Transport Networks: Evolution towards 6G

ICT Industry Talks / Munich, October 2024

Rudi Winkelmann

Winkelmann Management Consulting in collaboration with Nokia

Transport Network Evolution towards 6G

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Market Outlook and Requirements

Xhaul Networks

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RAN & Xhaul

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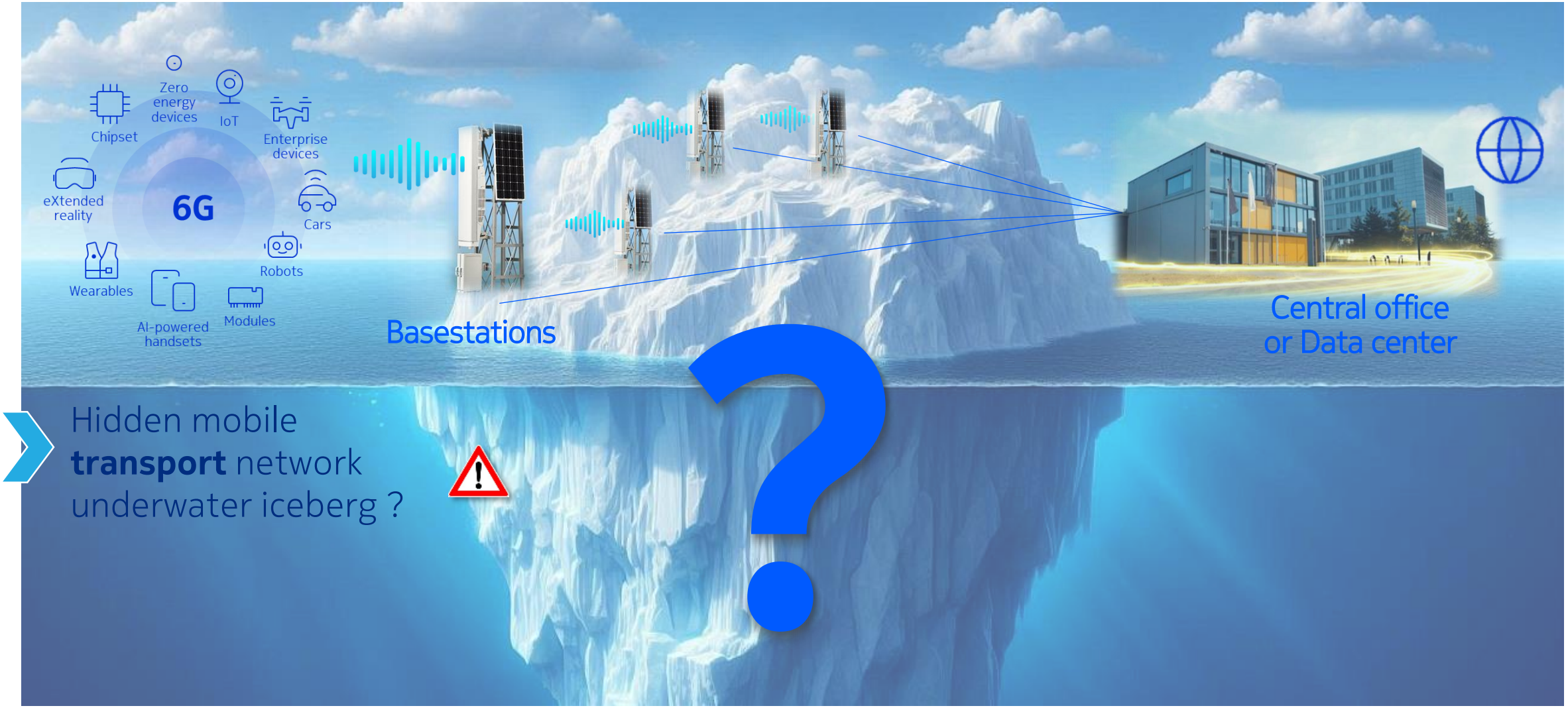
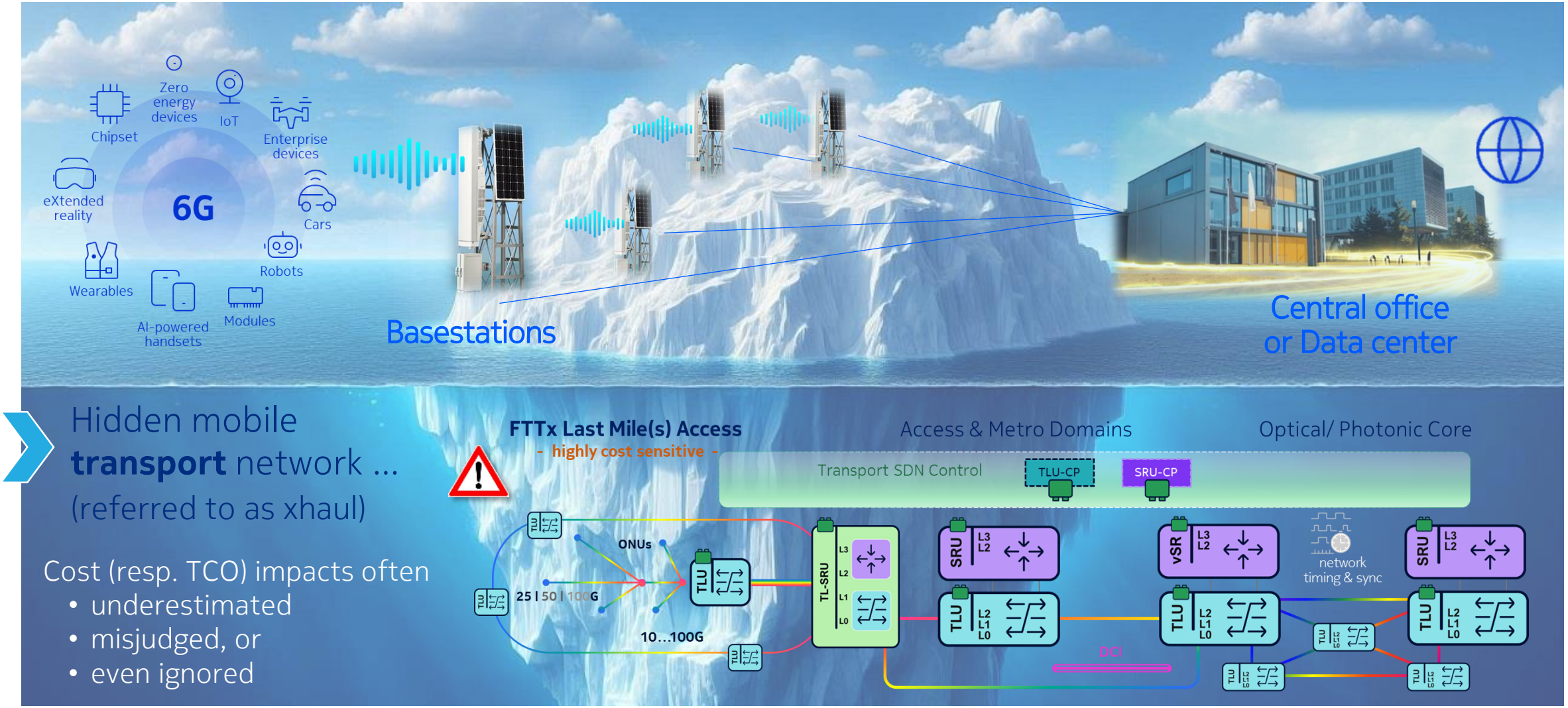
What we see and what we don’t see



What we see and what we don’t see



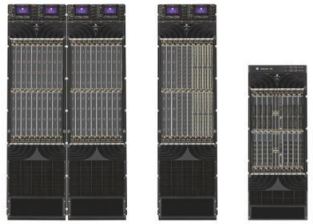
TCO: Total Cost of Ownership

About transmission, transport, transport networks and xhaul

Setting the scene and scope for 6G transport networks

Chip/ Component-level Connectivity

(sub) mm … cm



System-internal Communications

cm … 100m

Local–area **Networks (LAN)**

100m … 1000m

Wide-area **Transport Network (WAN)**

(sub)10km … 100km … 1000km +

xhaul

implemented Transport Functions

HW || FW || SW / API

Connection/ Transport: Layers – Protocols - Interfaces

standardized vs. proprietary || connection-less (packets) vs. connection oriented (circuits)

Media/ PHY Transmission Technologies

Fiber optical (active, passive, WDM, …) | Microwave radio/ Sat (cm, mm waves) | Copper (coax, Cat-x cables, PCB, …)

RAN architecture evolution towards 6G

New deployment schemes and open interfaces call for …

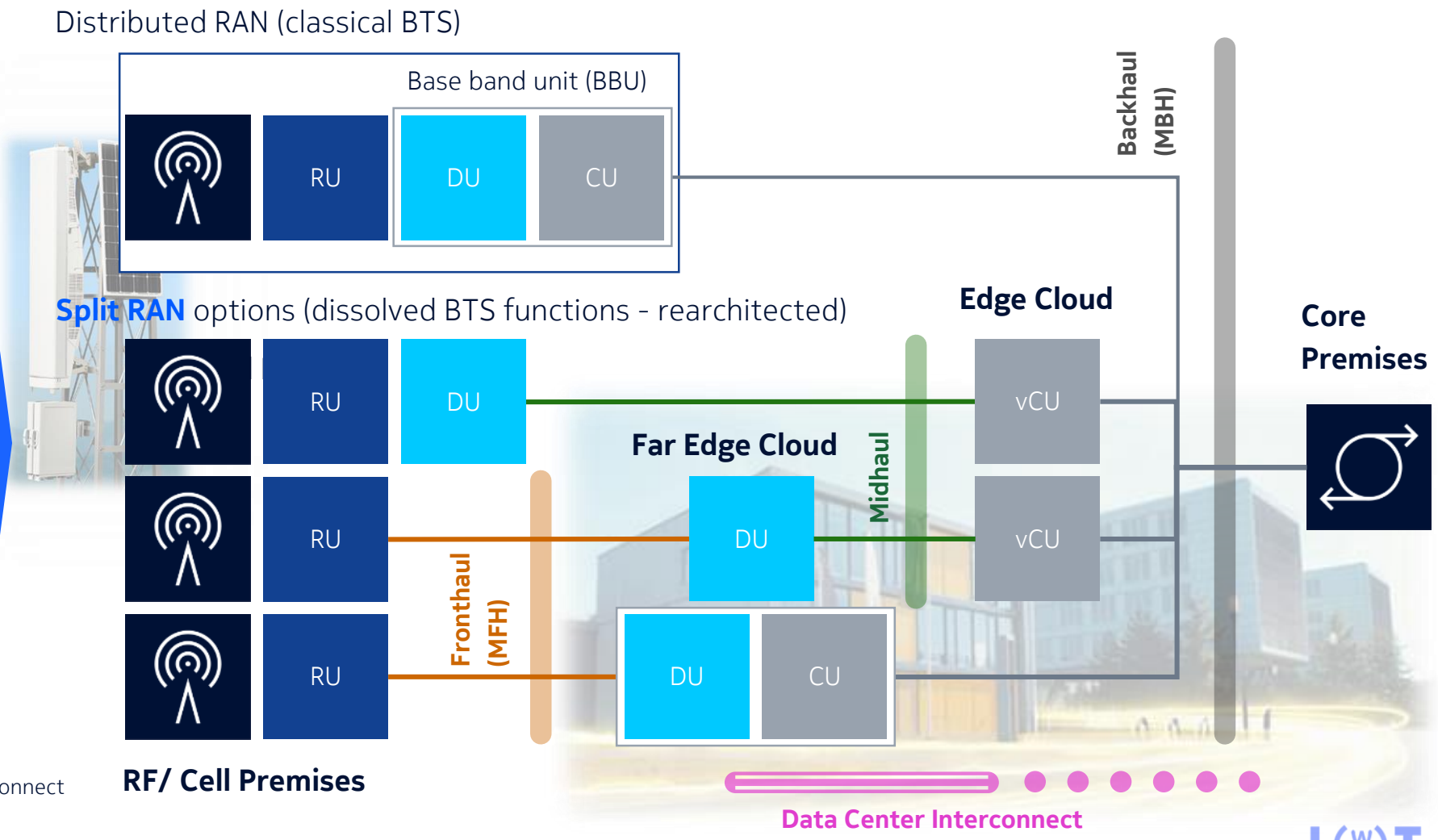
New Requirements

for RAN interfaces and

Transport Networks

aka

Xhaul* profiles



* Fronthaul, midhaul, backhaul, datacenter interconnect

Mobile market outlook - RAN and xhaul

Limited revenue growth asks for techno-economically scaling xhaul solutions

- RAN revenues will slightly fluctuate between $34…35bn in 2025-29 with an expected rebound from 6G in 2030[1]
- Xhaul revenues (~7.5bn in 2024) will remain flattish between 2025-28 with a 5yr CAGR at 0.5%[2]
- 5G MBH revenues will reach $4.3bn by 2028, thereof 53% to come from microwave systems[2]
- Microwave MBH share 55% by 2028 (vs. 44% wired), optical MFH share 87% by 2028 (vs. 13% microwave)[2]
- Significant surge in mobile subscribers and cellular traffic growth: forecasts indicate ~8.6bn[3] active 5G subscribers and 3.64 zettabytes[4] of p.a. global cell traffic by 2029

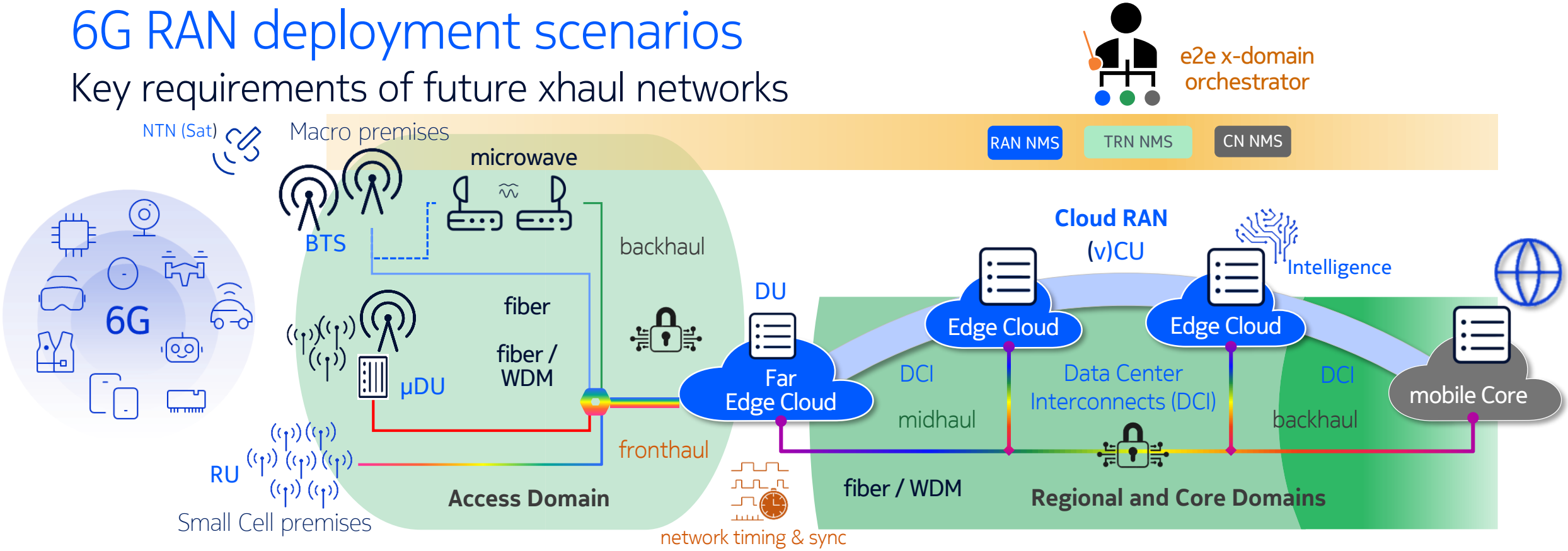
Limited revenue growth (continues) to **constrain** the capital spending of operators, thus making TCO scalable and energy efficient transport/ xhaul solutions **mandatory** for future RAN expansion, densification and radio technology upgrades.

References:

1. Del'Oro Group: Advanced Research Report: 6G I September 2024
2. Del'Oro Group: Microwave Transmission & Mobile Backhaul Report I July 2024
3. OMDIA: Mobile Subscription and Revenue Forecast Report (pg. 19) – 2Q24 ! August 2024
4. OMDIA: Cellular Data Traffic Forecast Report – 2Q24 (pg. 5) I September 2024

6G RAN deployment scenarios

Key requirements of future xhaul networks



Network Size and Load	Network Performance	Architecture Evolution	E2E Network Automation
• Radio upgrades at cell sites	• 20x higher throughput	• Techno-economic scalable	• Cross-domain orchestrated
• Increasing site densification	• 10x increased complexity	• Modular and programmable	• Multi-layer (self) optimized
• Enterprise/ Industry coverage	• Ultra-low latency capable	• AI assisted SON/ ML enabled	• Software defined networking
• In-building I NTN expansion	• Ultra reliable TR services	• Highly secure and trustable	• E2e network slicing

Principle behind architectural renewal

Decomposition - Disaggregation – Openness - Virtualization – Cloudification - Re-assembly

1

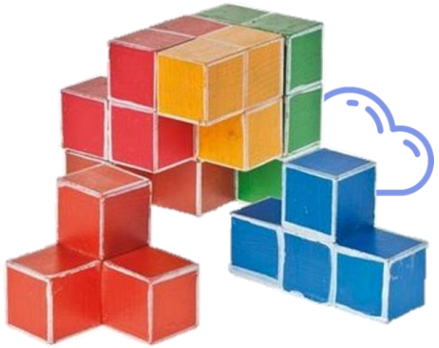
Monolithic
Network Entities

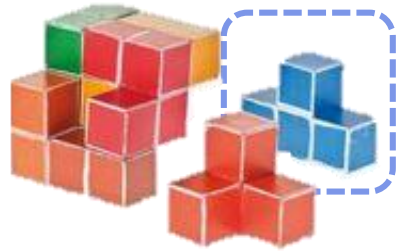
RAN – Transport – Core
vertical & closed

2

Decomposed Framework
of modular Network Functions

Physical – Virtual – Cloudified
open





3

Re-architected || programmable
Network Deployments as needed

truly x-domain e2e orchestrated
open & interoperable

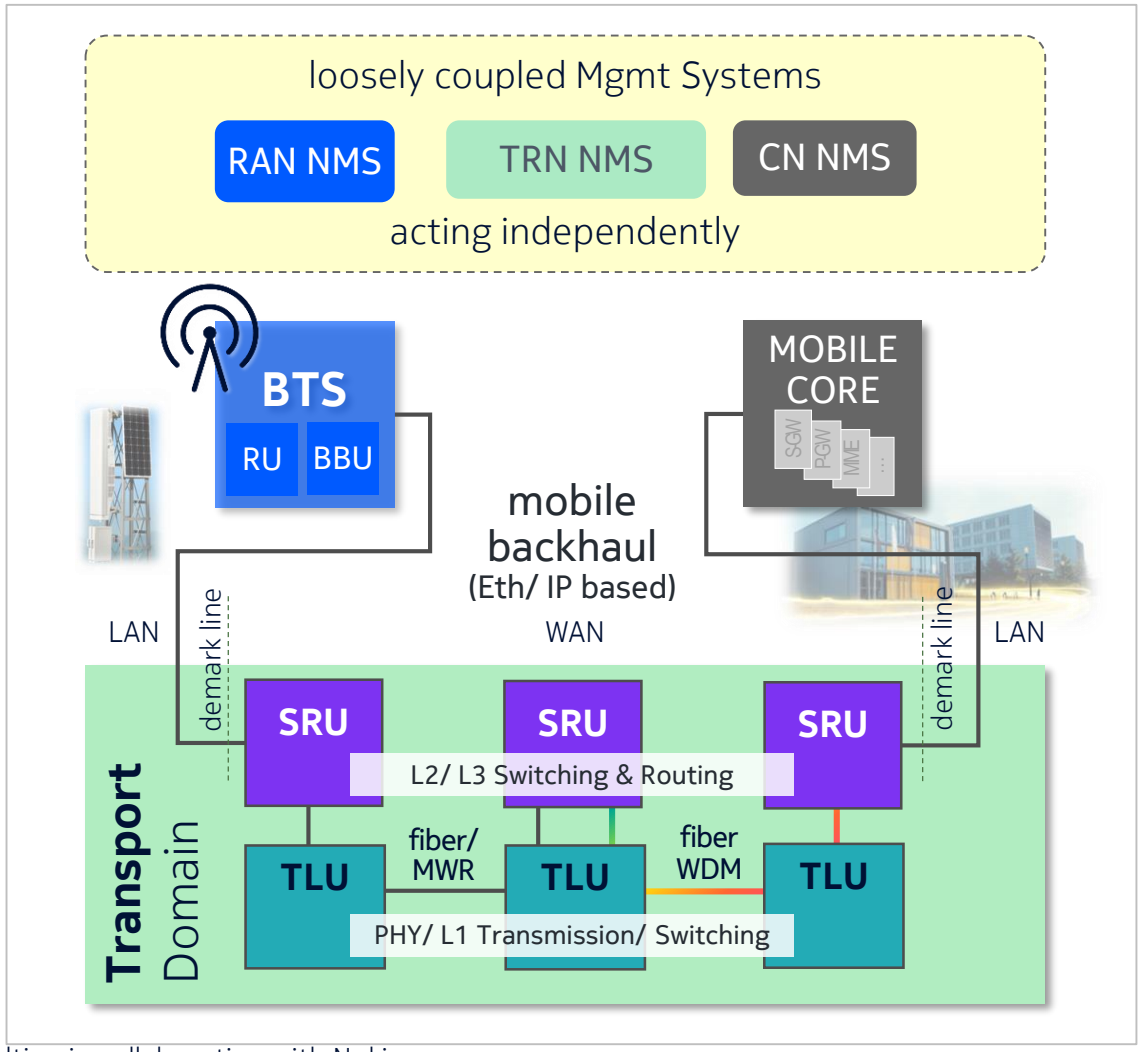
Traditional mobile network deployments

Distributed Radio Access Networks (D-RAN) and mobile backhauling

1

Monolithic Network Entities

RAN – TRN – Core vertical ll closed



BBU	Radio Base-band Unit
BH	Mobile Backhaul
BTS	Basestation
CN	Core Network
D-RAN	Distributed RAN
TRN	Transport Network
MWR	Microwave Radio
NMS	Network Management System
RAN	Radio Access Network
RU	Radio Unit
SRU	Switching & Routing Unit
TLU	Transmission Line Unit
WDM	Wavelength Diversion Multiplexing

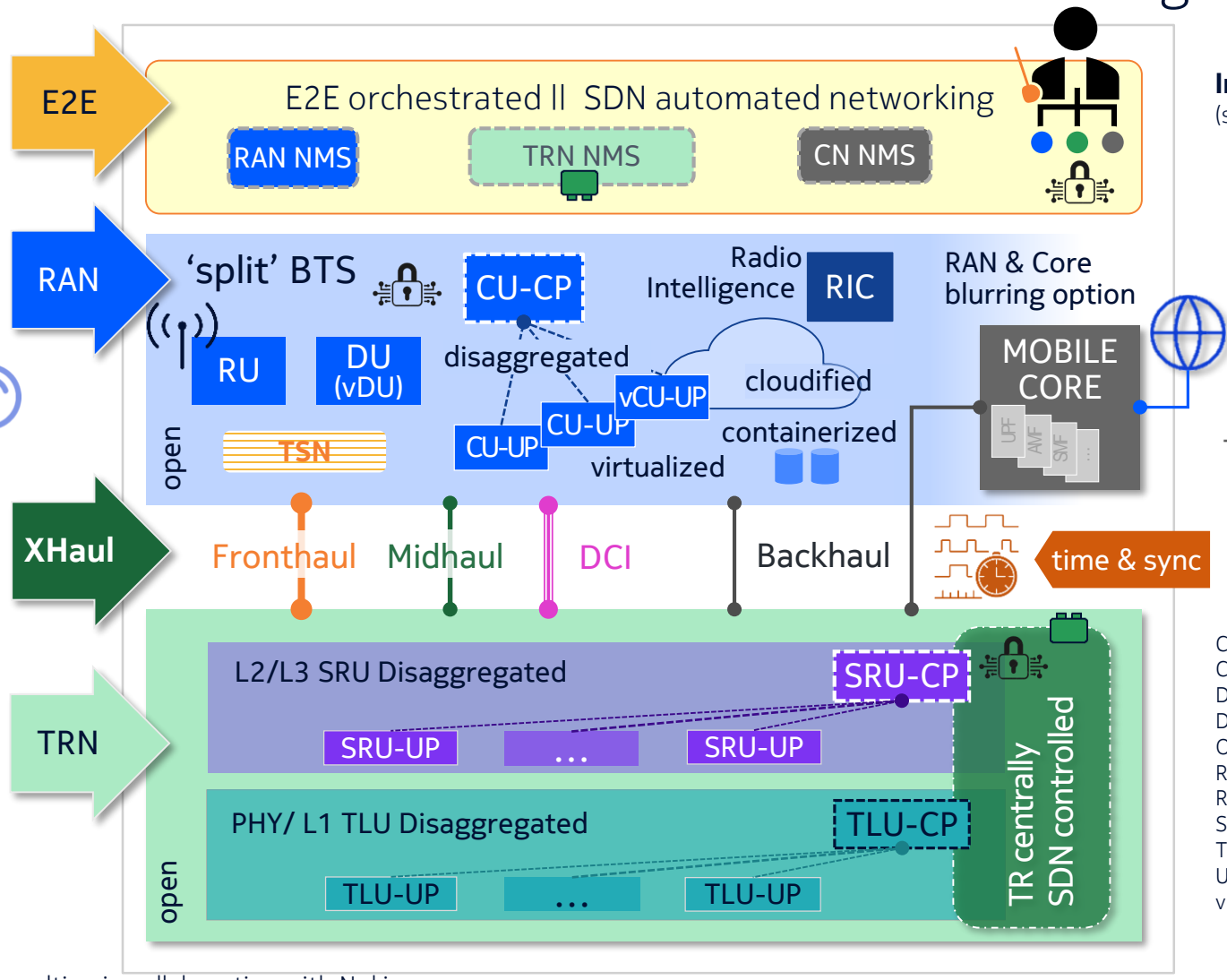
Future re-architected RAN and TR network framework

disaggregated – open – virtualized - containerized – cloudified – intelligent -orchestrated

2

Decomposed, modular Network Functions

Physical – Virtual – Cloudified
Open



Industry Alliances& Initiatives
(selected examples)

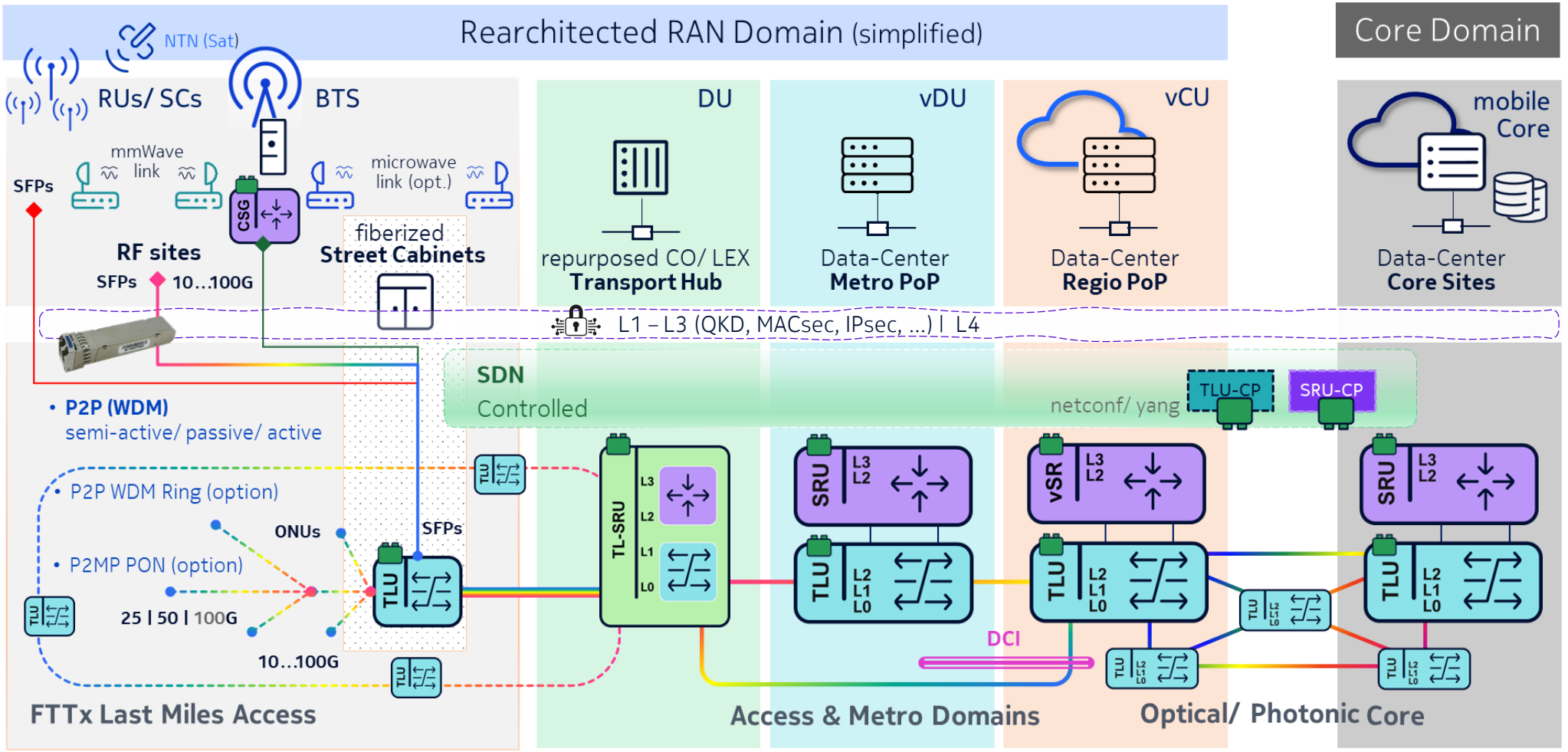
O-RAN ALLIANCE
AI-RAN ALLIANCE
THE LINUX FOUNDATION
ONF
TELECOM INFRA PROJECT
MOPA
IOWN GLOBAL FORUM

CP	Control Plane (suffix), e.g. CU-CP
CU	Centralized Unit (higher layers)
DCI	Data-center Interconnect
DU	Distributed Unit (lower layers)
O-RAN	Open RAN Alliance
RIC	Radio Intelligent Controller
RU	Radio Unit
SDN	Software-defined Networking
TSN	Time-sensitive Networks
UP	User (Data) Plane (suffix)
v	virtualized (prefix), e.g. vCU

Xhaul options for future rearchitected RAN deployments

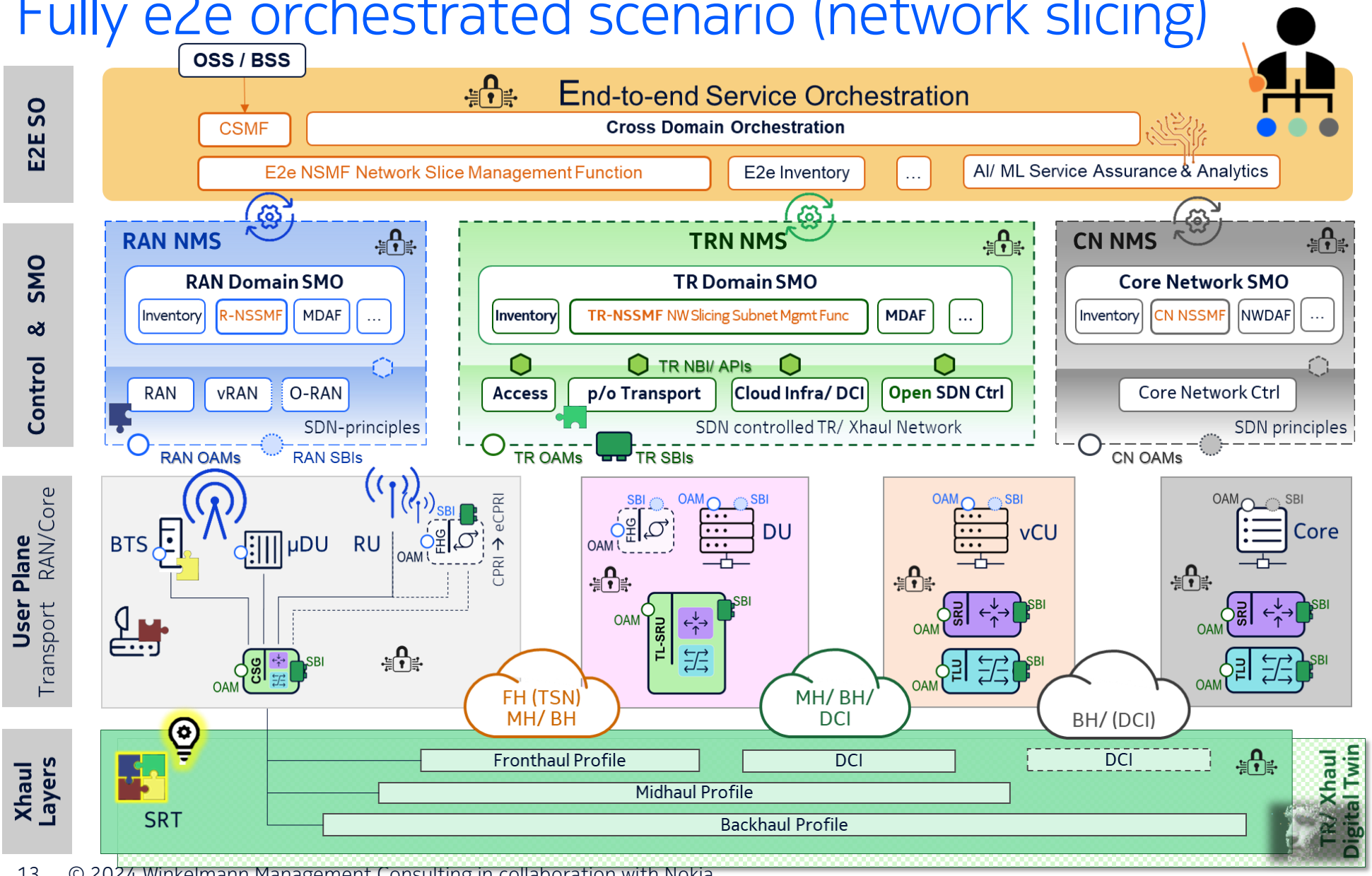
3

Re-architected, programmable Xhaul Network



CO	Central Office
FTTX	Fiber to the X
IPSec	IP Security (protocol)
MACsec	MAC Layer Security
P2MP	Point-to-multipoint
P2P	Point-to-Point
PON	Passive Optical Network
PoP	Point-of-Presence
QKD	Quantum Key Distr
SFP	Small Form Pluggables
SC	Small Cell

Fully e2e orchestrated scenario (network slicing)



3

- **Network slicing**
- **C/M & SMO plane**
- **E2e Orchestration RAN – Xhaul – Core**
- **Innovation**

CSG	Cell Site Gateway
CSMF	Coms Service Mgmt Func
FHG	Fronthaul Gateway
MDAF	Mgmt Data Analytics Func
NBI	SDN North Bound Interface (TR)
OAM	Operations Admin Maintenance
SBI	SDN South Bound Interface (TR)
SMO	Service Mgmt Orchestration
SRT	Simplified RAN Transport
vRAN	virtualized RAN

Summary and take-aways

Building sustainable mobile transport networks ready for the metaverse era

- 6G connectivity demands with new RAN models will increase mobile transport network complexity
- New RAN (fronthaul) interfaces will boost transport capacities, load and xhaul interface speeds
- New (ultra) low e2e latencies will require time-sensitive xhaul networks
- Cloud RAN solutions will change network topologies and ask for advanced transport resiliency schemes
- Increasing ask for openness (x-vendor) and interop (x-domain)
- Transport networks (all layers/ planes) to become an integral part of a fully e2e secured and trusted mobile network
- Novel 6G use-cases will drive operational agility and e2e effectiveness highly impacting xhaul networks
- Techno-economically scalable xhaul framework essential for RAN monetization and profitability
- Investments in xhaul upgrades need to be done well ahead of new xRAN deployment models
- Unified transport infras (TaaS) in cost-sensitive, fixed access areas (mobile, residential, Enterprises)
- Increasing trend of 'ITzation' also in the transport domain (DCI, virtualization, cloudification, AI, digital twins)
- Use of digital twins to increase the efficiency wrt network planning, operations or (virtual) testing
- Smart and integrated / multi-layer optimized xhaul solutions (e.g., transport, switching, routing, RAN radio functions, management, security)
- Network programmability, automation and e2e services orchestration to become mandatory

Acronyms

AI	Artificial Intelligence
BBU	Radio Base-band Unit
BH	(Mobile) Backhaul aka MBH
BSS	Business Support System
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CAGR	Compound Annual Growth Rate
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TaaS	Transport As A Service
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TLU	Transmission Line Unit
TRN	Transport Network
TSN	Time-sensitive Networks
UP	User (Data) Plane (suffix)
v	prefix: virtualized, e.g. vCU
vRAN	virtualized RAN
WDM	Wavelength Diversion Multiplexing
x	prefix/ suffix: deployment variant, e.g. xHaul, FTTx, xRAN

References and acknowledgements

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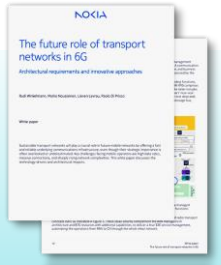

THE FUTURE ROLE OF TRANSPORT NETWORKS IN 6G
Lieven Levrau, Marko Nousiainen,
Paolo Di Prisco, Rudi Winkelmann (editor)

Link to white papers
- https://bit.ly/BL-6G-TRNetworks (Nokia/ Bell Labs)
- https://bit.ly/ITG-6G-TRNetworks (VDE/ ITG)

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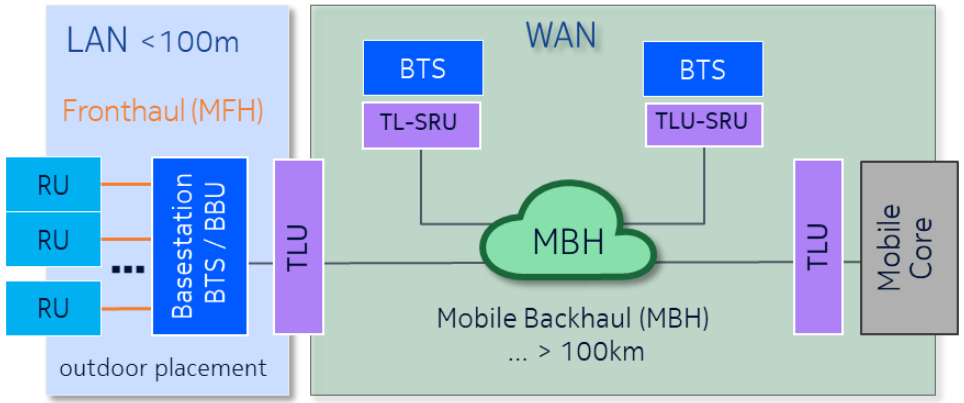
Backup section

The hidden xhaul TCO challenge

Fronthaul-enabled xhaul networks in (passive) fiber-sparse environments

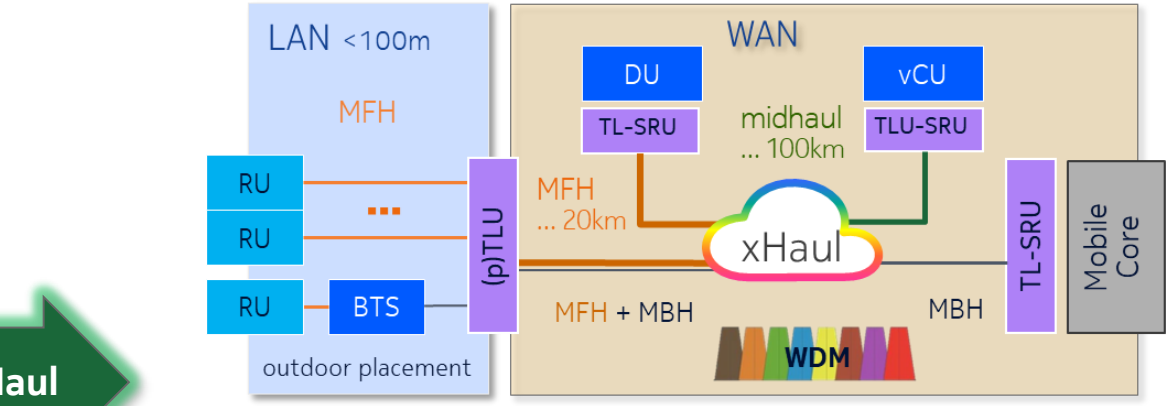


- Traditional mobile backhaul over external TR WAN
- Local fronthaul network at cell site premises (LAN)

b/w SFP	LAN	WAN	Backhaul Characteristics	TCO Impact
1-10G	X	X	• Low cost SFPs • Easy plug & play • Intra-site LAN and WAN • Traditional LAN cabling, and simple WAN deployment practices up to 10G	moderate
25G	X			
50/100G	X			

→ Usually scales well at moderate cost for up to 10G

xHaul



- MFH enabled xhaul over WANs using WDM techniques
- Fronthaul interfaces exposed to external TR WAN

SFP

WDM SFP	LAN	WAN	Xhaul Challenges	TCO Impact
1-10G	X	X	Low-cost SPFs Easy plug & play deployment	moderate
25G	X	X	+ Expensive SFPs and reach limitations + Demanding optical link engineering	high
100G	X	X	++ Significant drawbacks on reach ++ High cost SFPs (e.g. coherent optics)	very high

→ TCO challenge* beyond 25G to cope with fiber impairments

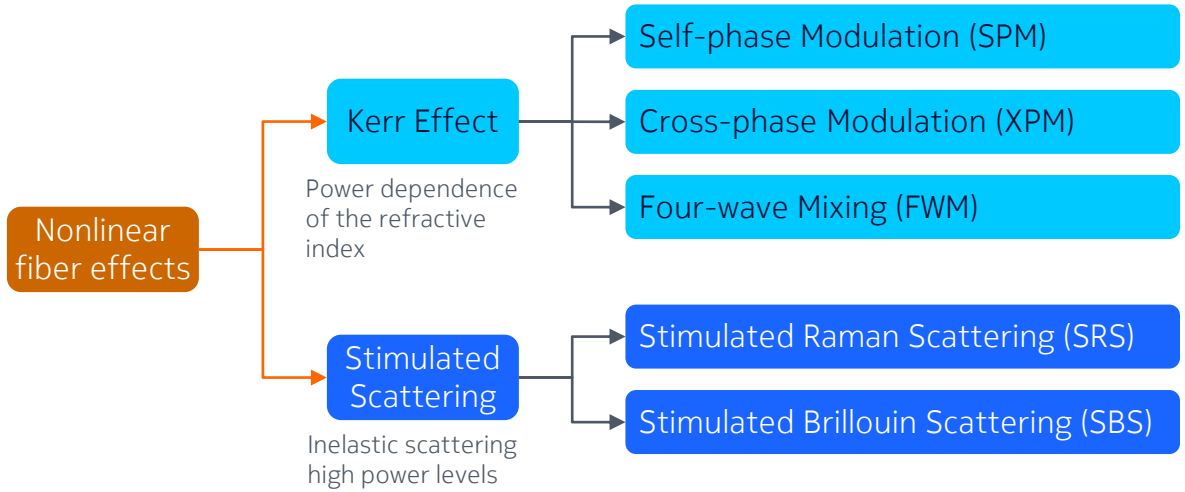
* mainly due to 25/100G SFP cost and adv. optical network provisions: **fiber non-linearities**, link reach and more stringent SFP requirements

SFP* optical Small Form Pluggable (**non-coherent**: NRZ/PAM4 mod.)
TL-SRU: Transmission Line/ S&R Unit
(p)TLU (passive) Transmission Line Unit
*ETR: Extended Temp. Range [-40 to +85°C]

Impairments of fiber (nonlinear effects)

Impact on xhaul network techno-economics beyond 25G

- For intense electromagnetic fields, any dielectric medium behaves like a nonlinear medium
- Fundamentally, the cause of nonlinearity lies in the ‘inharmonic motion’ of bound electrons under the influence of an applied field
- Nonlinear fiber effects (NLE) are proportional to the optical power density of signals and significantly affect the signal phase, pulse shape, and optical power envelope → OSNR
- Nonlinear effects become visible as a techno-economical problem for line rates above 10Gbps, particularly in context of WDM systems
- Traditional dimensioning rules for 1…10Gbps which imply linear techno-economical scalability do no longer apply for 25Gbps+ xhaul interfaces



The intensity of scattered light grows exponentially if the incident power exceeds a certain threshold value

NLE	Transport counter measure e.g. for WDM FH dimensioning & operations
SPM	Decrease the single-wavelength optical power
XPM	Do both incident optical power and dispersion compensation, use Raman amplifiers
FWM	Reserve a certain amount of dispersion in the operating band to avoid zero dispersion
SRS	Decrease the single-wavelength optical power and total optical power for equalization
SBS	Decrease the single-wavelength optical power, add a low-frequency scrambling signal