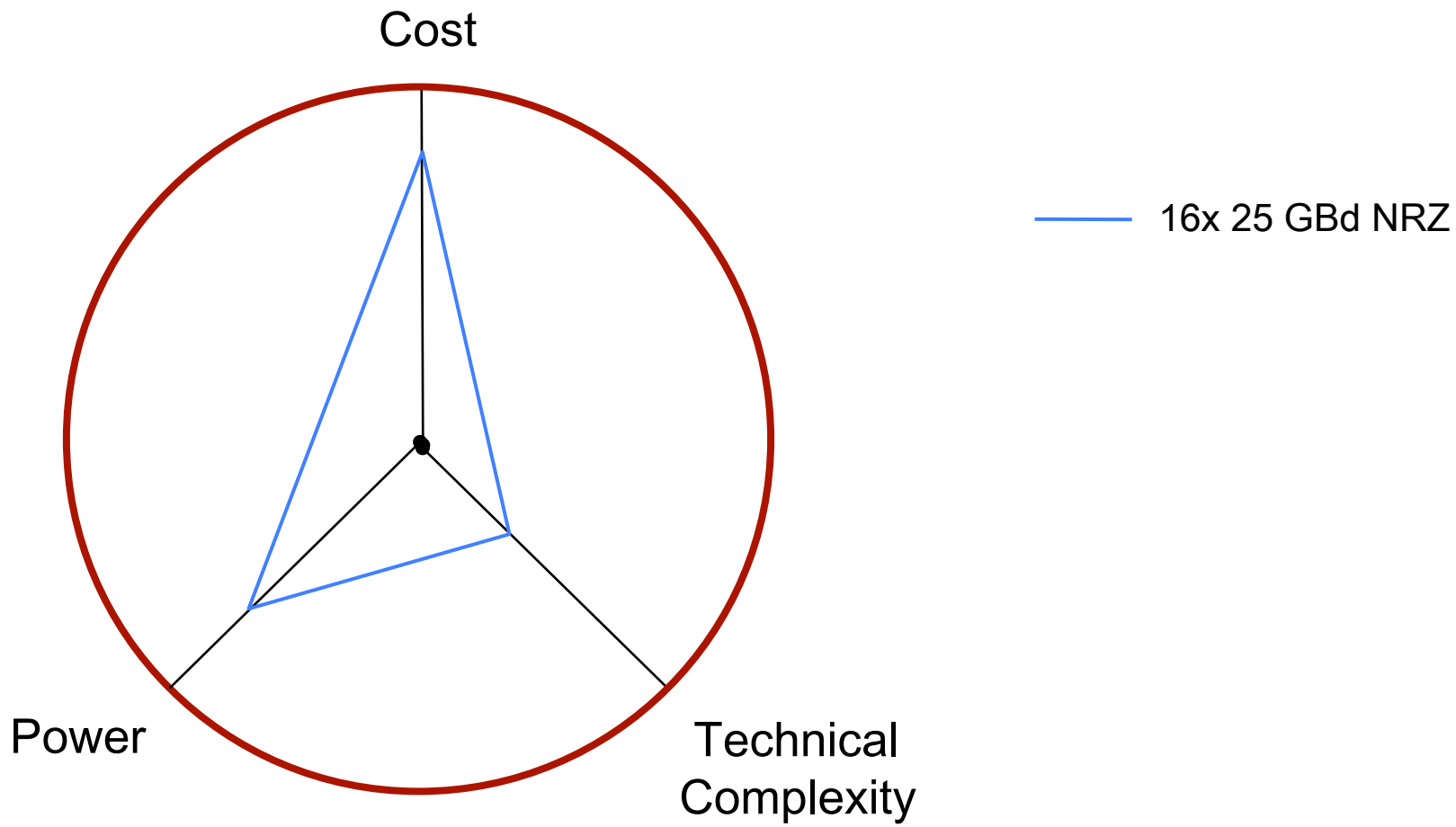
Technical Complexity & Cost Balance (10 km)

Solutions	4x25 GBd NRZ	16x25 GBd NRZ	8x25 GBd PAM4	8x50 GBd NRZ	4x50 GBd PAM4
Relative Cost of TOSA	1.0	3.0	1.9	2.9	??
Relative Cost of ROSA	1.0	3.8	2.8	3.7	??
Relative Cost of IC	1.0	4.0	2.6	4.0	??
Relative Total Cost	1.0	3.4	2.3	3.3	??

- 8x25 GBd PAM4 solution achieves Technical Complexity (Time-To-Market) balance with lowest cost.

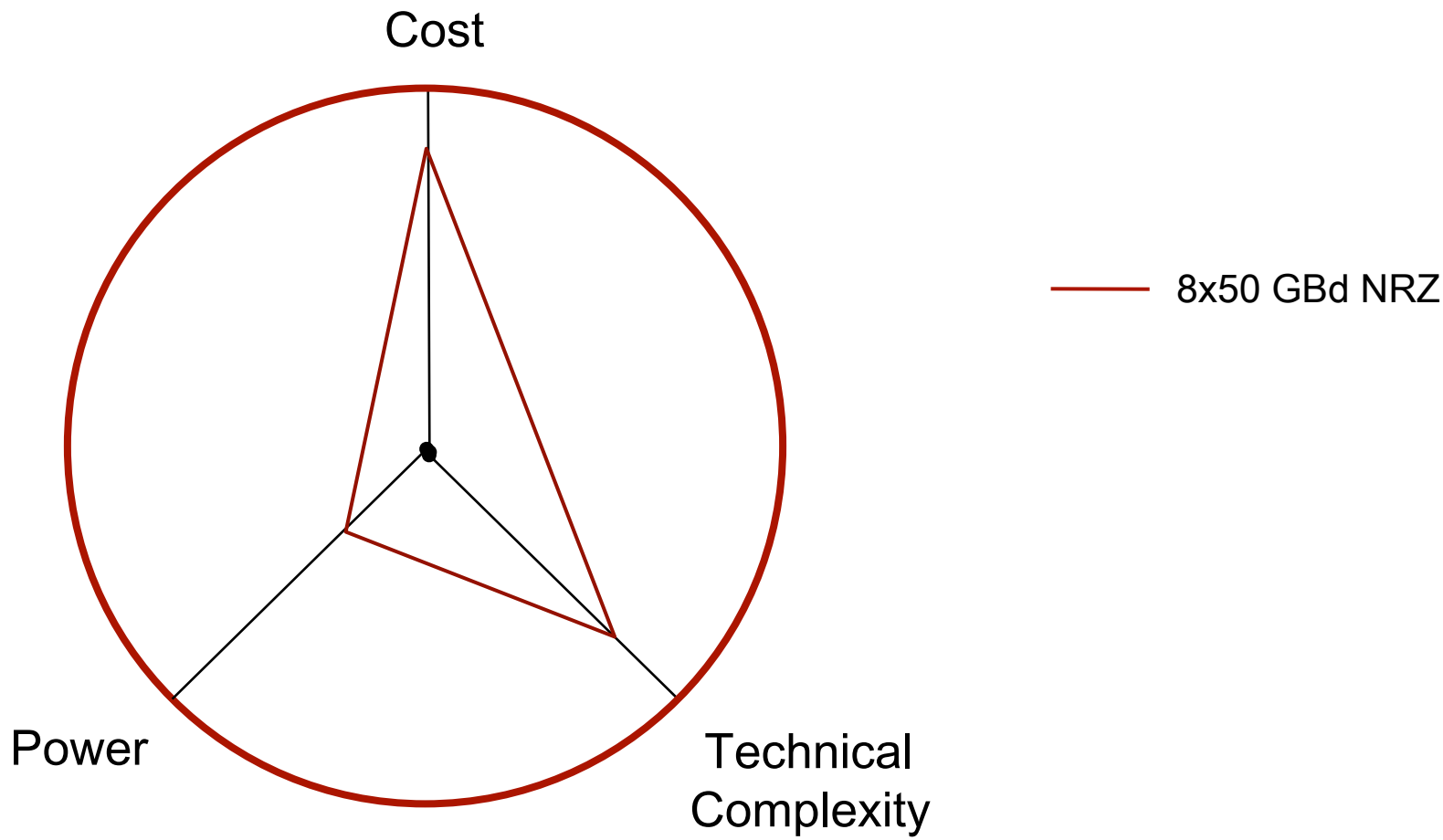
- 4x50 GBd PAM4 solution not proven via simulation to work for 10 km

Technical Complexity & Cost Balance



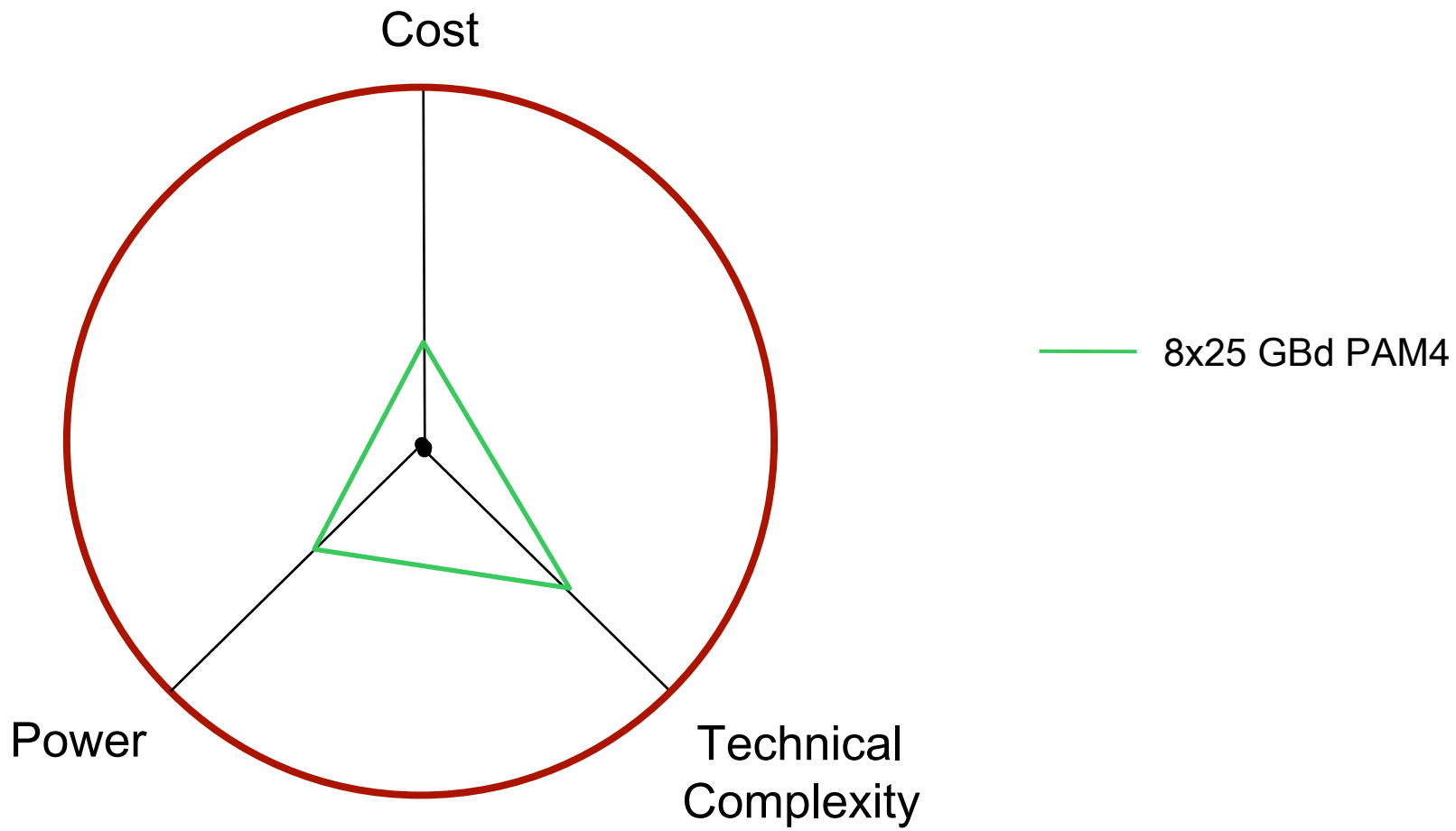
While relatively low in technical complexity, a high number of channels leads to higher cost, power and lower reliability.

Technical Complexity & Cost Balance



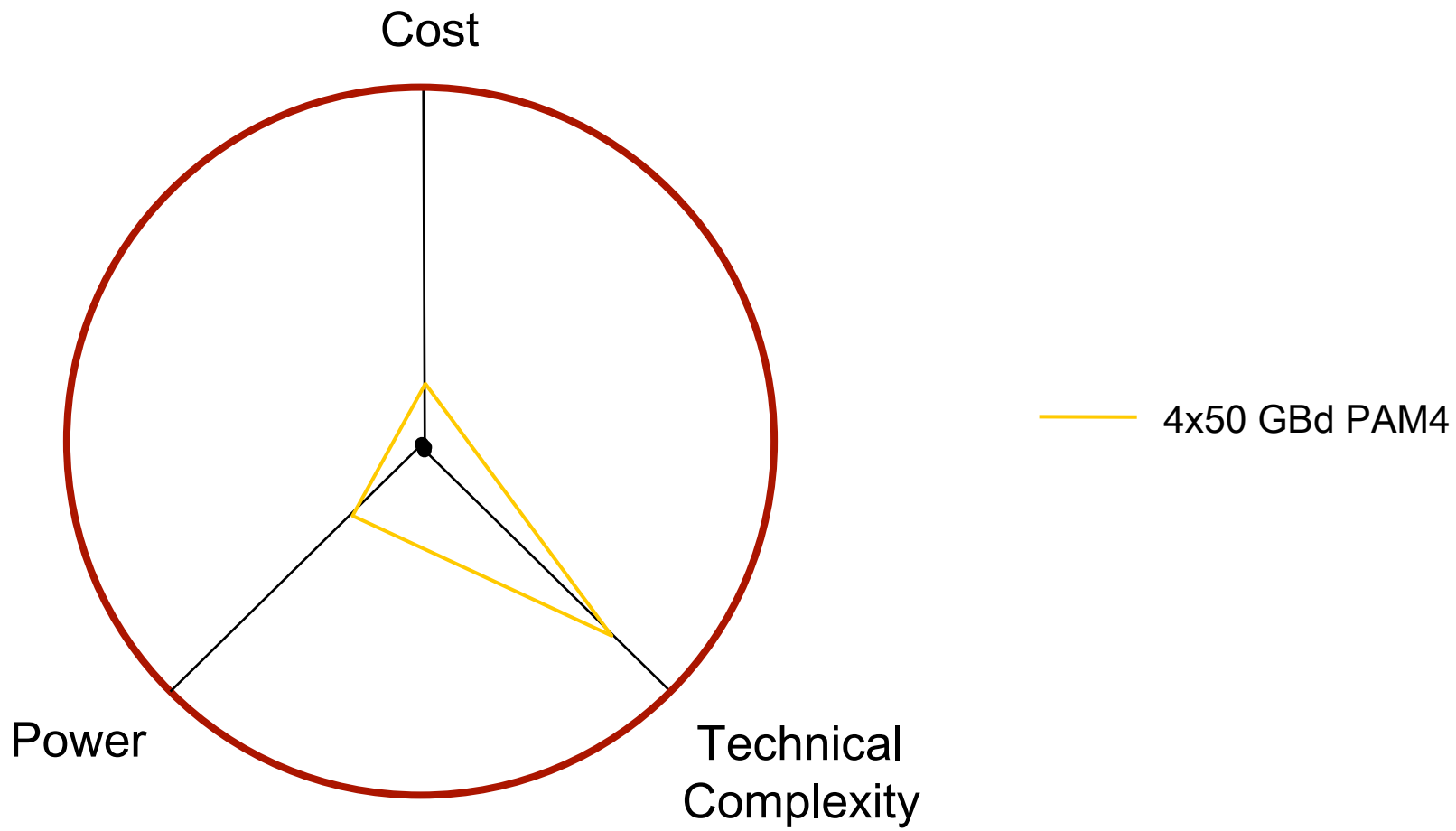
While reducing the number of channels can reduce cost, the complexity of those channels goes up. 50 GBd NRZ devices are not yet readily available and will push the envelope of technology. Ultimately, this approach should lower power.

Technical Complexity & Cost Balance



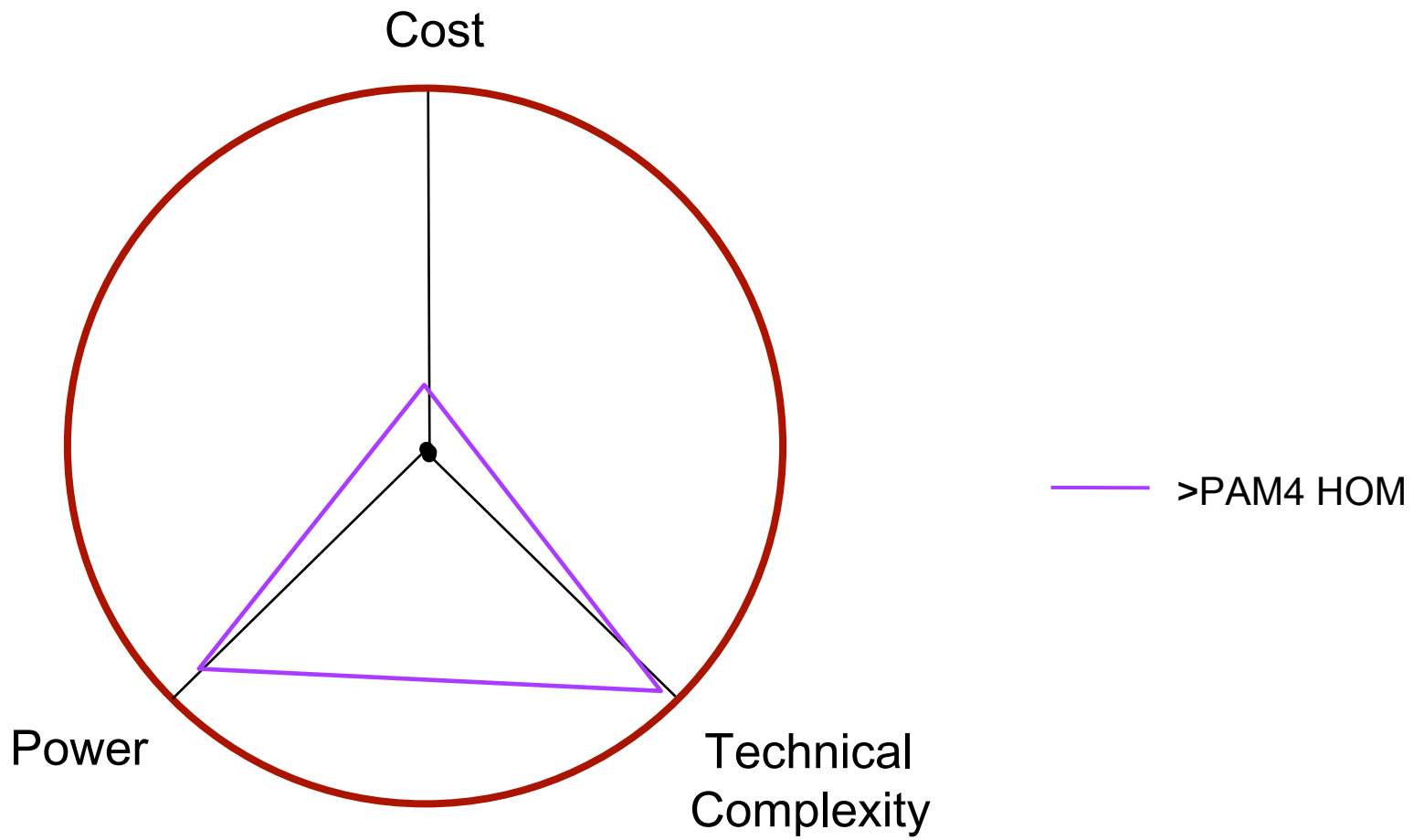
By reducing the number of channels, reduces cost of optics. By using lower baud rate, is more technically available and lower cost components can be used. Power is lower than 16x25 GBd NRZ, and is more reliable

Technical Complexity & Cost Balance



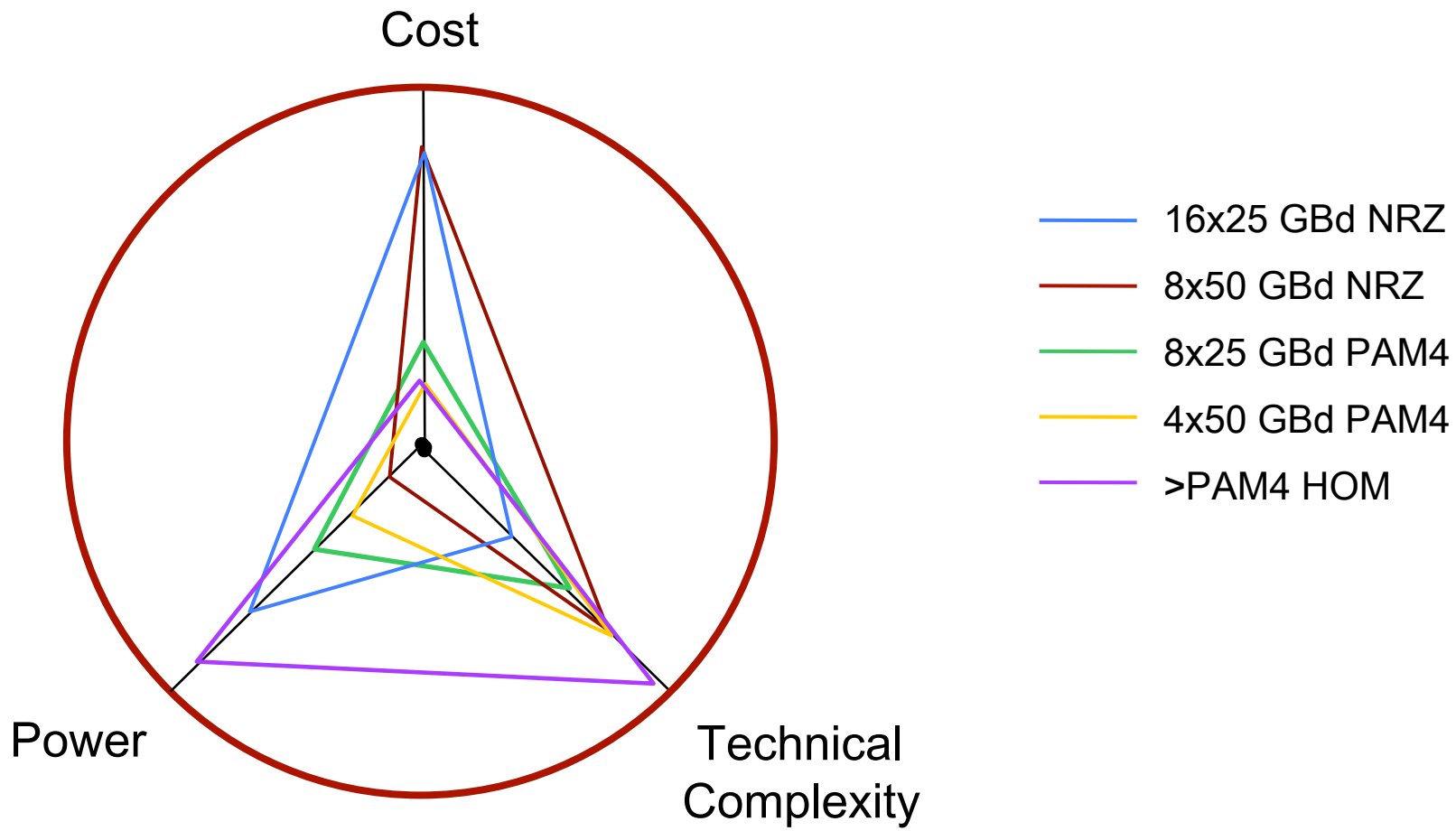
By reducing the number of channels down to 4, substantially reduces cost of optics. Higher baud rate, is more technically complex and but long-term lower cost solution. The power is lower than 8x25 GBd PAM4, and is more reliable

Technical Complexity & Cost Balance



Due to technical complexity and power challenges, >PAM4 HOM remains unrealistic for this generation of standard. Longer term, offers a future for higher speed and lowest cost.

Technical Complexity & Cost Balance



- 8x25 GBd PAM4 solution achieves Technical Complexity (Time-To-Market) balance with lowest cost in the shorter term.
- 4x50 GBd PAM4 solution achieves lowest cost in a practical timeframe.

Conclusions (2 km and 10 km Objectives)

- Market demand for 2 km and 10 km solution have been demonstrated throughout Study Group effort (BMP)
- Cost requirement for the 10 km solution is ~1.7x the cost of a 2 km solution and both can come in below 100G Cost per Gb for comparable application/ solutions (EF)
- Technical approaches are considered, and multiple solutions appear feasible and worthy of consideration (TF) (EF)
- Time-to-market for 8x25 GBd PAM4 is slightly lower than 4x50 GBd PAM4 (lowest cost alternative)
  - We believe the market can tolerate that higher cost in the short term and migrate to 4x50 GBd PAM4 solution as market matures
- Recommendation: Continue to investigate and refine research on 10 km and 2 km proposals

Thank you