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F6G: Vision, Key Enabling Technologies and Research Topics

ECOC 2022 Workshop “F5G and Evolution towards F6G”

Jean-Luc Beylat with Jochen Maes & Rene Bonk

Nokia Bell Labs

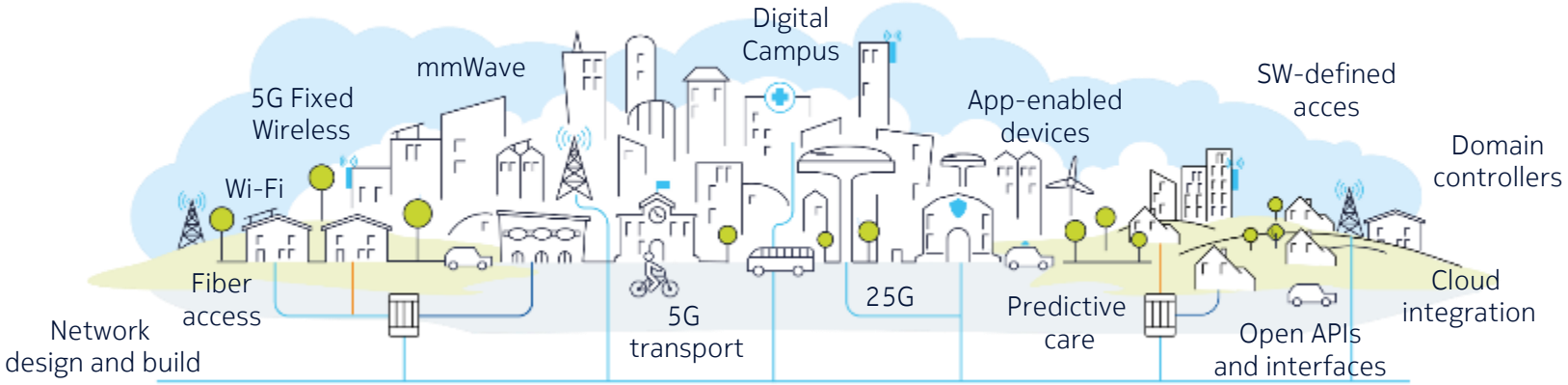
September 2022

Broadband Zero

Zero left behind
Connect everyone
and everything

Zero limits
Innovative technologies for new
use cases and business models

Zero touch
Automate and optimize
the network



Zero waste
Delivering the benefits of broadband while minimizing environmental impact

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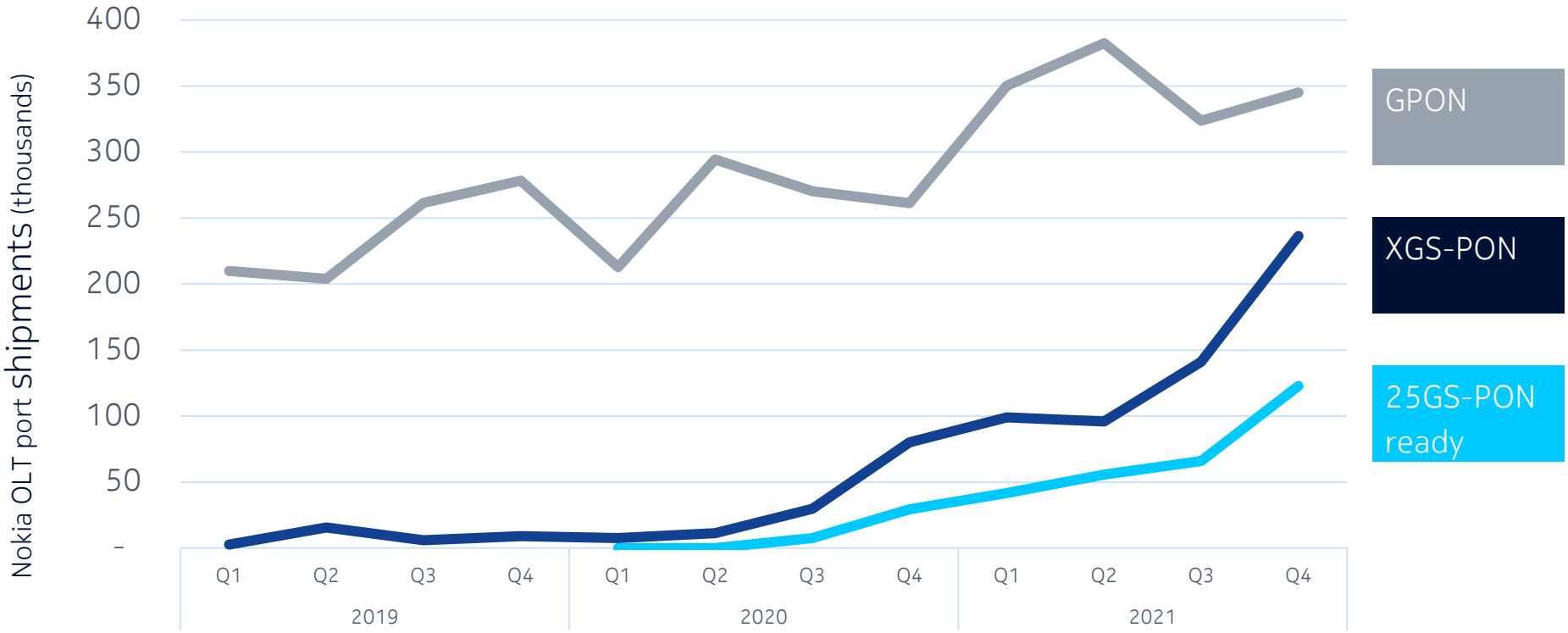
Selection of Passive Optical Network system generations

Majority of 700 million fibre broadband global subscribers served by PON (Dec.'20)

PON Generation	1	2	3	4	5	6
Selection of PONs, focus on ITU-T & MSA	TPON, etc.	BPON (G.983.x)	GPON (G.984.x)	XGS-PON (G.9807)	25GS-PON (MSA)	50G-PON (G.9804) 100G-PON
1st deployment	1990s	2003	2007	2018	2021	open
Typical DS\US rate [Gbit\s]	<0.1\ <0.1	0.622\ 0.156	2.5\ 1.25	10\ 10	25\ 25, 10	50\ 12.5, 25, 50
Key use case, service, focus on market intro.	Residential POTS\ISDN	Residential, Triple Play	Residential, IP TV	Residential, OTT Video	xhaul 5G, business, virtual reality	xhaul 6G, business, mixed reality

R. Bonk et al., Nokia Bell Labs, "Optical Access Networks – From FTTH-Centric to New Use-Cases," Broadband Coverage in Germany, 15th ITG-Symposium, 2021

Next Gen PON is a reality today



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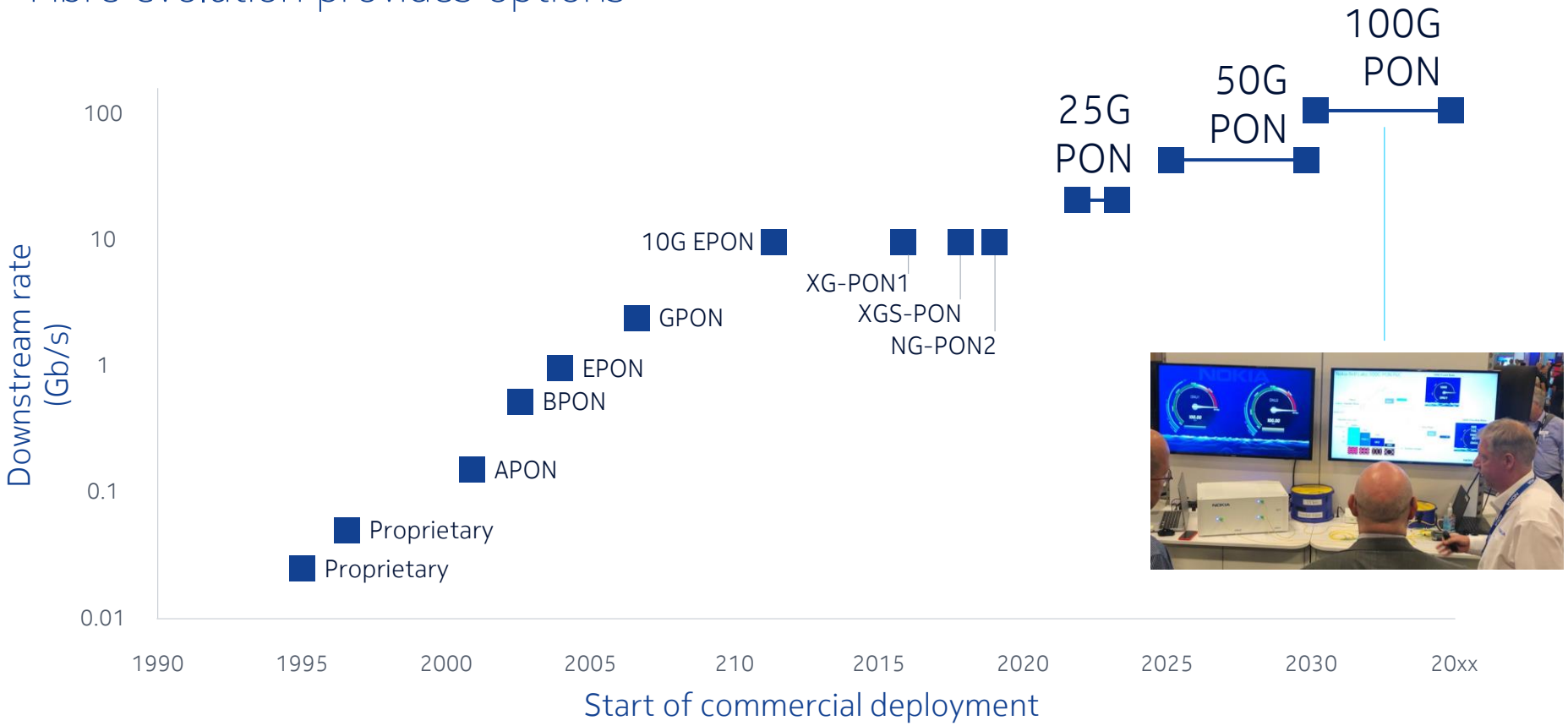
Fibre evolution provides options



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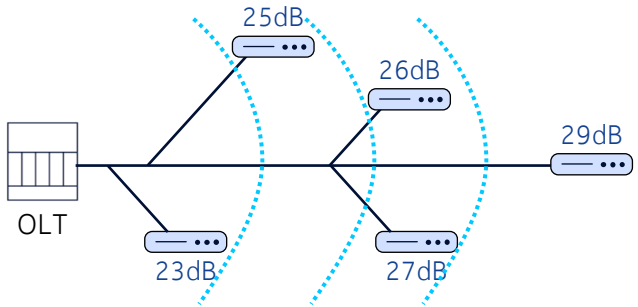
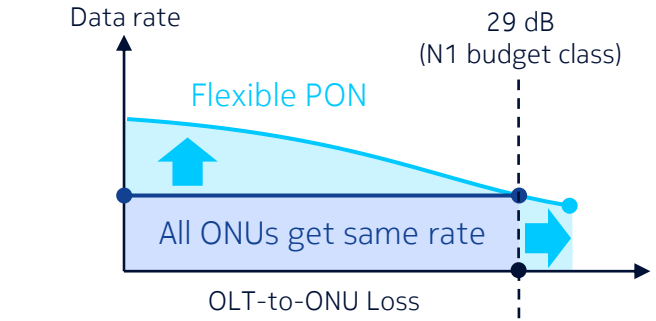
Pushing the boundaries with flexible PON

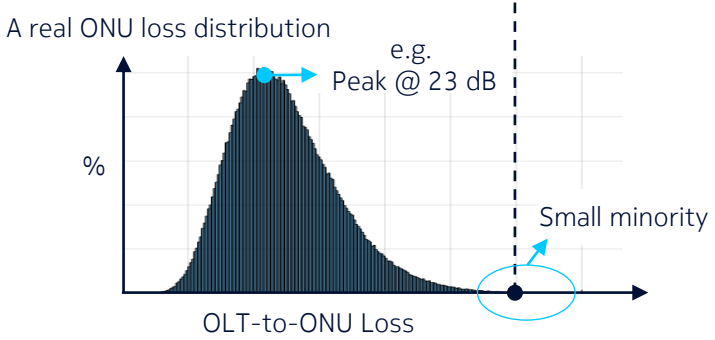
Delivering the best bitrate for a given optical distribution network



ONU loss budgets depends on ODN characteristics like:

- Split architecture
- Reach
- Statistical variations





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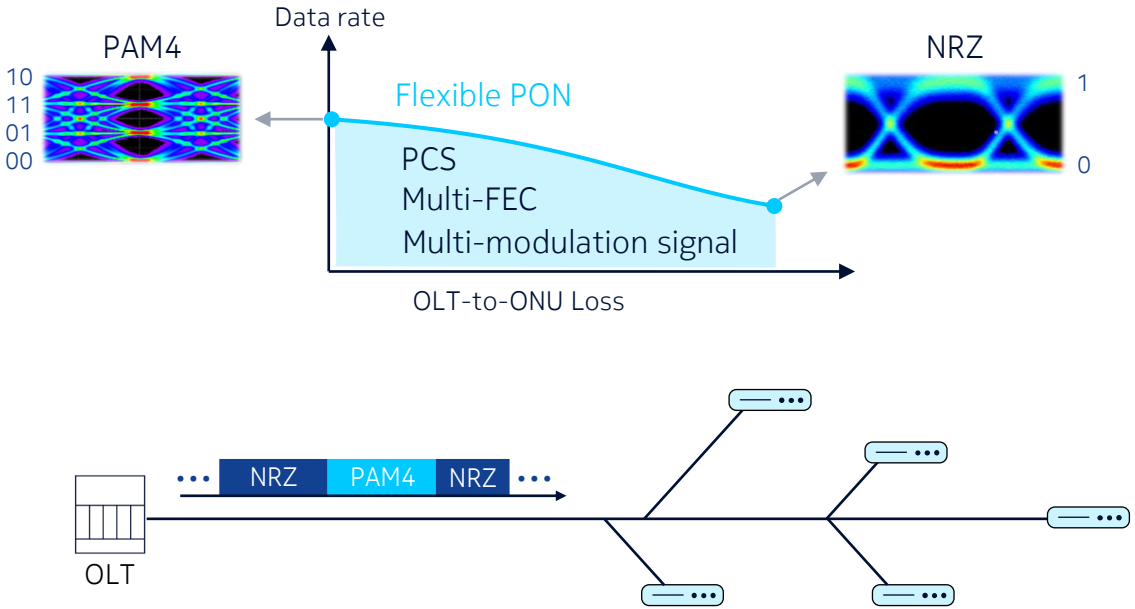

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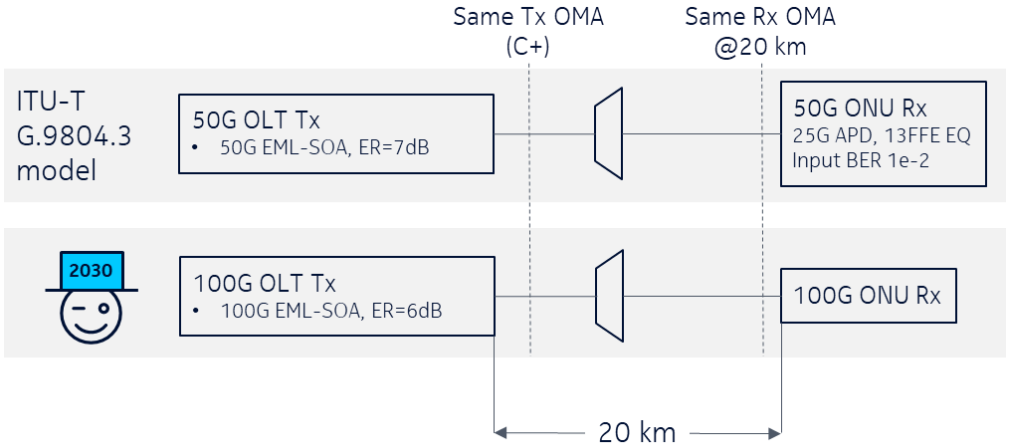
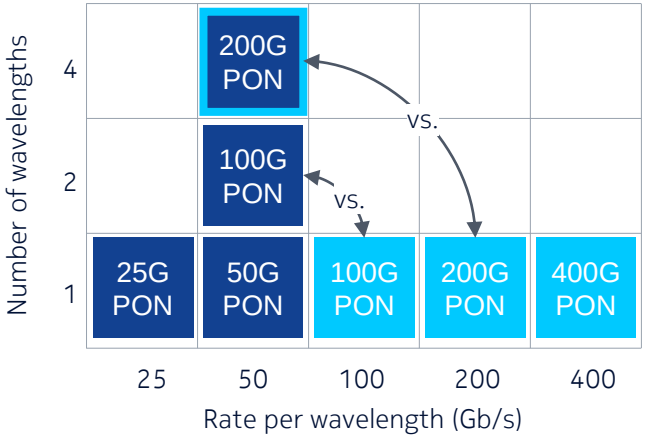
Two views of the future

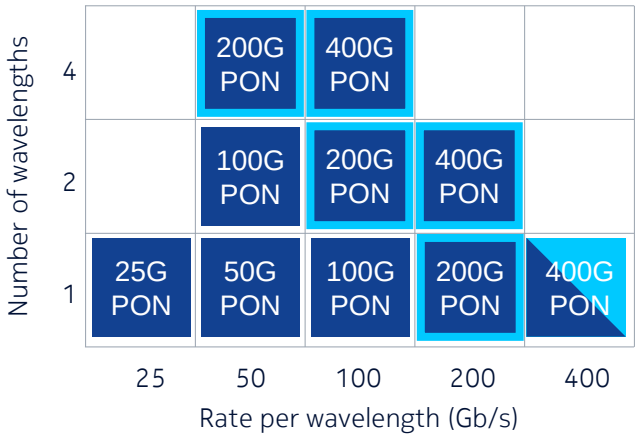


E. Harstead and R. Bonk, OFC 2022.

"">=100G IM-DD PON is too hard"



"PON successfully leverages DC and CMOS"



IM-DD

IM-DD

Coherent

Wavelength constraints limit coexistence

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PON systems are increasingly being eyed for different applications

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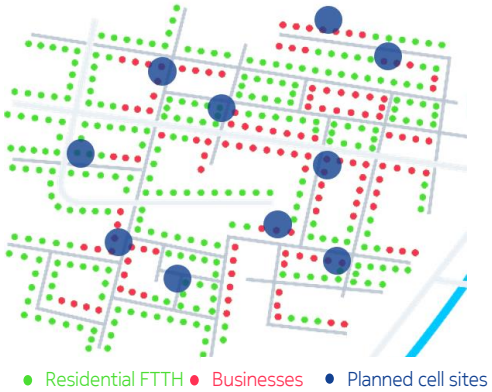
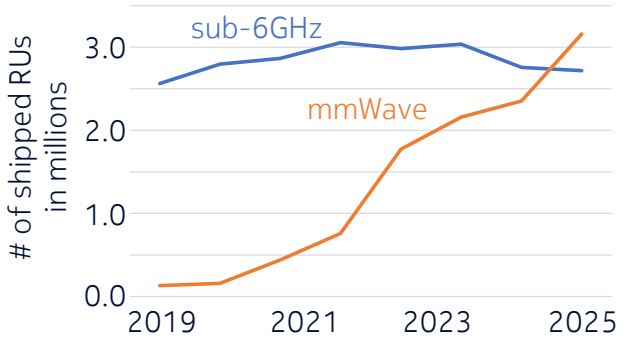
Mobile xhaul: RAN-over-PON

Need for low-cost optical transport in growing 5G densification

PON systems & their optical distribution networks can play a major role for small cells

- Lessons learned from 4G LTE macro cell backhauling: PON attractive in dense cell cite deployments
- Densification in 5G more real, but good business case requires low-cost optical transport
- Strong small cell growth for 2019-2026 expected: >30 million total small cell radio units





Source: Small Cell Forum, SCF Market Forecast 2021, June 21

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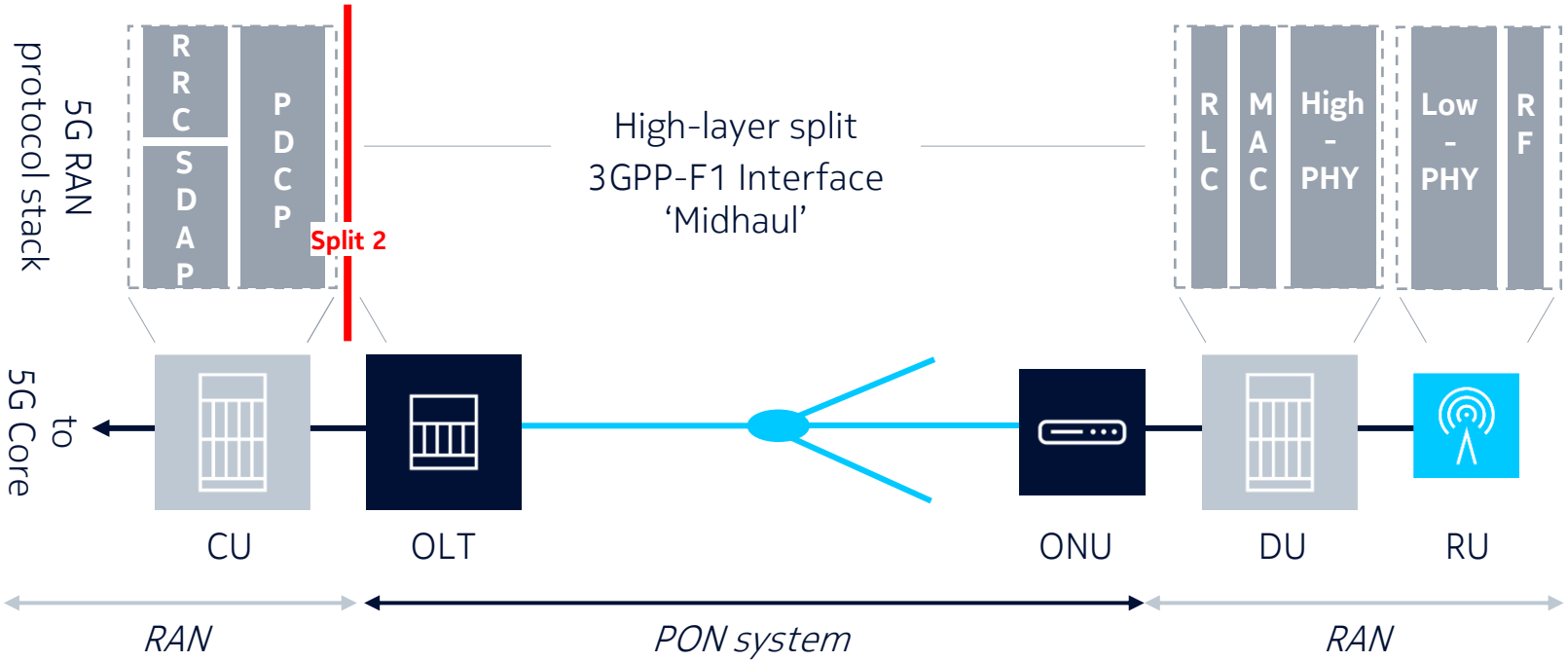
RAN-over-PON: enabling small cell connectivity

Functional RAN split – F1 interface by 3GPP



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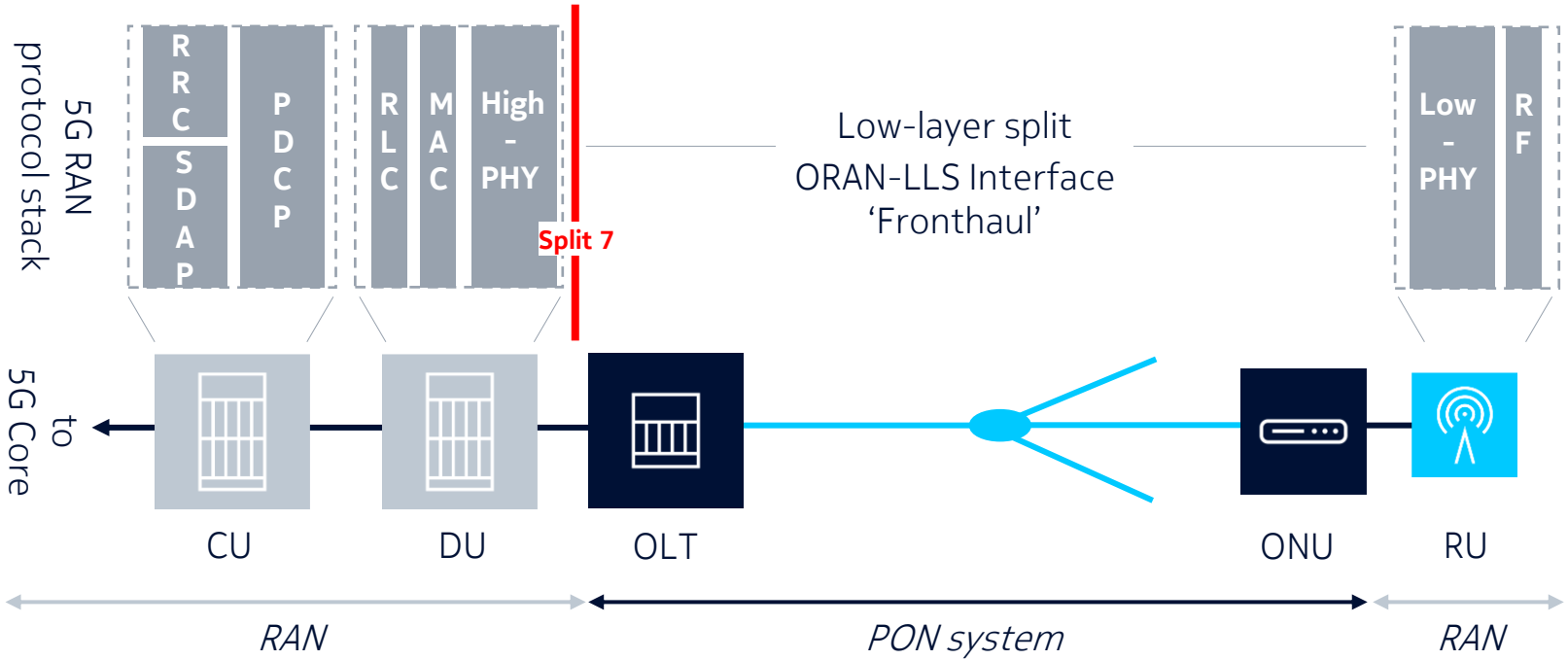
RAN-over-PON: enabling small cell connectivity

Functional RAN split – LLS interface by ORAN



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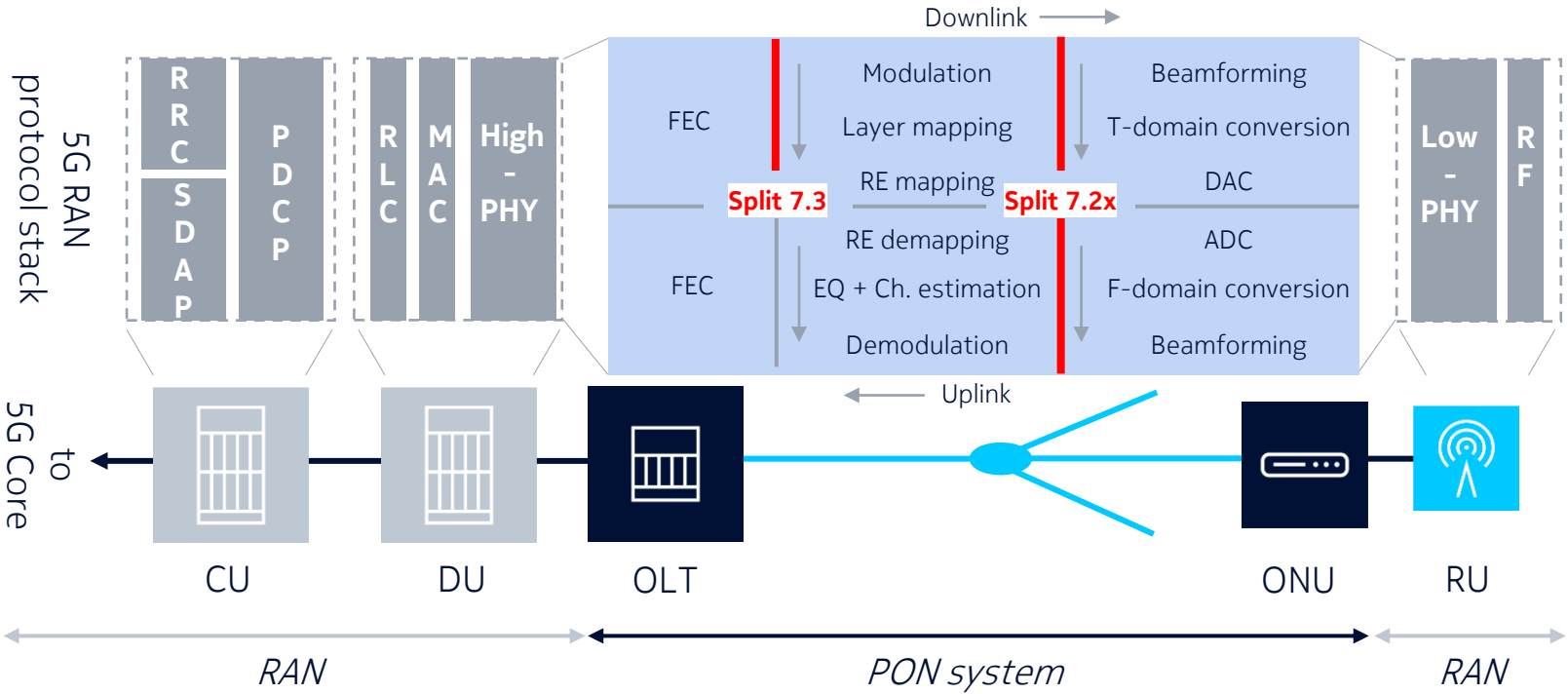
RAN-over-PON: enabling small cell connectivity

Functional RAN split – LLS interface by ORAN of 7.2x, and 7.3 split variant



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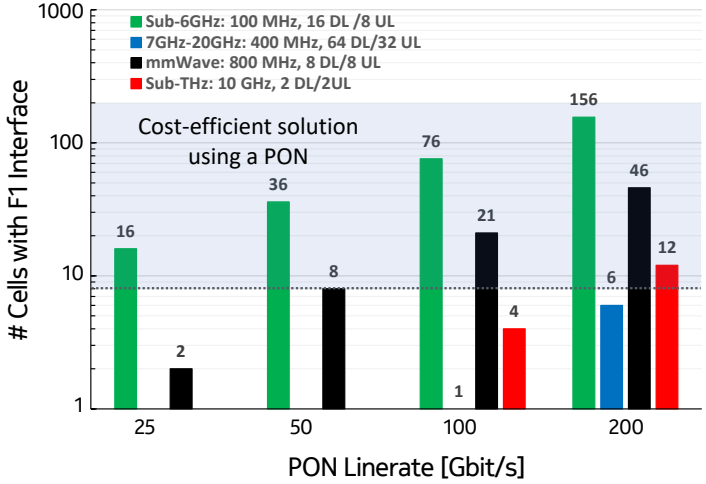
Trends for 6G RAN-over-PON

Challenging requirements won't end with 5G RAN

6G mobile research exploring connection of digital, physical and human worlds
Areas: connected autonomous vehicles, digital twin, extended reality, industry 5.0, smart grid 2.0, …

Expected impact for PON systems and architectures

- Enhanced optical transport capacity
- Lower latency and higher transport determinism
- Further disaggregation and cloudification
- Trustworthiness, security & sustainability



T. Sizer et al., Nokia Bell Labs, "Integrated Solutions for Deployment of 6G Mobile Networks," JLT, 2021

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The Need for PON Speeds Towards 6G RAN Transport

ITU-T standardization status for 50G-PON

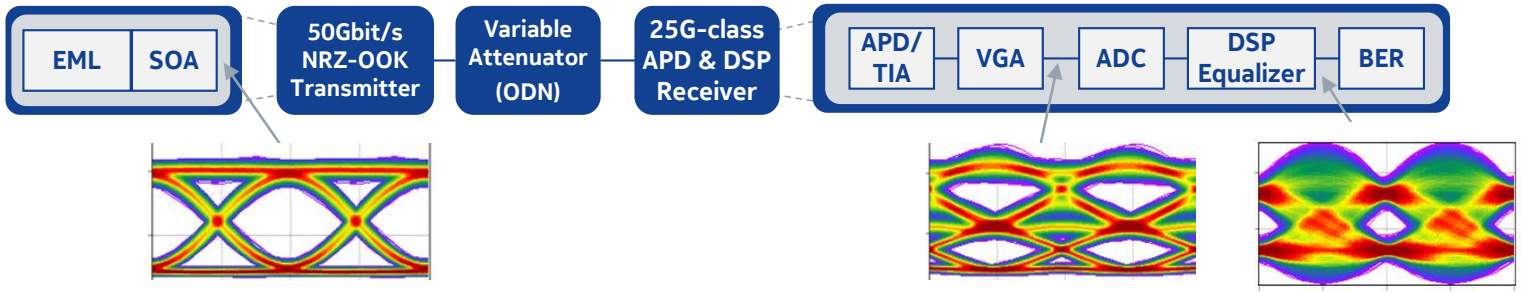
SG15/Q2 consented in April'21 first three recommendations forming 50G-PON

General requirements (G.9804.1), com TC (G.9804.2) and PMD (G.9804.3) available

50G downstream specs build around 25GHz-class BW-limited receiver components

- DSP-based equalization and hard-input LDPC FEC (threshold 1E-2)
- SOA-based OLT transmitter

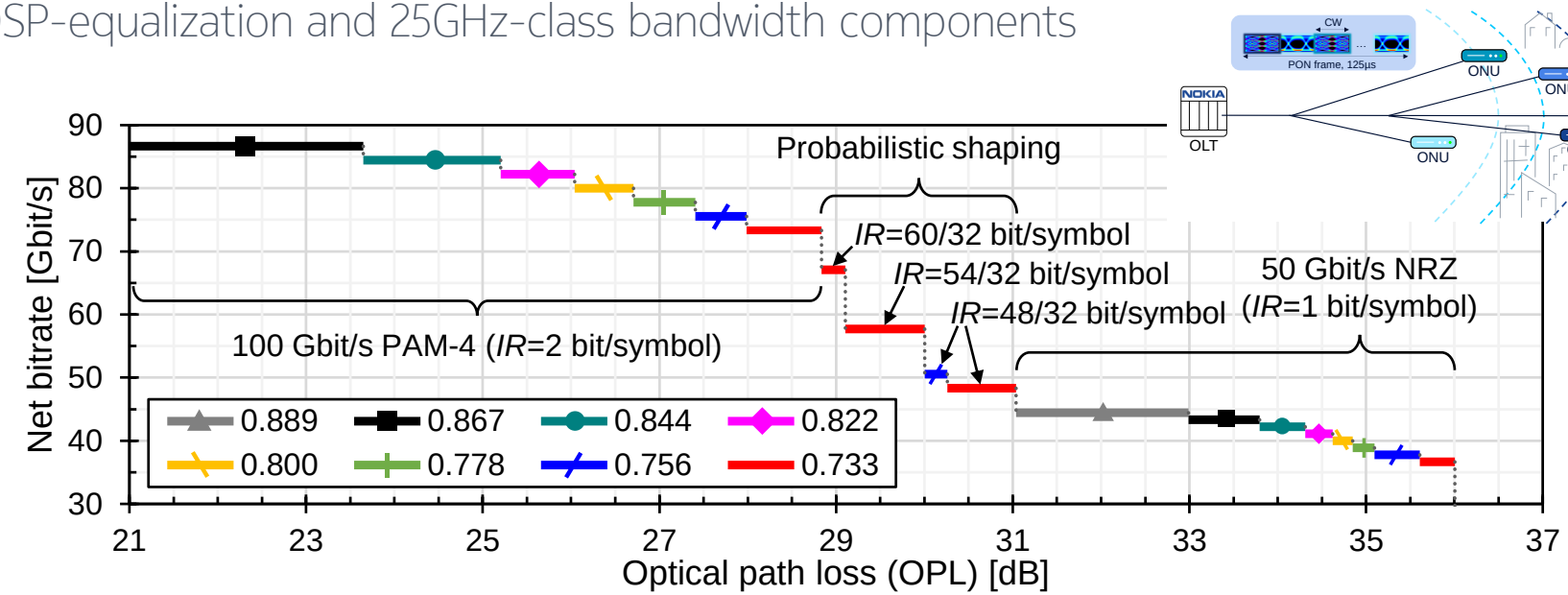
Upstream: flexible FEC for upstream under exploration, 50G US spec. started



R. Bonk et al., "50G-PON: The First ITU-T Higher Speed PON System," IEEE ComMag, March 2022

100G flexible PON demonstration

DSP-equalization and 25GHz-class bandwidth components



100G operator trial with >85 Gbit/s net rate

R. Borkowski et al., Nokia Bell Labs, "Operator Trial of 100 Gbit/s FLCS-PON Prototype with Probabilistic Shaping and Soft-Input FEC ", JLT, 2021

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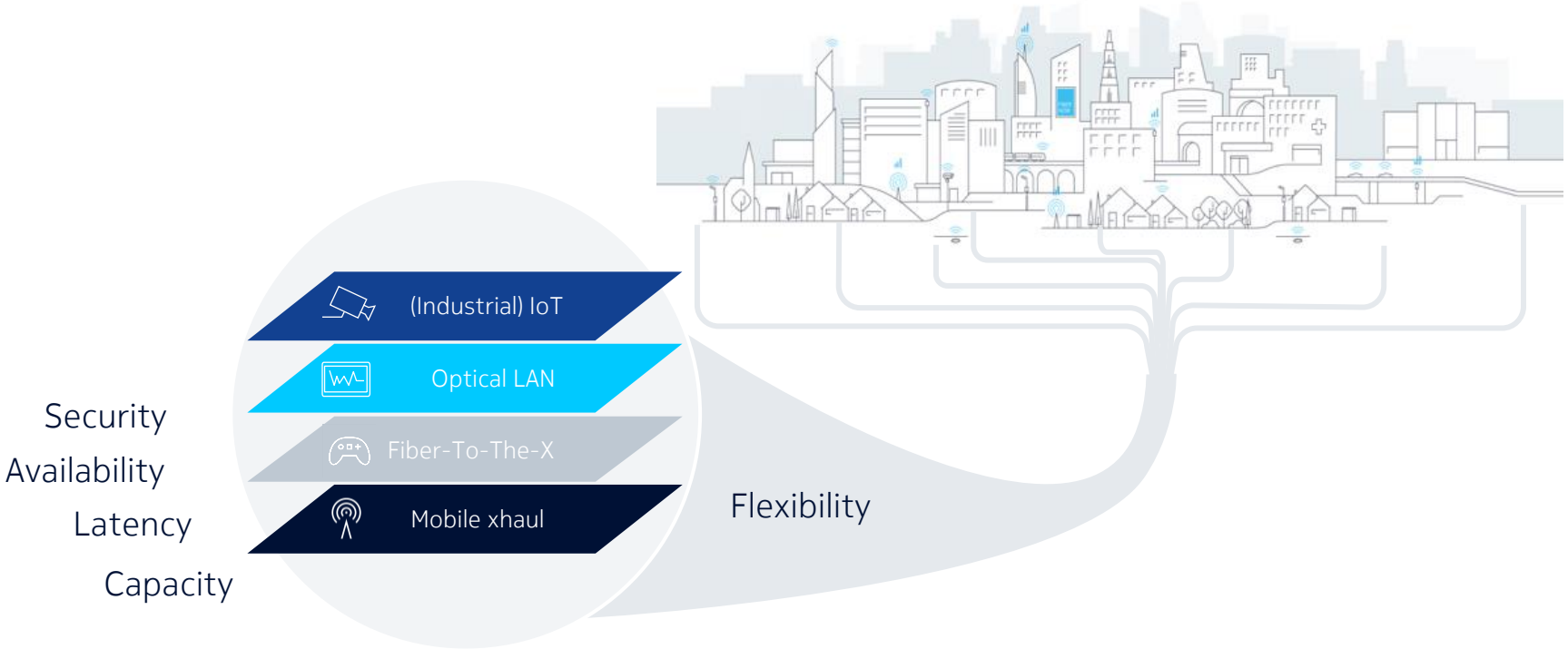
Disaggregated & Cloud RAN over PON – Let us evaluate the smart city (Fibre-to-the-X)

PON systems are increasingly being eyed for different applications

Each with different requirements



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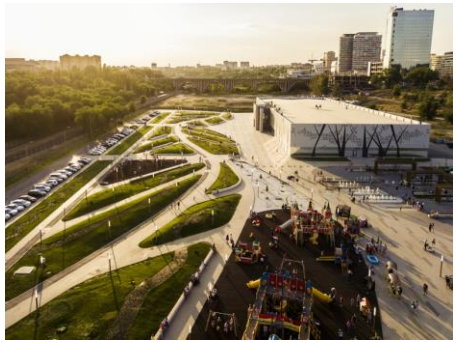
Smart city applications using PON (fiber-to-the-x)

Smart mobility demands for a disaggregated and secure network

Wide application range for smart city

Public safety, smart administration & environment, …



Smart mobility (automated shuttles, …)

KIGLIS
smart networks for smart cities

Onboard info- & entertainment

Broadband network connectivity drives stringent req. on bandwidth and latency

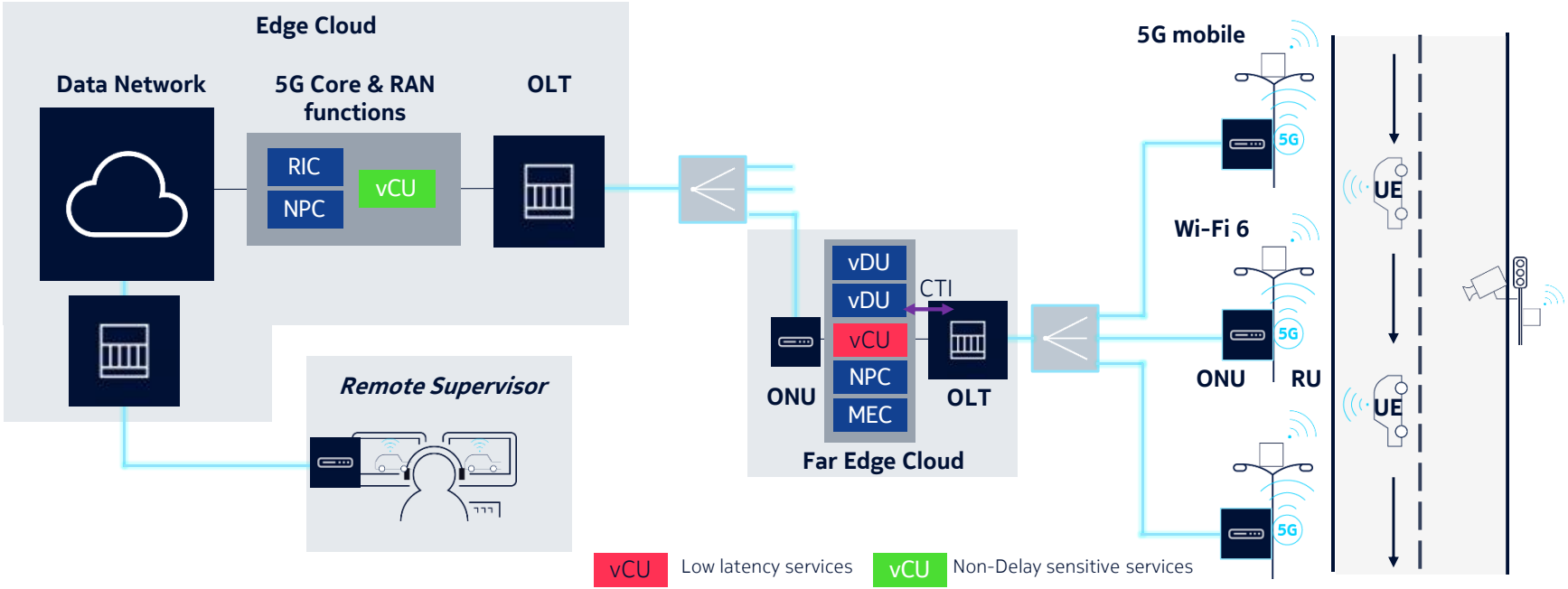
Technical remote supervision

Secure & available communication network for remote supervision of vehicles (99.999% availability)

(German law for automated driving enabling SAE level 4 from 2022 onwards)

PON as part of a critical network infrastructure

KIGLIS
smart networks for smart cities



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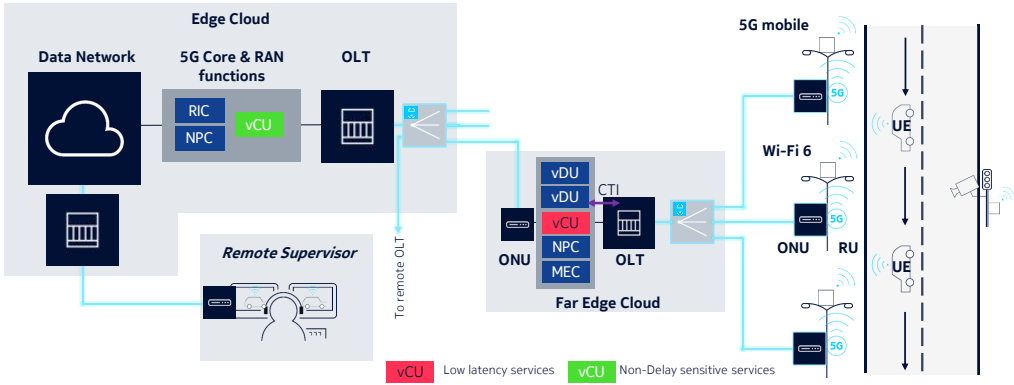
PON as part of a critical network infrastructure

KIGLIS
smart networks for smart cities

Requirements for teleguidance

- Remote supervisor for teleguidance of vehicles stuck in traffic conditions
- Scene information required, like 360° video, lidar and radar
- V2X information exchange needs to be secure, available and trusted



Availability & security

- Primary point of attack: publicly accessible splitter locations → ensure physical inaccessibility
- Availability enhancements with PON protections (e.g. type B for far edge locations)
- Security: confidentiality (encryption), authorization (authentication), integrity (non-repudiation)
  - Enable PON security mechanisms (E: AES128/256, A: e.g. IEEE 802.1X, I: identifiers)
  - Use F1 / LLS interface security: IPsec (3GPP), + MACsec (eCPRI), ORAN exploring situation

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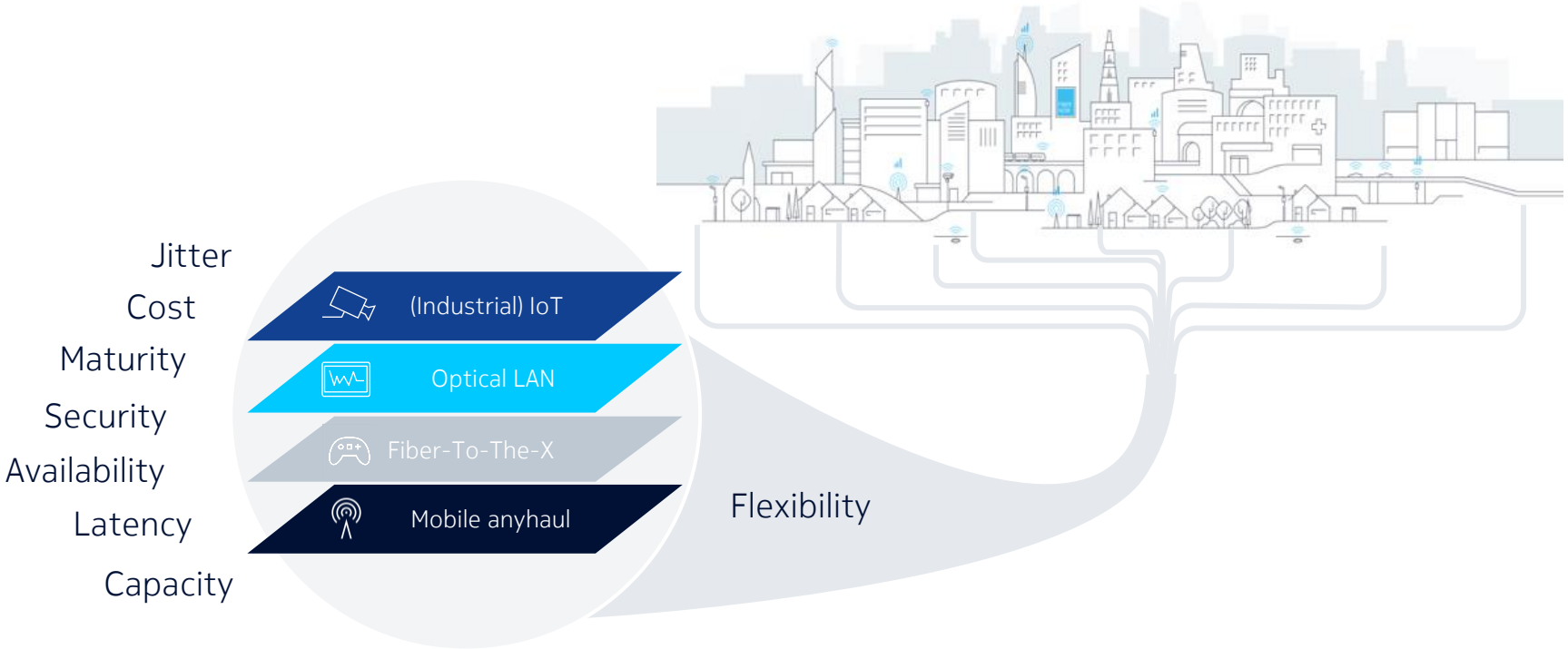
PON for OLAN and future industrial applications

PON systems are increasingly being eyed for different applications

Each with different requirements



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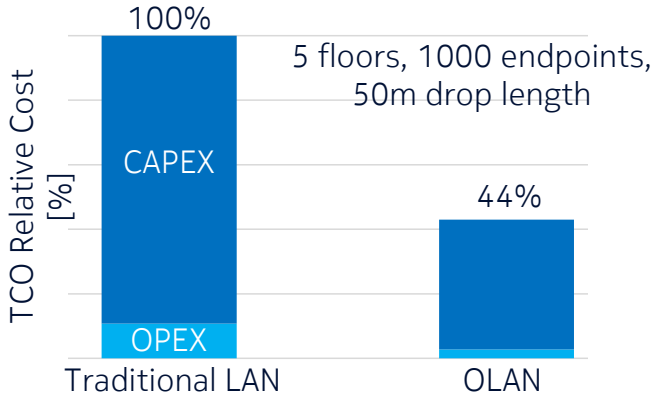
Optical LAN

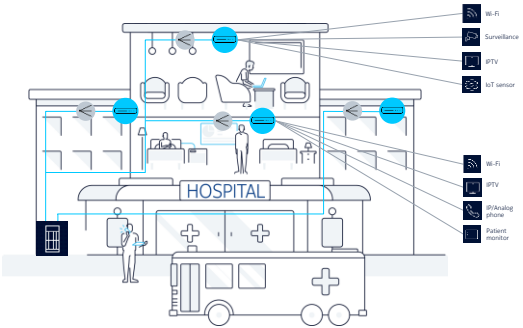
Leveraging maturity and low cost of PON systems

- PON in LAN deloyments to boost performance
- Reduce cost and power consumptions
- Offer a varity of new use cases for PON systems

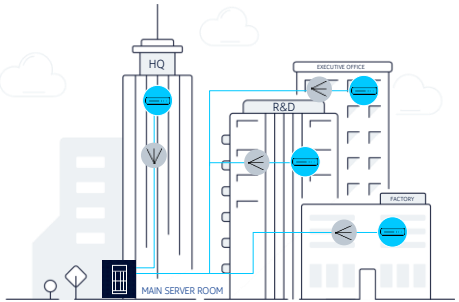


Airports

Hospital, Hotel, Administrations



Enterprise



https://www.nokia.com/networks/solutions/nokia-optical-lan-pol
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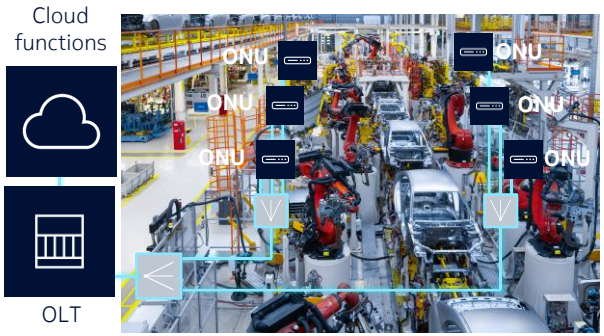
Communication in industrial applications

Convergence of OT and IT into a single infrastructure for Industry 4.0 / 5.0

- Enhanced productization for OT using cloud-based analytics and digital twinning from IT
- OT: control of many simple devices from central entity
- OT: strict deterministic requirements
- OT: proprietary solutions of field buses in use today
- Time sensitive networking enhances Ethernet capabilities (IEEE802.1) for real-time appl. and convergence

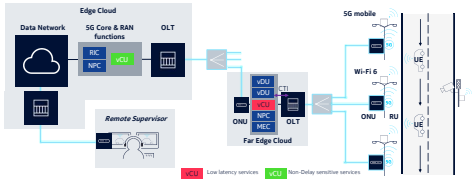


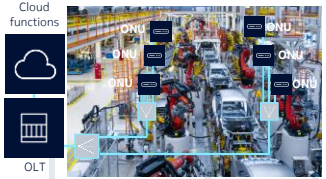
Exemplary requirements for factory automation, an isochronous real-time operation:

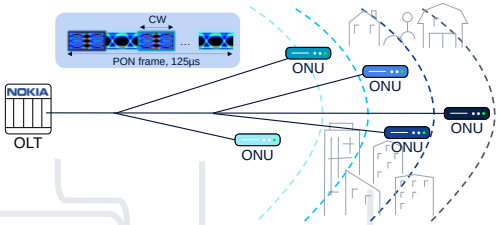
- Periodic network access per device with cycle times ≤ 1ms-30ms
- Line rates of 100Mbit/s – 1Gbit/s using data size of 15-64 byte
- Jitter: ≤ 1µs and latency ≤ 1ms
- Reliability: >99.9999%

PON systems are increasingly being eyed for different applications

Summary







Jitter
Cost
Maturity
Security
Availability
Latency
Capacity

(Industrial) IoT
Optical LAN
Fiber-To-The-X
Mobile xhaul

Flexibility

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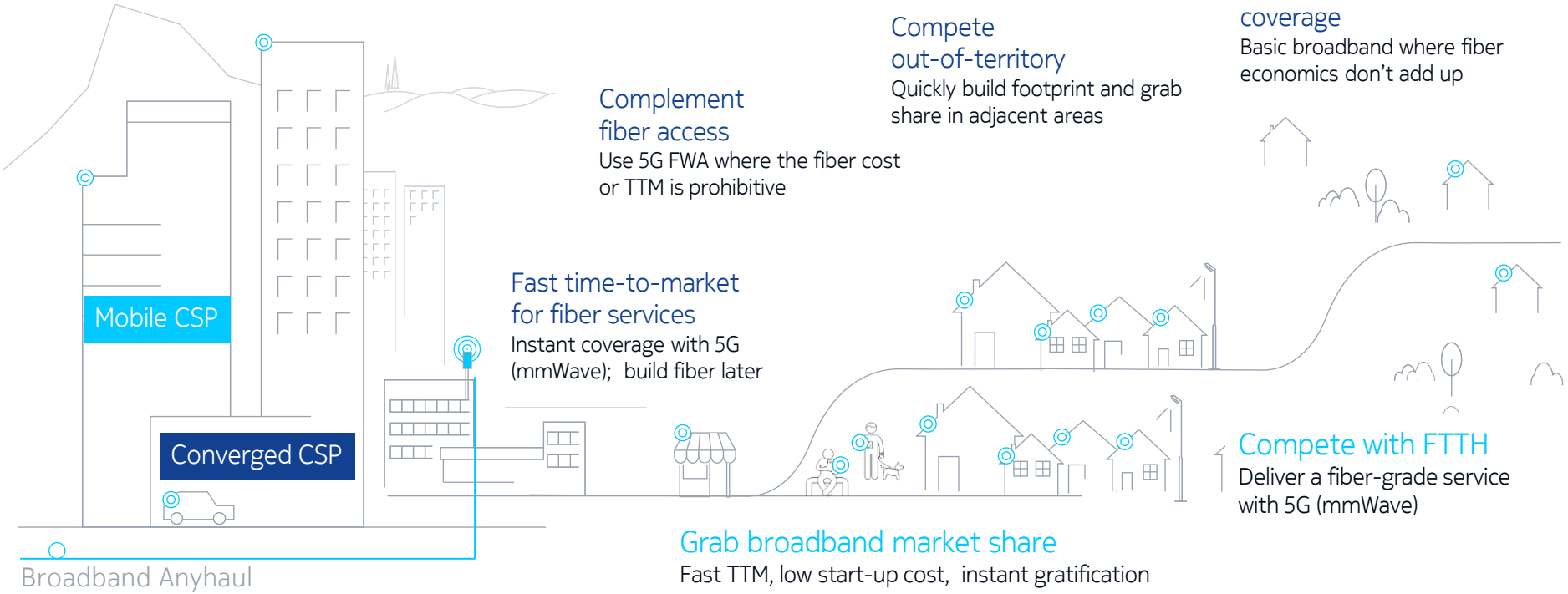
5G Fixed Wireless Access benefits all operators

Coverage, time to market and revenues



Complement fiber access

Use 5G FWA where the fiber cost or TTM is prohibitive

Compete out-of-territory

Quickly build footprint and grab share in adjacent areas

Rural coverage

Basic broadband where fiber economics don't add up

Fast time-to-market for fiber services

Instant coverage with 5G (mmWave); build fiber later

Compete with FTTH

Deliver a fiber-grade service with 5G (mmWave)

Grab broadband market share

Fast TTM, low start-up cost, instant gratification

By 2030 the access network will see

Zero limits

PON break through the 50Gbit barrier

50G

Low cost mobile transport networks

xHaul

Matched capacity and create margins

100G Flex

Deterministic networking

Industry4.0

Zero left behind

Multi-Gigabit connect of all homes and buildings

G.(mg)fast

Compete or complement

FWA

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