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Opportunities and Challenges in the Evolution beyond F5G

High speed PON evolution, and why it's (really) needed

Ed Harstead, Nokia Fixed Networks, ed.harstead@nokia.com

ECOC 2022

Directions in PON technology evolution

Capacity

25G+

- 25Gb/s today
- 100Gb/s demo

SDN

- Network slicing
- Automation

Low latency

- 1 ms
- Industry 4.0, Anyhaul

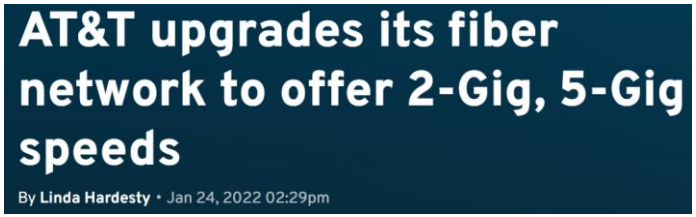
Reliability

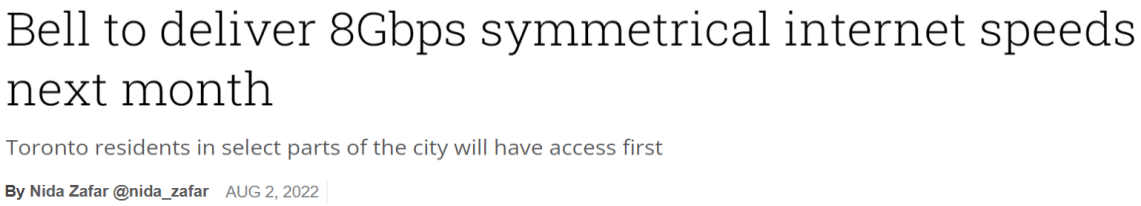
- Mission critical
- Minimum five nines

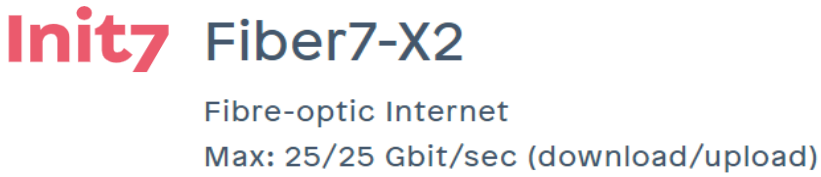
Green

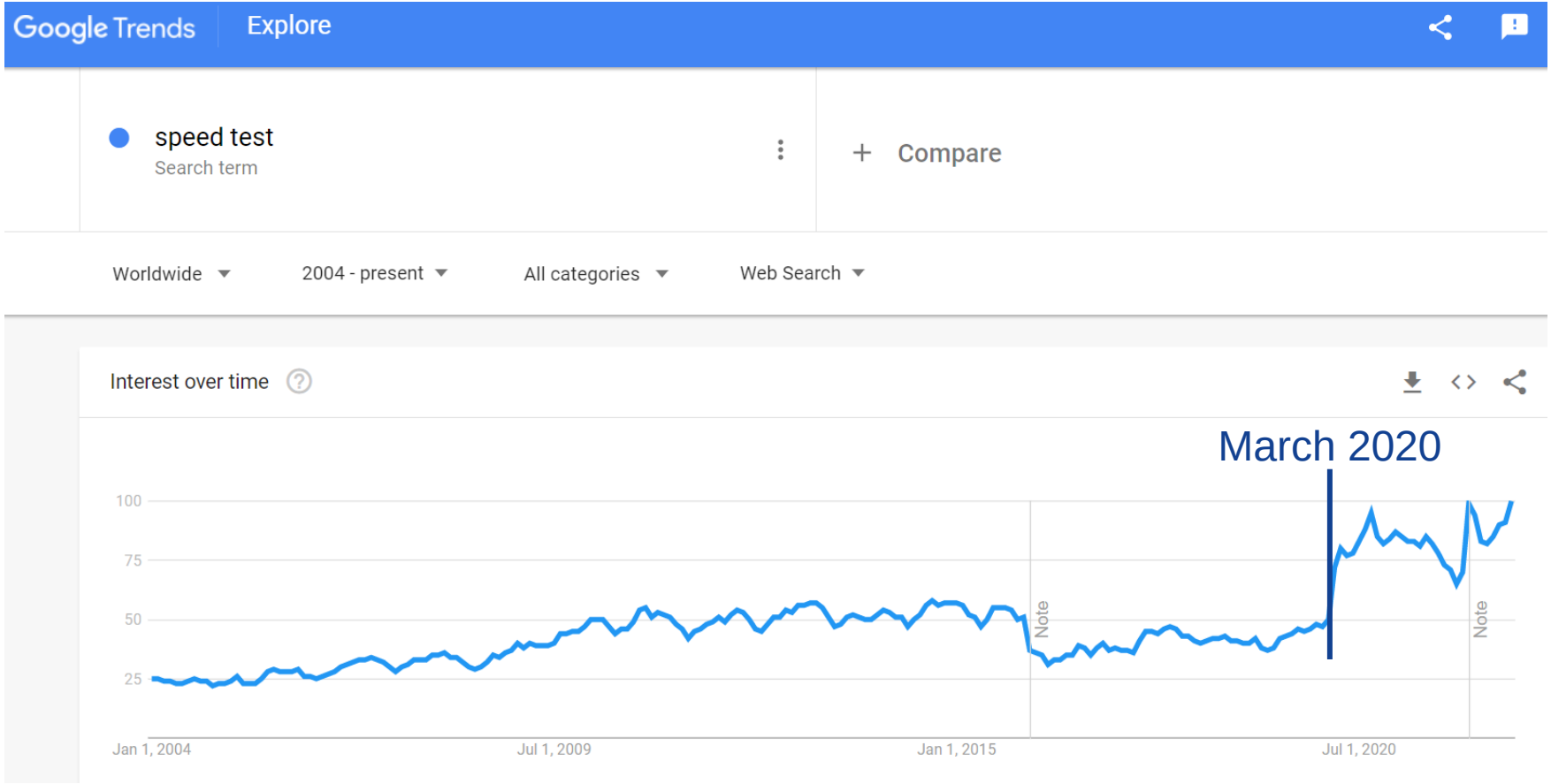
- 6-8x lower carbon footprint than copper, coax or wireless

Sample headline speed announcements in 2022









Notes: an improvement to our data collection system was applied

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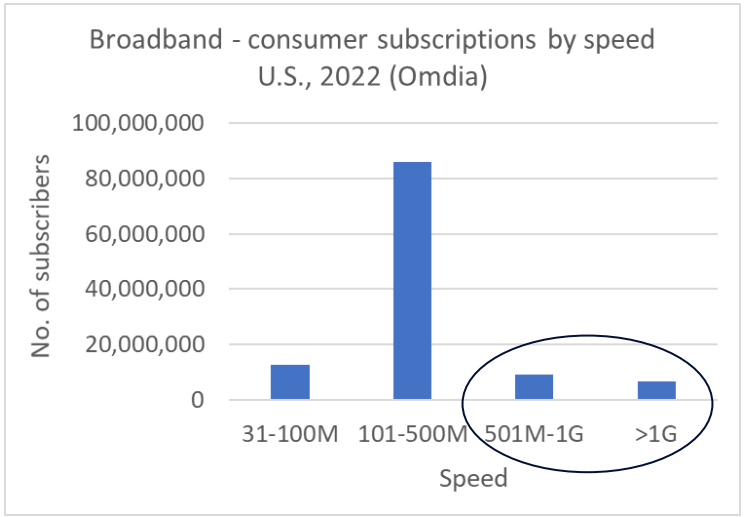
Bandwidth can be monetized!



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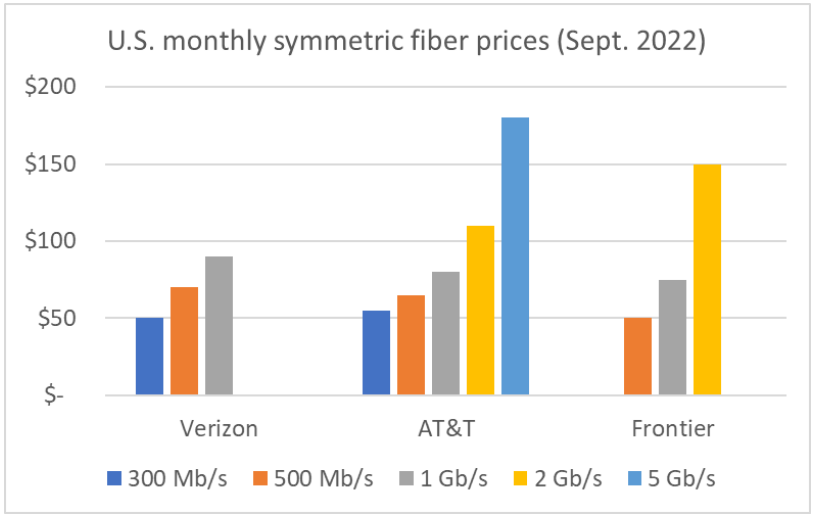
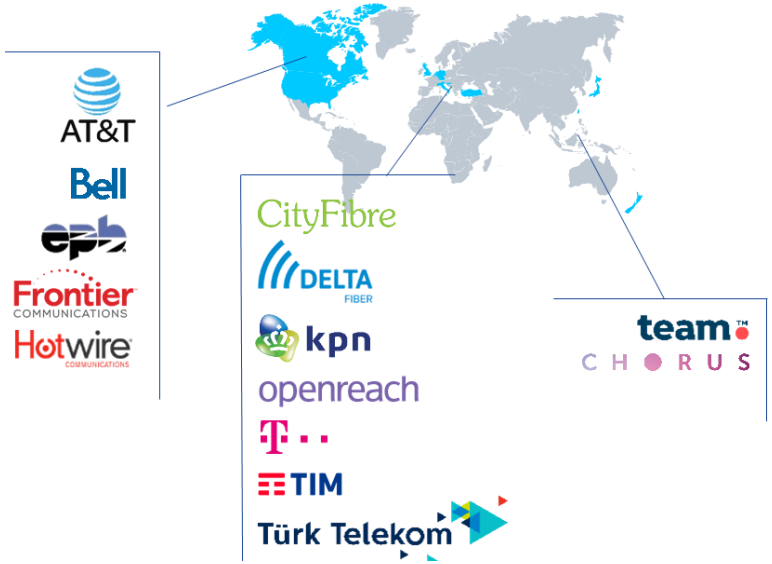


U.S. operators are receiving about **$8B annual revenue** just for upgrading subscribers from 500M to 1G+ service.

Delivering 10G+ services: the 25GS-PON rollout

14 publicly-announced 25GS-PON trials



- The 25GS-PON MSA membership is >50:
  - silicon, optics, CPE, system + test equipment vendors
  - 12 operators.
- More than 500,000 25GS-PON-ready OLT ports in operator networks today.

broadband forum

The BBF has agreed to start work on an interoperability test specification and YANG data model for 25GS-PON

Chattanooga's EPB boosts its speed to 25G across its footprint

Chattanooga boasts fastest communitywide internet service in the world The latest upgrade uses 25GS PON

August 24, 2022 at 7:31 p.m.

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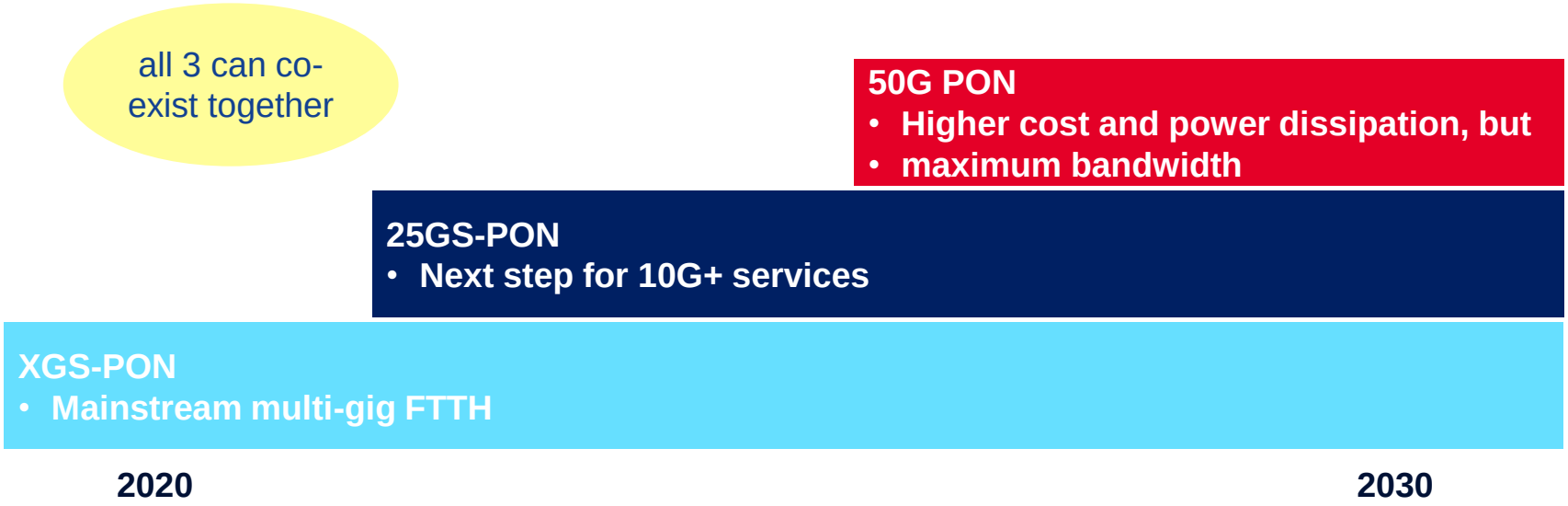
PON capacity roadmap for this decade



- There are 100s of operators in the world, all with different pressures, strategies and timelines.
- The $10B PON industry is big enough for 3 tools in the toolkit.

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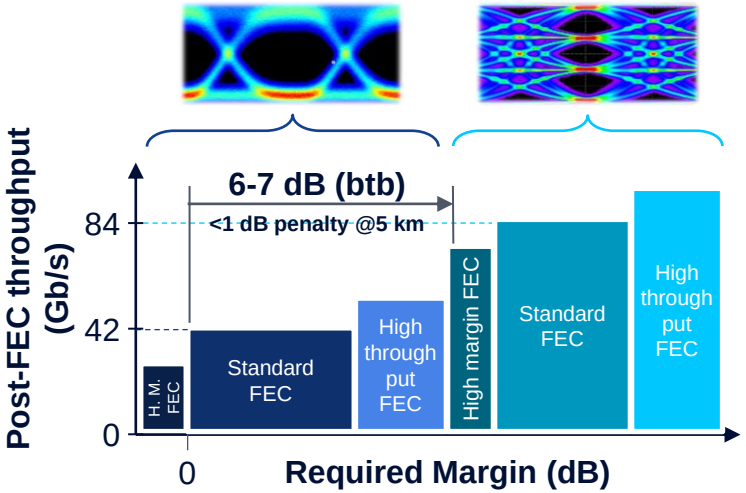
Towards 100G PON: Flex rate PON

- Unused margins in the PON channel can be exploited for ~2x throughput
- Flex-rate PON is under study in ITU-T to allow 50G (NRZ) PON to flex up to 100G PAM4.
- Flexible FEC and flexible modulation, just like DSL, DOCSIS, cellular, WiFi



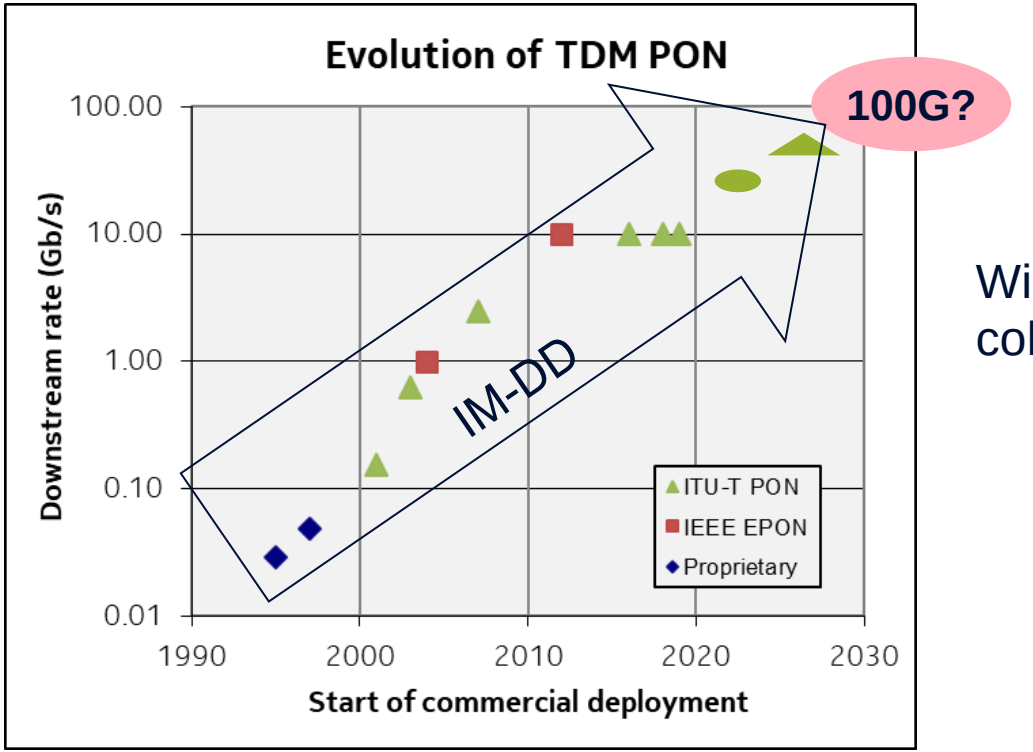
R. Borkowski et al., "FLCS-PON – A 100 Gbit/s Flexible Passive Optical Network: Concepts and Field Trial", JLT, Aug. 2021.

Bell Labs trial with Vodafone, Jan. 2021

- *Note that this higher throughput is opportunistic, it is not guaranteed.*
- Can IM-DD PON support guaranteed 100G, full loss budgets and 20 km?

- Rene Bonk, “Flexibility in PON - Enabler for New Use Cases”, WS03, today, 14:00–17:30, Samarkand + Osaka
- Amitkumar Mahadevan, “Digital Signal Processing for Next Generation PONs”, Tu4C.1

TDM PON evolution: what comes after 50G?



Will 100G PON be IM-DD or coherent?

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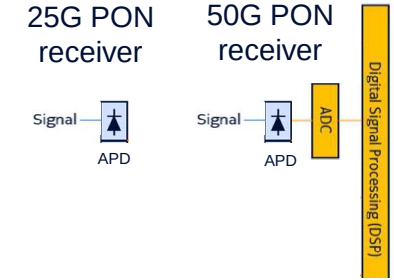
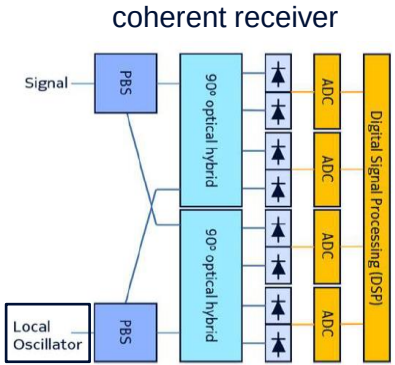
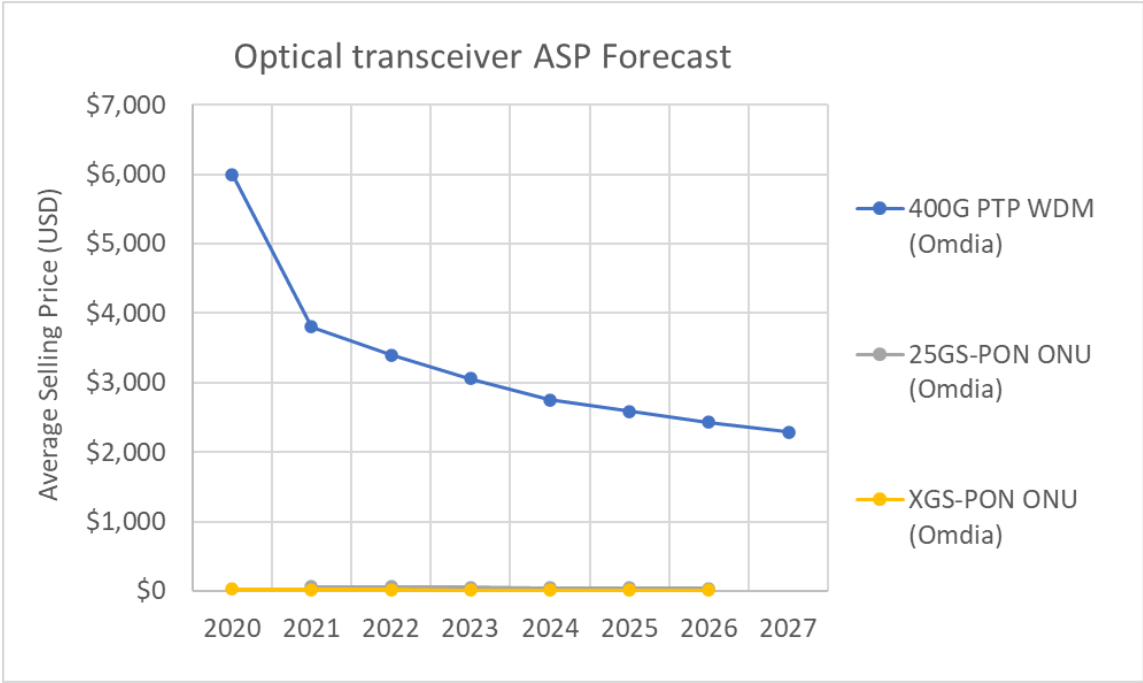
Coherent PON: the challenge

- Coherent detection will help on power budget: ~10 dB improvement over best-case direct detection.
- But can it be cost-effective? And at what power dissipation?







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100G IM-DD PON: the challenges can be overcome… in time.

Let's put ourselves in the year 2030 and see what is possible with NRZ modulation:

- Higher speed components: the intra-data center market is already driving 100 Gbaud.
- Increased fiber dispersion can be mitigated with
  - continuously improving DSP equalization
  - lower chirp transmitters
  - moving the downstream wavelength closer to the zero-dispersion wavelength.
- The power budget challenge can be met with an
  - SOA optically pre-amplified ONU receiver
  - stronger FEC.

Conclusion: a 100G PON using conventional IM-DD technology will be the most practical.

- Lower cost, lower power

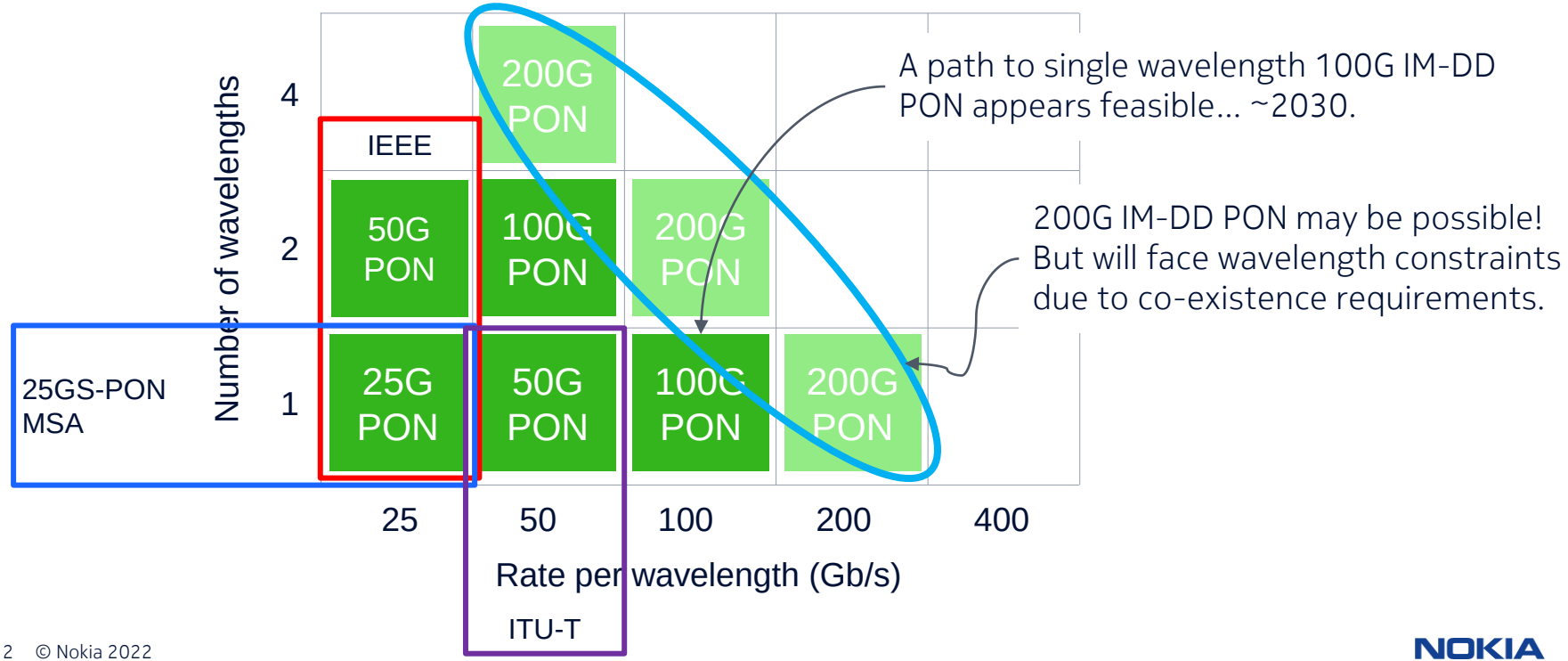
simulation

Receiver Parameter	50G PON NRZ	100G PON NRZ
(Tx OMA	11.25 dBm	11.25 dBm)
Sensitivity, OMA, 20 km	-22.75 dBm	-22.75 dBm
Tx chirp alpha	0.5	0.3
Wavelength	1340-1344 nm	1318-1322 nm
SOA gain	-	20 dB
SOA NF	-	6 dB
SOA filter width	-	4 nm
PD gain	8 (APD)	1
Effective bandwidth	18.75 GHz	50 GHz
ADC resolution (ENoB)	5	6
ADC sampling rate	50 GSa/s	100 GSa/s
Input BER	1e-2	2e-2
Equalization	13FFE	21FFE/3DFE

E. Harstead, R. Bonk, "Progress and Limits of IM-DD PON, and Directions for Coherent PON", OFC 2022.

A view of the future: IM-DD continues to successfully leverage

- the intra-DC ecosystem and
- decreasing CMOS node sizes.



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