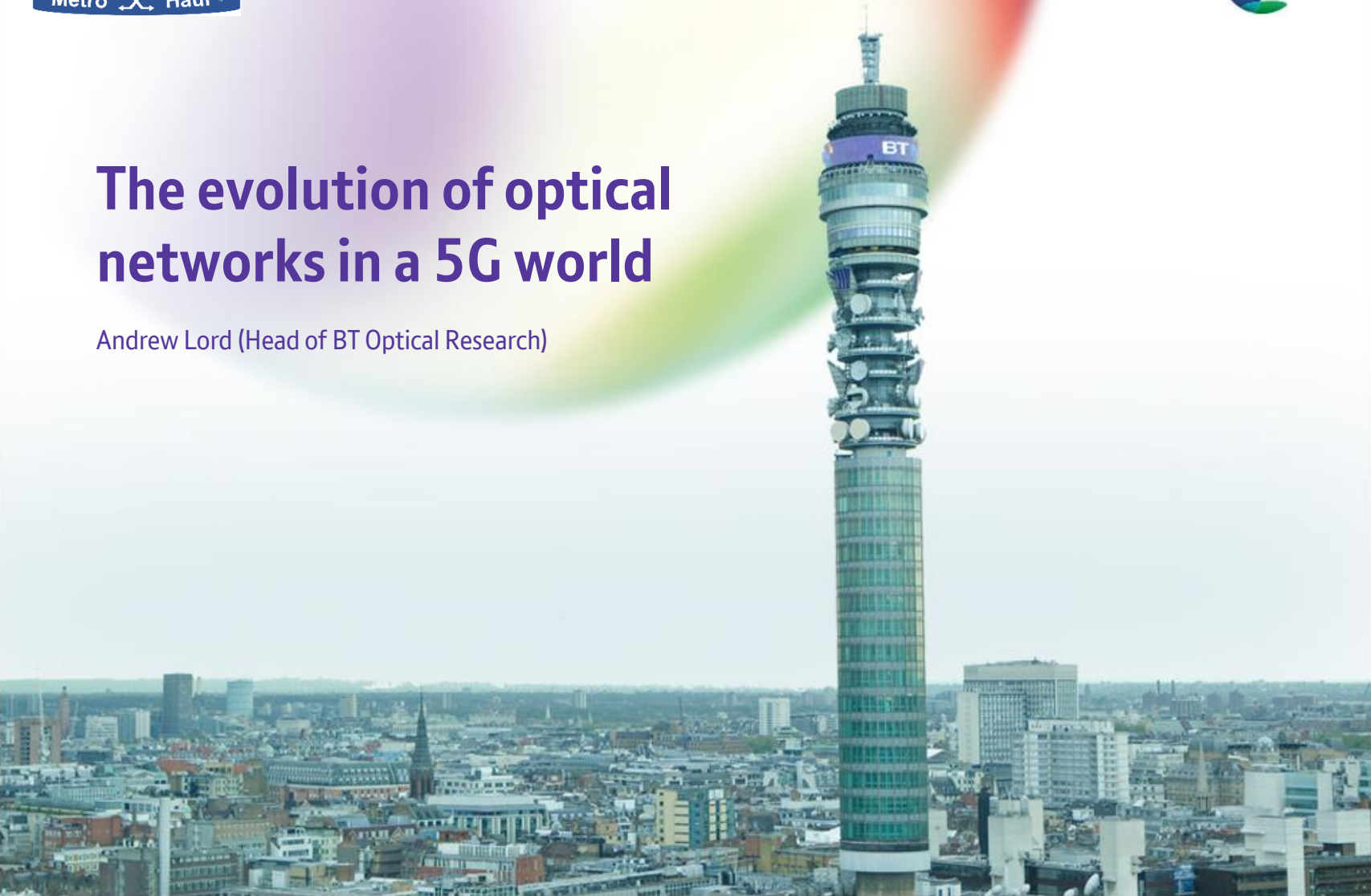
The evolution of optical networks in a 5G world

Andrew Lord (Head of BT Optical Research)



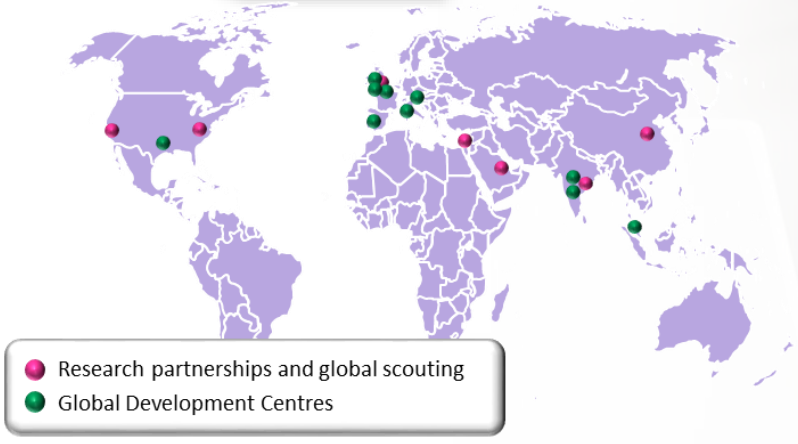
How times change

Talk Outline

- What is traffic doing? 5G drivers
- BT network drivers
- Optical network architectures in the light of 5G
- EU Metro-Haul project
- Focus on the metro
- Core discussion
- Conclusions

- Acknowledgements
  - My BT team
  - Metro-Haul EU project partners

Who we are



- In 180 countries around the world
- £24bn revenue, £5bn free cashflow
- c.100,000 people
- Recruiting 1700 grads and apprentices for 2018

Adastral Park

3,850 people
3,000 BT people and 850 partners including 128 Graduates and Apprentices this year

98
High tech companies

54,000
visitors per year including 4,000 school visitors

102
Number of inventions filed in 2016/17

BT's Global engineering HQ

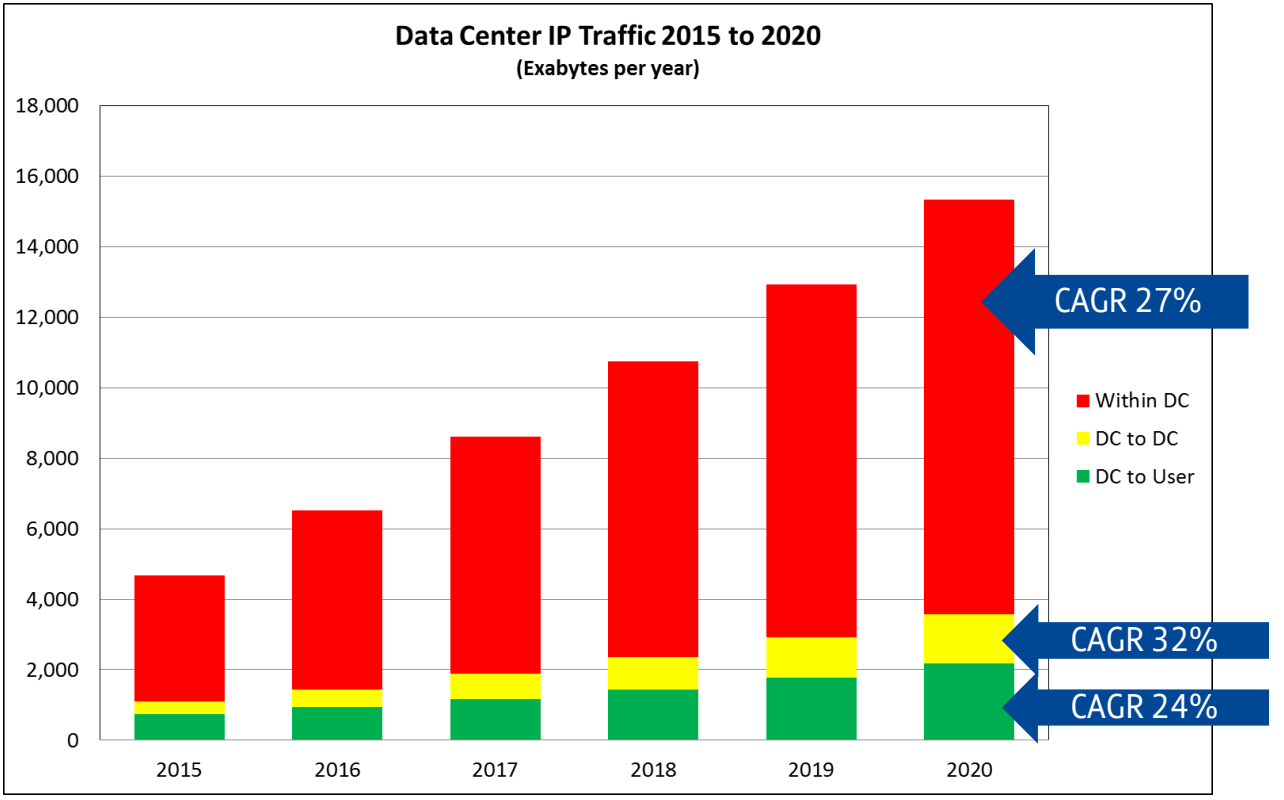
UK operations centre

Largest test & integration facility in Europe

Adastral vision
To become a national centre for a global digital economy

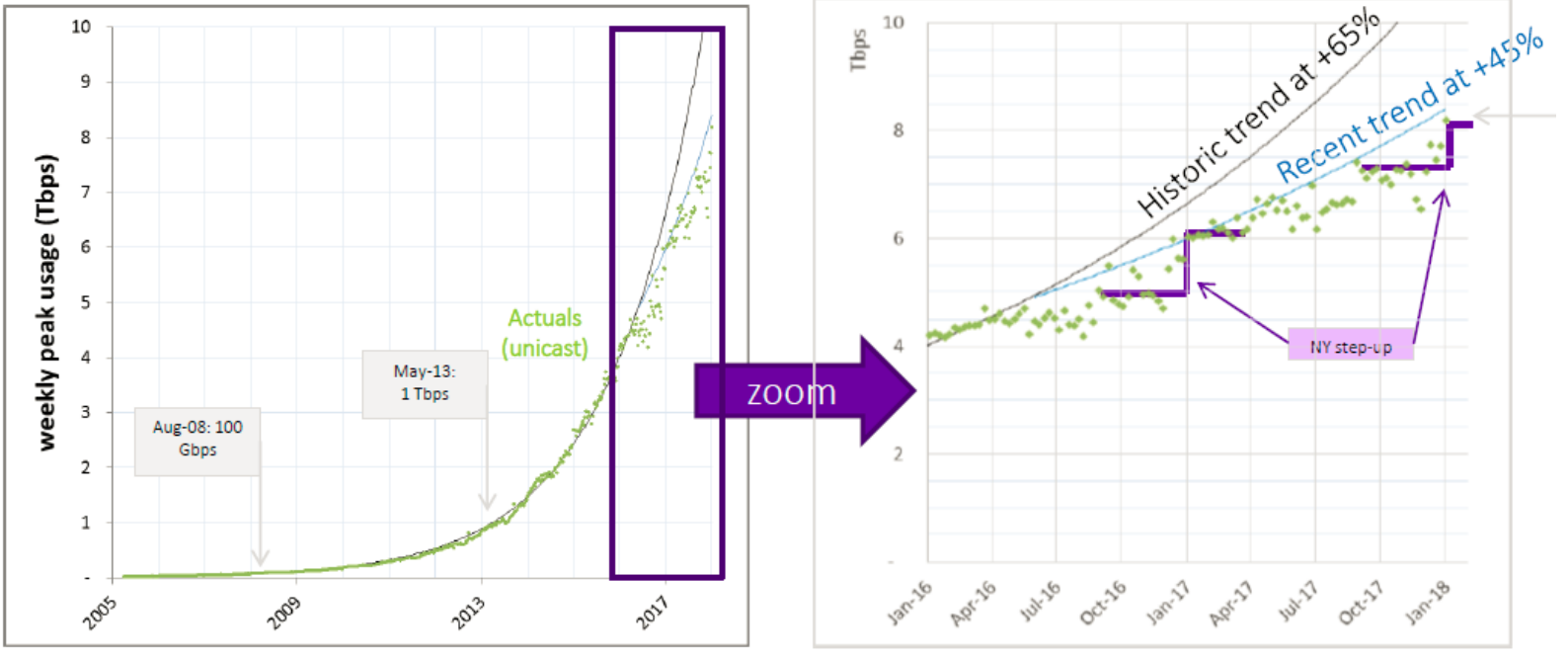
www.btgraduates.com

Inter/Intra data centre traffic



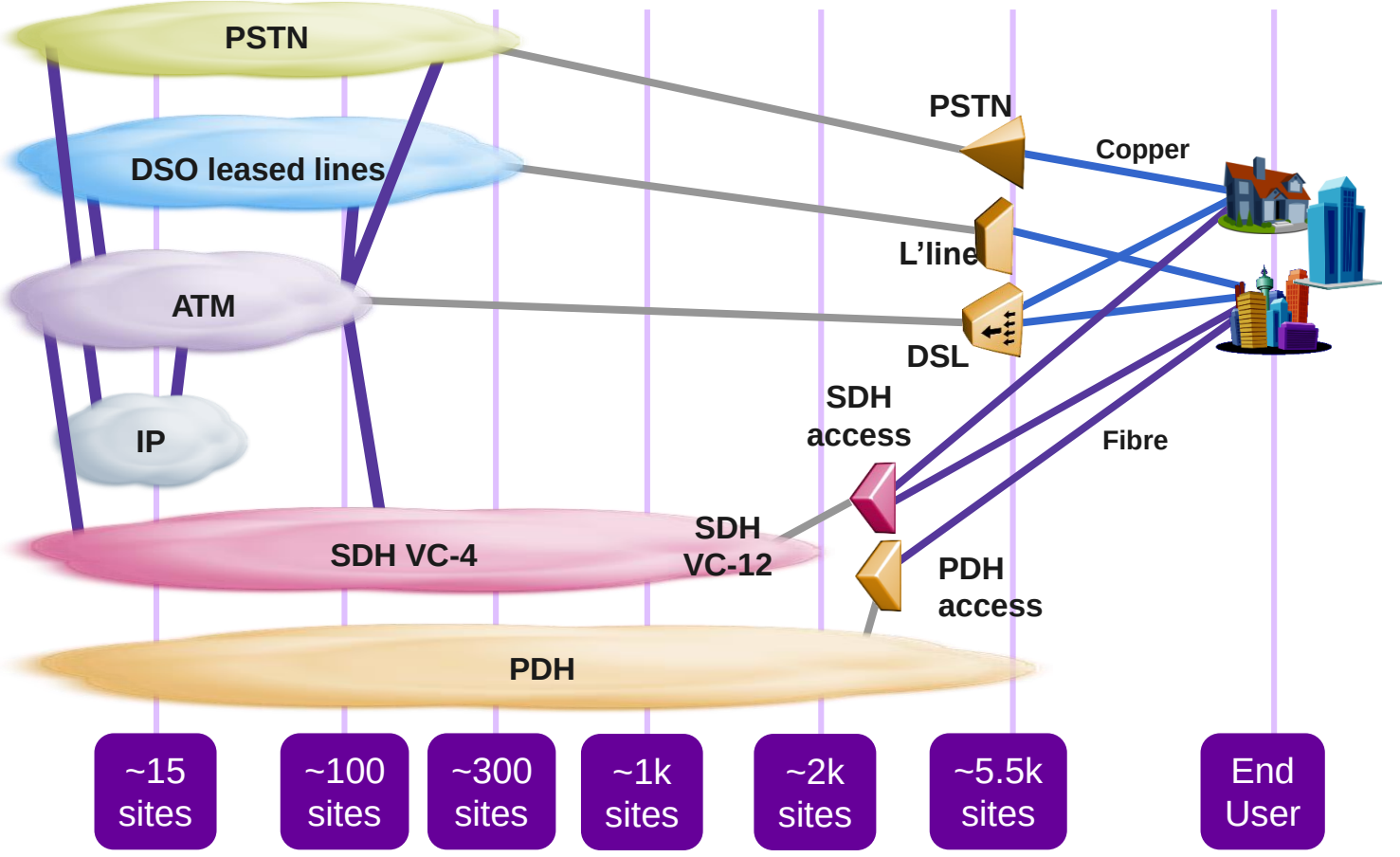
Source: Cisco CGI, 2015-2020

Growth of aggregate core traffic continues and is slowing slightly

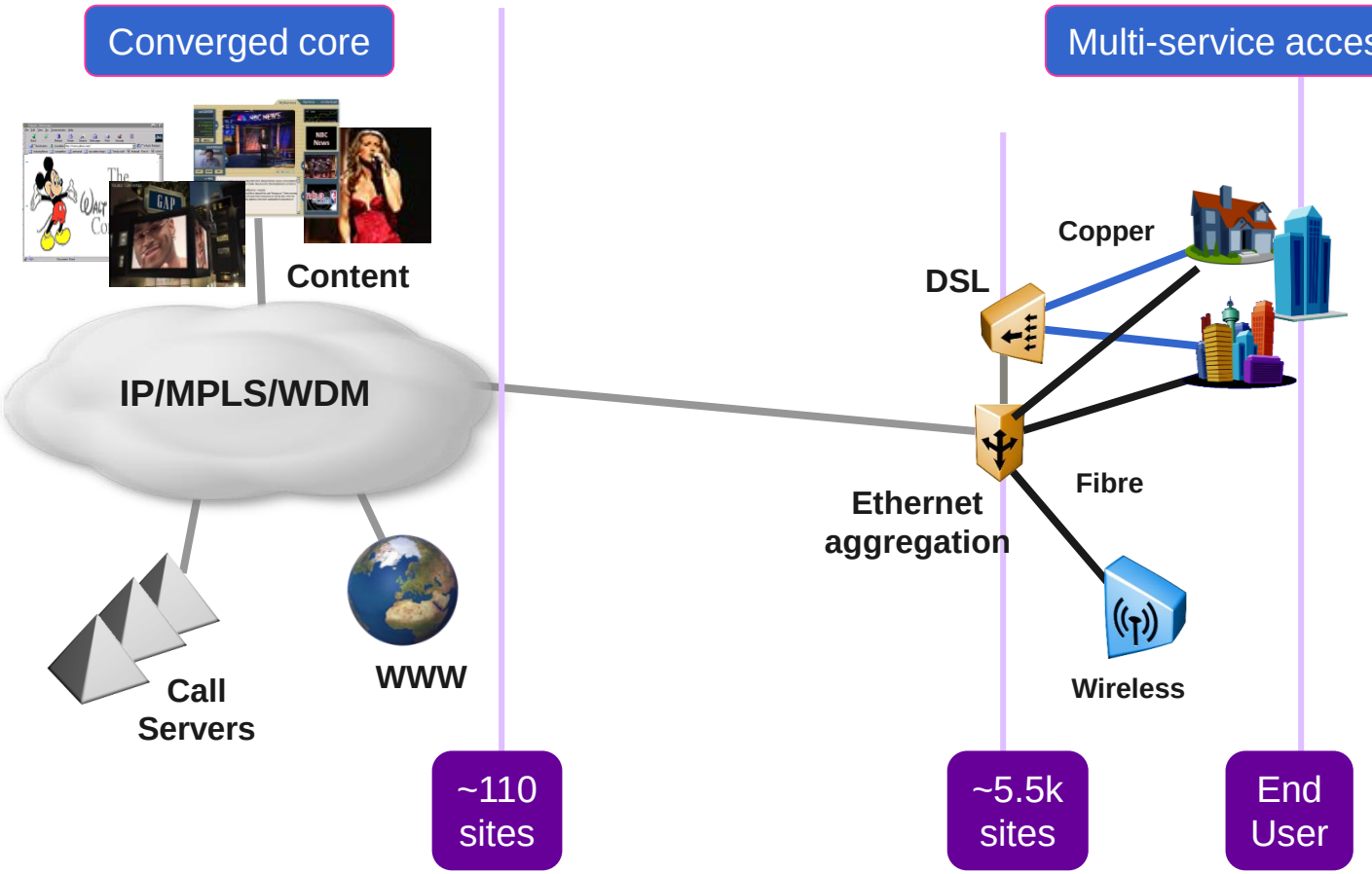


40% + growth is mirrored around the world

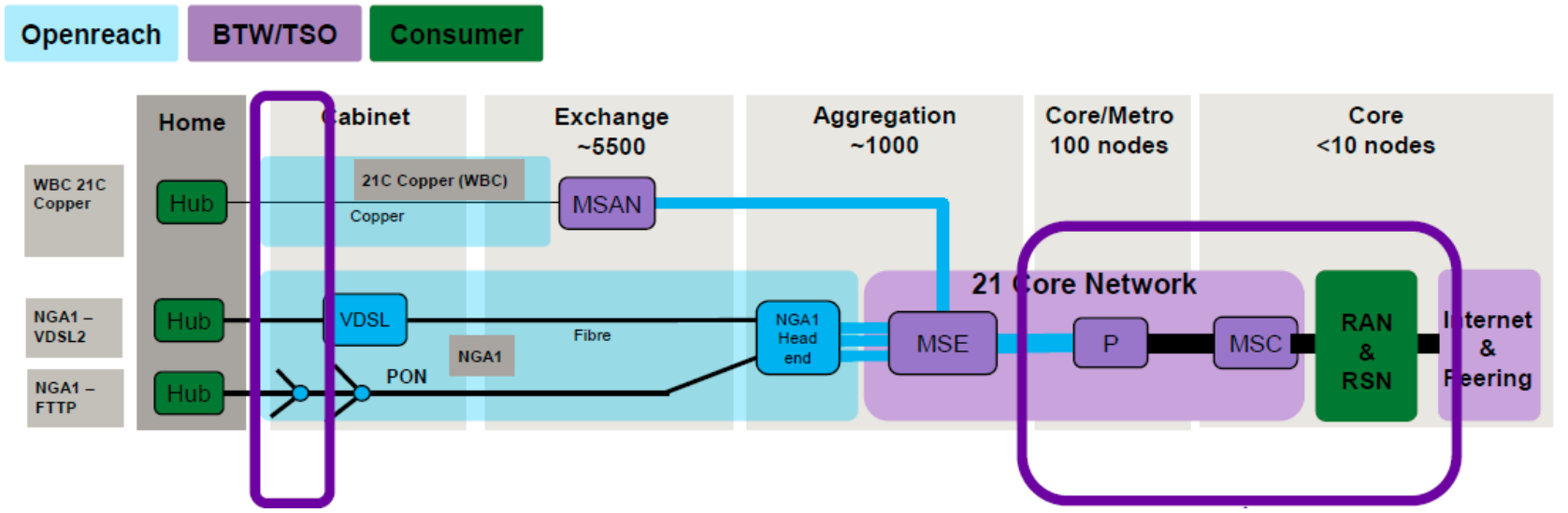
BT Network (2004)



BT 21CN Network (2017)

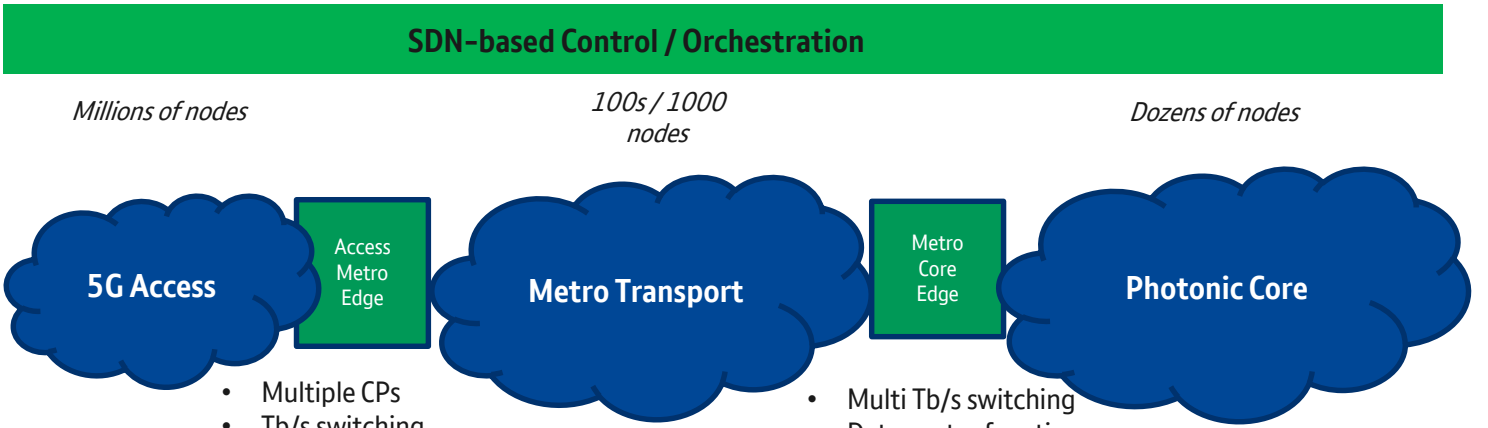


BT network architecture – details



- Architecture has been in place for many years
- Is it fit for purpose in the future?
- Convergence?
- 40% year on year growth
- Huge demand on space, power in exchange buildings

Network bottle-necks / challenges



- Multiple CPs
- Tb/s switching
- Remote storage / compute
- NfV
- Dynamic config
- Whitebox

- Multi Tb/s switching
- Data centre functions
- Multi layer 1-3
- ROADM
- Sliceable spectrum

- Gb/s access
- Wireless femtocells
- Deep fibre
- 5G KPIs
- Convergence
- Infrastructure cost

- 10-25G transport
- Many wavelengths
- Limited flexibility
- 20km – 50km – 100km

- > 1Tb/s per fibre
- Increased flexibility
- Cost less critical
- Elastic Optical Networks

Security, Monitoring, Resilience

EU Metro-Haul project seeks to answer these questions

The overall METRO-HAUL objective is to architect and design cost-effective, energy-efficient, agile and programmable metro networks that are scalable for 5G access and future requirements, encompassing the design of all-optical metro nodes (including full compute and storage capabilities), which interface effectively with both 5G access and multi-Tbit/s elastic core networks.

- 36 months – June 2017 – May 2020
- Partners: BT, Telecom Italia, CTTC, Telefonica, University of Bristol, UPC, CNIT, NAUDIT, OpenLightComm, Lexden Technologies, Zeetta Networks, Fraunhofer HHI, Tech University Eindhoven, Coriant Portugal, Ericsson, Politechnic University of Milan, ADVA, Nokia, Old Dog Consulting, SeeTec
- Project Lead – BT
- Structure
  - WP1 – Project Management
  - WP2 - Use Cases, Service Requirements, and Network Architecture Definition
  - WP3 - Metro Node and Optical Transmission Solutions
  - WP4 - Network Control & Management of the Software-enabled Metro Network
  - WP5 - Validation & Demonstration including Vertical Industries
  - WP6 - Dissemination and exploitation activities

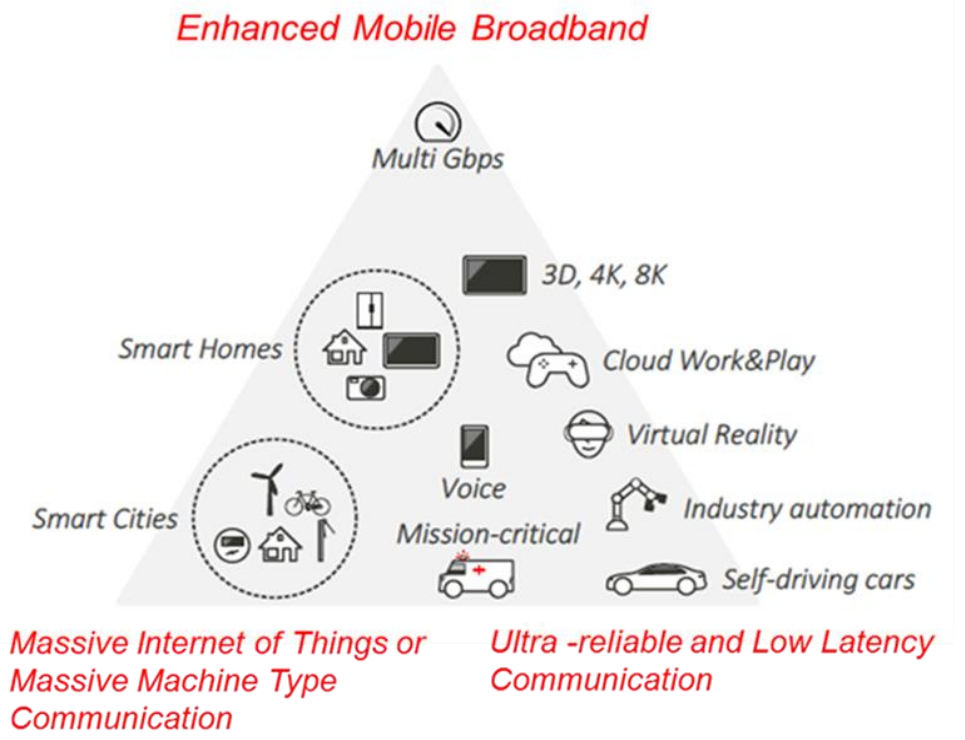
Metro-Haul Main Objectives – unpacked

- Architect and design cost-effective, energy-efficient, agile and programmable metro networks
  - Scalable for 5G access and future requirements
  - Design of all-optical metro nodes (including full compute and storage capabilities)
  - Interface with both 5G access and multi-Tbit/s elastic core networks.
- Challenges:
  - Optical challenge, cost effective and agile, involving both the optical architecture and also innovative new optical component technologies -> disaggregated white boxes
  - Network management challenge. SDN/NFV control framework supporting 5G operational and both end-user and vertical oriented services, including slicing.
  - Monitoring challenge. Implementation & AI-based tools for interpreting vast amounts of data
- Use Cases
  - Video Security for Smart Cities - Intelligent video security based on automatic object/person identification and tracking.
    - 5G Berlin testbed coupled with DT's Berlin metro infrastructure.
  - Crowdsourced Video Streaming - Simultaneous sourcing of video from different individuals in an event with a large crowd.
  - Additional demonstrations will be planned to be showcased in relevant events.

5G PPP published KPIs and Use Cases

- 1000 times higher mobile data volume per geographical area
- 10 to 100 times higher typical user data rate
- 10 times lower energy consumption
- End to end latency < 1ms
- Scalable management framework enabling fast deployment of novel applications
- Reduction of the network management OPEX by at least 20% compared to today

https://5g-ppp.eu/kpis/

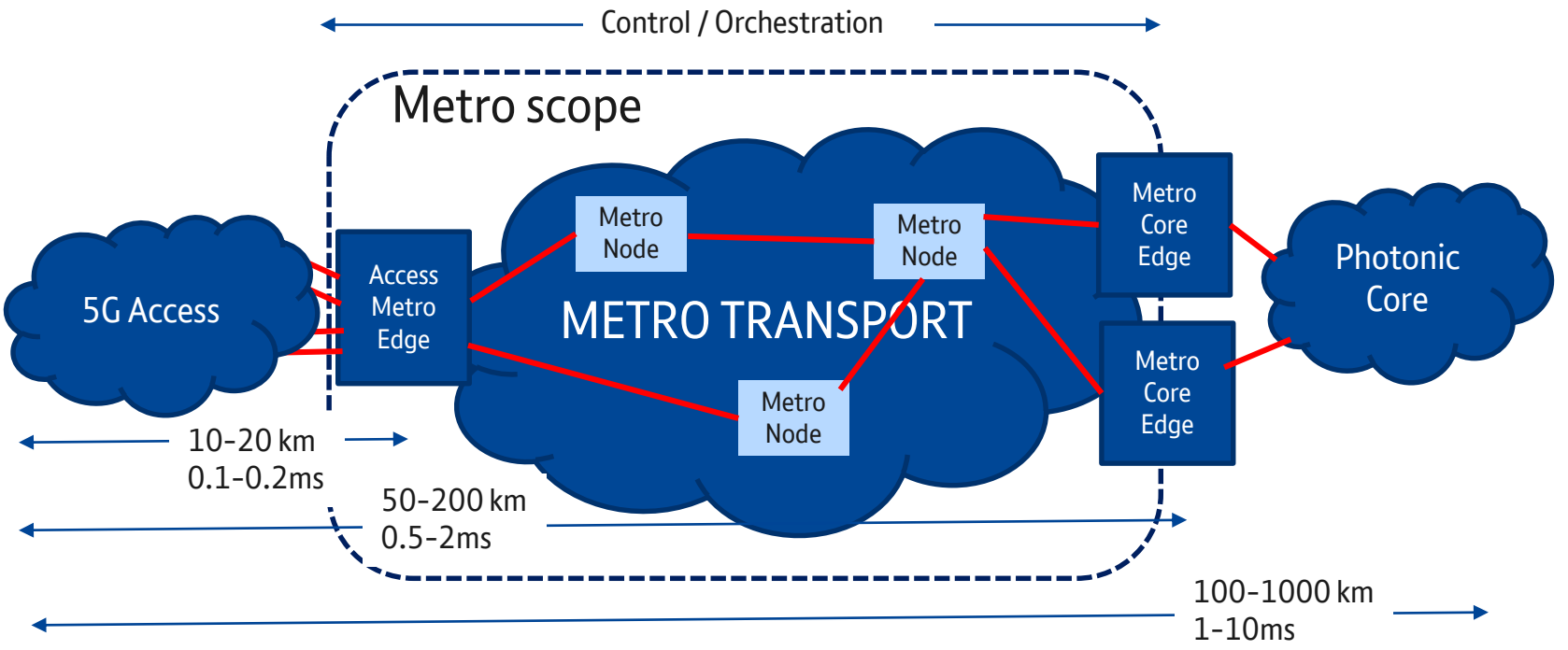


Metro-Haul KPIs derived from 5G PPP KPIs

- 100x more 5G capacity supported over the same optical fibre infrastructure
  - Note – this includes metro network bandwidth savings from service offload at the edge
- 10 times less energy consumption
- Latency-aware metro network in which latency-sensitive slices are handled at the metro edge ensuring the metro network adds no additional latency
- End to end SDN-based management framework enabling fast configuration time to set up or reconfigure services handing 5G applications. Specifically 1 minute for simple network path set-up and 10 minutes for full installation of a new VNF and 1 hour for setting up a new virtual network slice.
- Reduction in CAPEX by a factor of 10, plus a reduction in OPEX of at least 20%

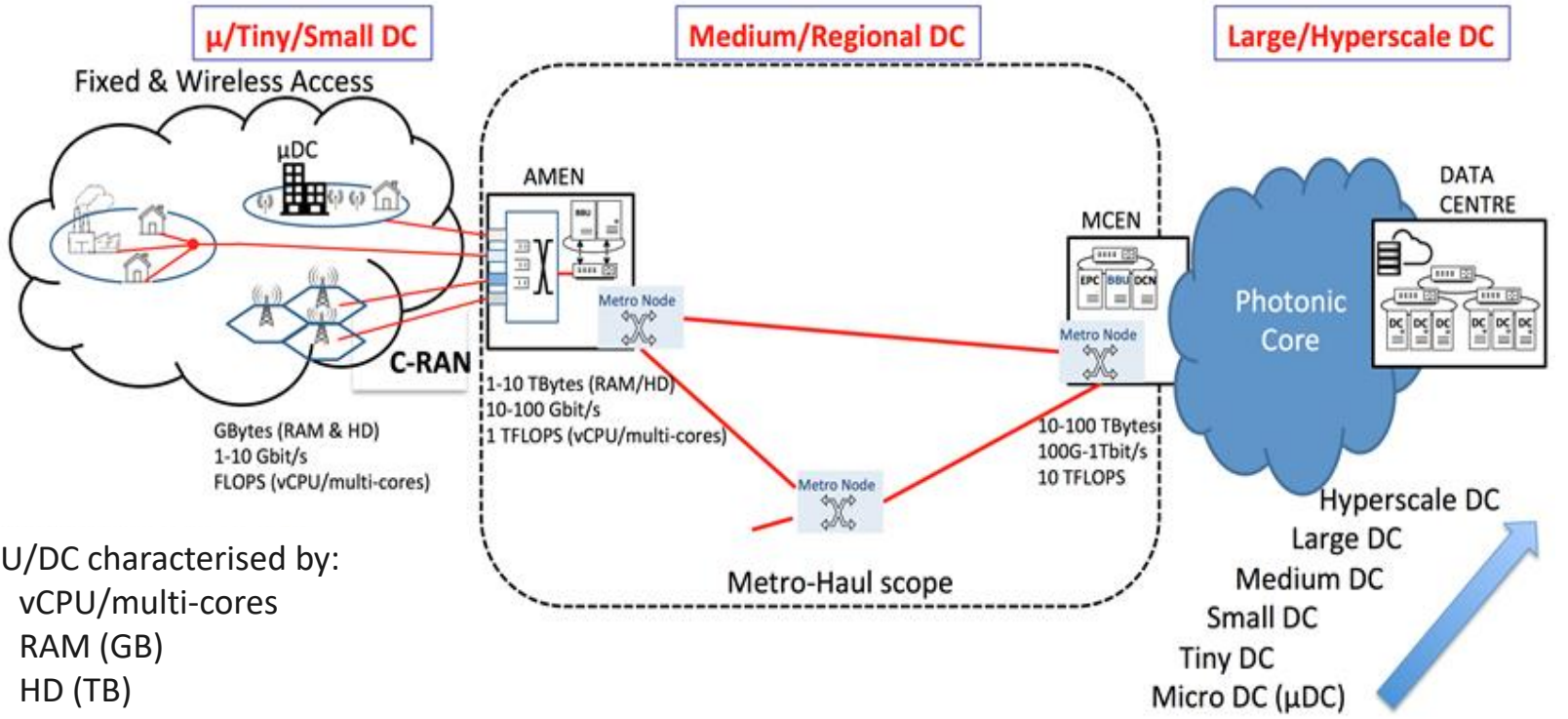
Key goal is to demonstrate these 'optical' KPIs and then show how they are essential to achieve '5G' KPIs

Metro-Haul architecture and scope



Access Metro Edge Node (AMEN) – multiple ubiquitous access technologies, cloud enabled (storage, compute)
Metro Transport Network – metro node: pure transport
Metro Core Edge Node (MCEN) – Larger cloud capabilities
Metro Control Plane – full orchestration

Datacenter flexibility to meet 5G requirements



BBU/DC characterised by:

- vCPU/multi-cores
- RAM (GB)
- HD (TB)
- Bandwidth pipes (Gb/s-Tb/s)

- 5G KPIs suggest end-user bandwidths of 1-10 Gb/s, with latencies of 1-5 ms
- Provision of the other 5G services (mIoT, CriC/URLLC, and eMBB)
- Assume that the compute (storage, processing, data-pipes etc.) dimensioning of a 2017 C-RAN solution will increase by a factor x4 by 2020, and a further factor x4 (i.e. x16 overall) by 2025

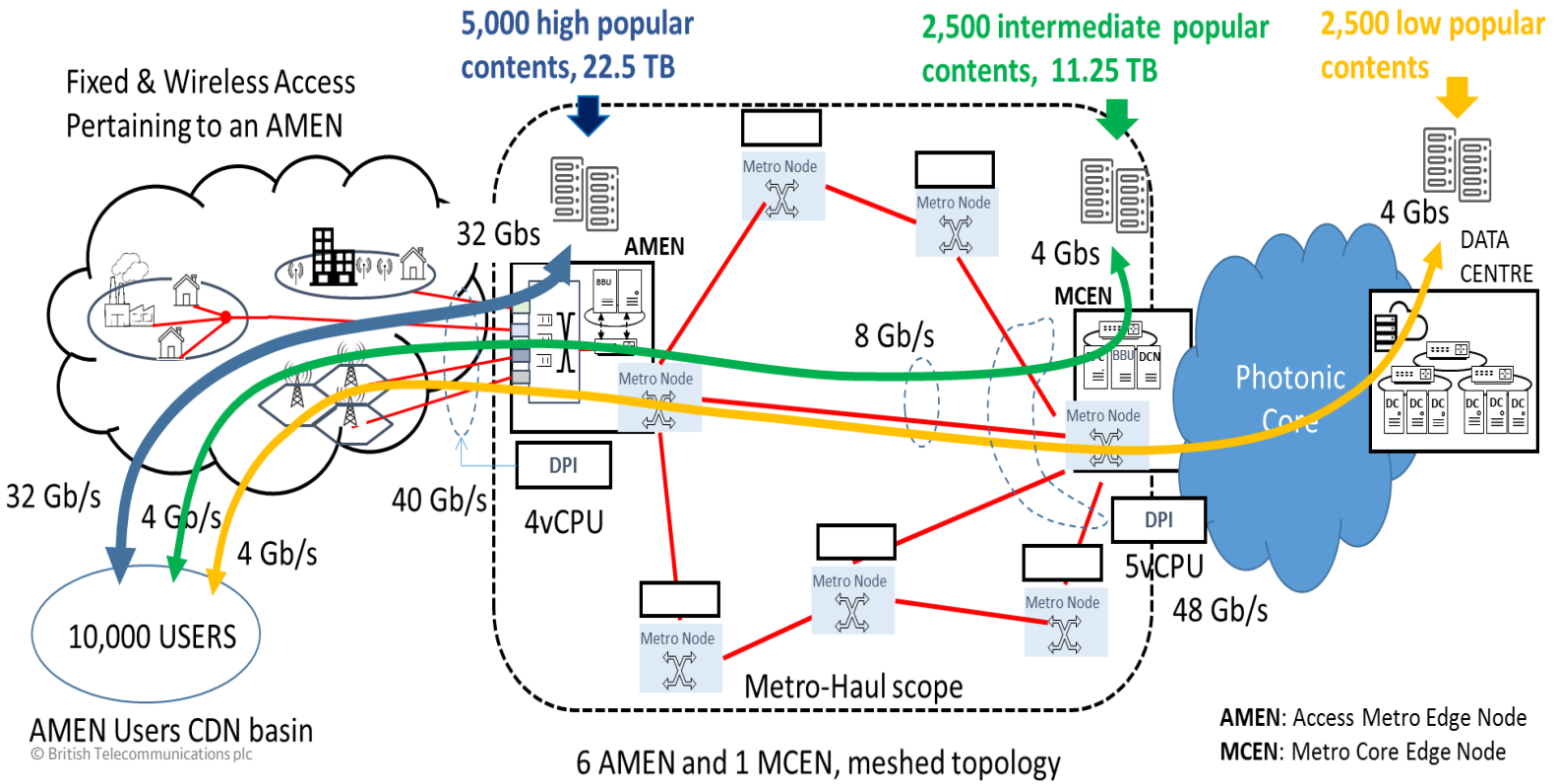
Metro Haul Use Cases

Vertical	Use Case	CoS
Media and Entertainment	Content Delivery Network	eMBB
	Live TV Distribution	eMBB + URLLC
	6DoF Virtual Reality	eMBB + URLLC
	Crowdsourced Video Broadcasts	URLLC
Cloud Services	Service Robotics	eMBB + URLLC
	Enterprise Access with NG Ethernet	BB + URLLC
Utilities	mIoT Utility Metering	mIoT
Automotive	ITS and Autonomous Driving	eMBB + URLLC
Industry 4.0	Smart Factories	eMBB + URLLC + mIoT
Public Safety and Environment	RT LL Object Tracking and Security -	URLLC
Operator orientated	Secure SDN Control. Video Distribution	BB + URLLC

- 3GPP definition is assumed
- Enhanced mobile broad band (eMBB)
- Massive internet of things (mIoT)
- Ultra-reliable low latency connections (URLLC).

CDN Use Case example

- In the vision of Metro-Haul network architecture
  - CDN caches popular video contents at AMENs and MCENs.
  - Main functions located at AMENs and MCENs to enable efficient video caching and delivery are Storage capacity, Video interfaces to deliver video contents and Traffic inspection capabilities.

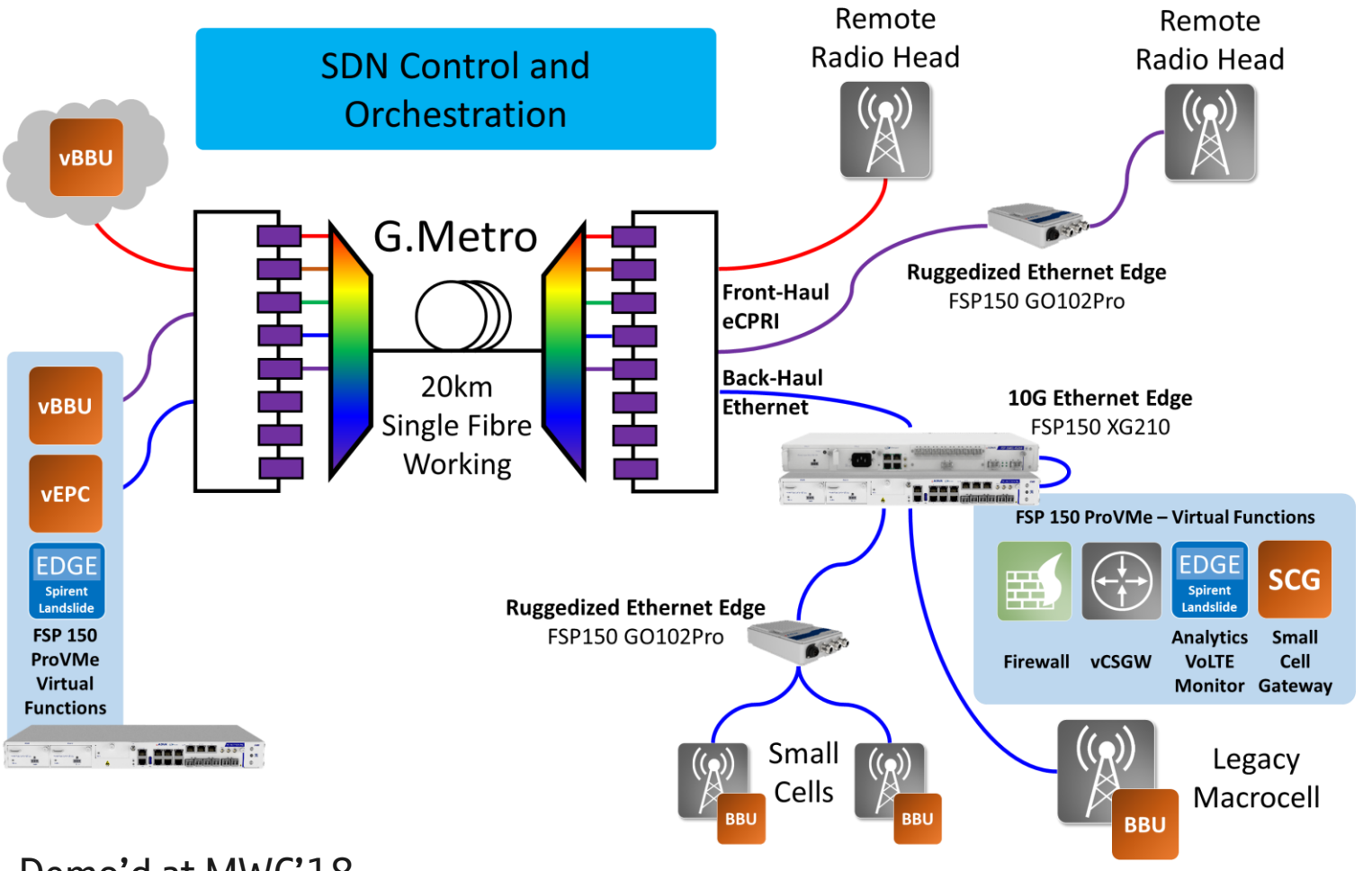


Mapping onto Metro Haul architecture

Task	Throughput			Storage		Computing capacity	
	AMEN	MCEN	Optical	AMEN	MCEN	AMEN	MCEN
UHD/4K/8K video streaming	32Gb/s	24Gb/s	Nx10Gb/s	22.5TB	11.25TB	-	-
Video traffic inspection, analysis and cache reconfiguration	40Gb/s	48Gb/s	10Gb/s	-	-	4 vCPU	5 vCPU
Peak-hours/Flash crowd phenomenon	32Gb/s	24Gb/s		-	-	-	-

Task	Monitoring and Data analytics	Management, Control and e2e Orchestration
UHD/4K/8K video streaming		Fast recovery mechanisms (protection and restoration)
Video traffic inspection, analysis and cache reconfiguration	Traffic monitoring for early detection of new popular videos	Local and Global reconfiguration of virtual cache
Peak-hours/Flash crowd phenomenon	Traffic monitoring for fast detection of a flash crowd phenomenon	Local and global reconfiguration of virtual cache

Early Use Case – 5G Network Slicing demo



Demo'd at MWC'18

Metro networks – ripe for innovation

- Vast numbers of femtocells needed to provide future 5G bandwidth
- Backhaul = deep fibre
  - Potentially hundreds of 10G + circuits over shortish range (20km typical)
- Requirements will be
  - Ultra cost effective optical transport (Facebook talk about 1Gb/s = 1$ for IDC.)
  - Short reach DWDM
  - Some dynamic / optical switching capability
- Existing WSS WAY too expensive
- Recent research starting to focus on this critical area
  - Papers at ONDM from NTT and Nokia
  - PON-based technology
  - New modulation schemes – PAM4 and others – focused on chromatic dispersion tolerance
  - Novel new optical filters
  - Filtered and filterless (and hybrid) networks
  - Fixed vs tunable lasers? G.Metro?

But we will need v low cost, short range, flexible high speed DWDM

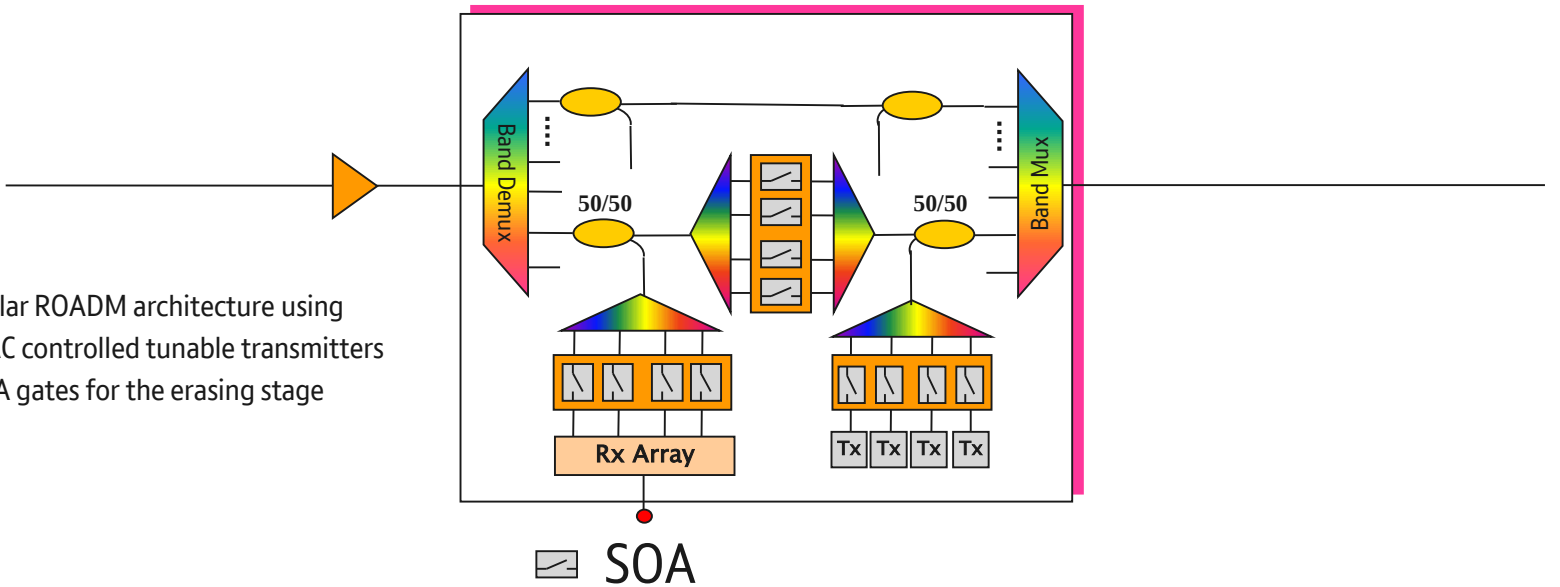
PON proposed for metro in 2009!!

Design, Performance Evaluation and Energy Efficiency of Optical Core Networks Based on the CANON Architecture

OFC 2009 OThQ4

- **A.Stavdas*, T. Orphanoudakis*, C.(T) Politi*, A.Drakos* and A. Lord****
- *University of Peloponnese
- **British Telecom

CANON nodes architecture (RN)

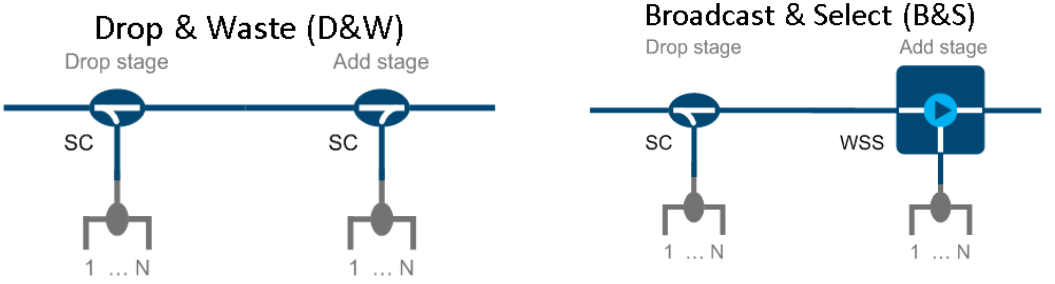


Modular ROADM architecture using

- MAC controlled tunable transmitters
- SOA gates for the erasing stage

Types of metro optical network

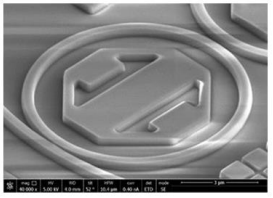
- Main requirement here is **very low cost** 10G-25G WDM with v limited reach (<50km) and some switching
- Architecture
  - Meshed, chains, horse shoes…
  - Traffic flows expected to be hubbed from the Access Metro Nodes to the Metro Core node
  - Resilience – increased traffic likely to mean increased resilience requirements
- Flexibility – optical switching technology
  - Considerable attention to filterless network architectures – requiring coherent transmission
  - Fixed filter approaches AWG etc) or cost effective WSS filters with some flexibility
  - C+L band

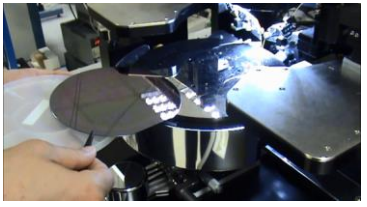


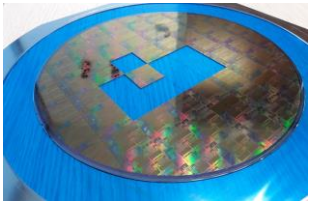
- Data rates
  - 10G
  - 25G (similar to 10G technology)
  - Cost effective 100G coherent

Integrated silicon photonics

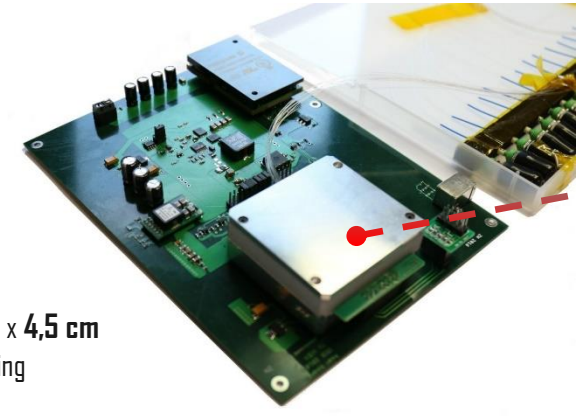
- **Ericsson technology**
- Integration onto chips will enable huge cost reduction
- Performance doesn't have to match LCoS-based WSS
- 200 mm wafer realization



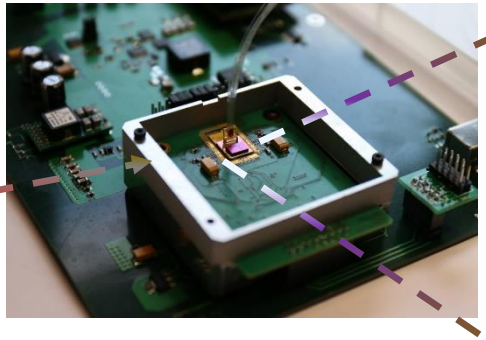


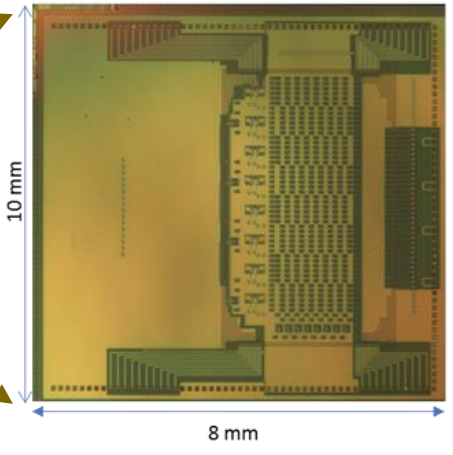


With CNIT…turned into a whitebox optical switch allowing fast open innovation



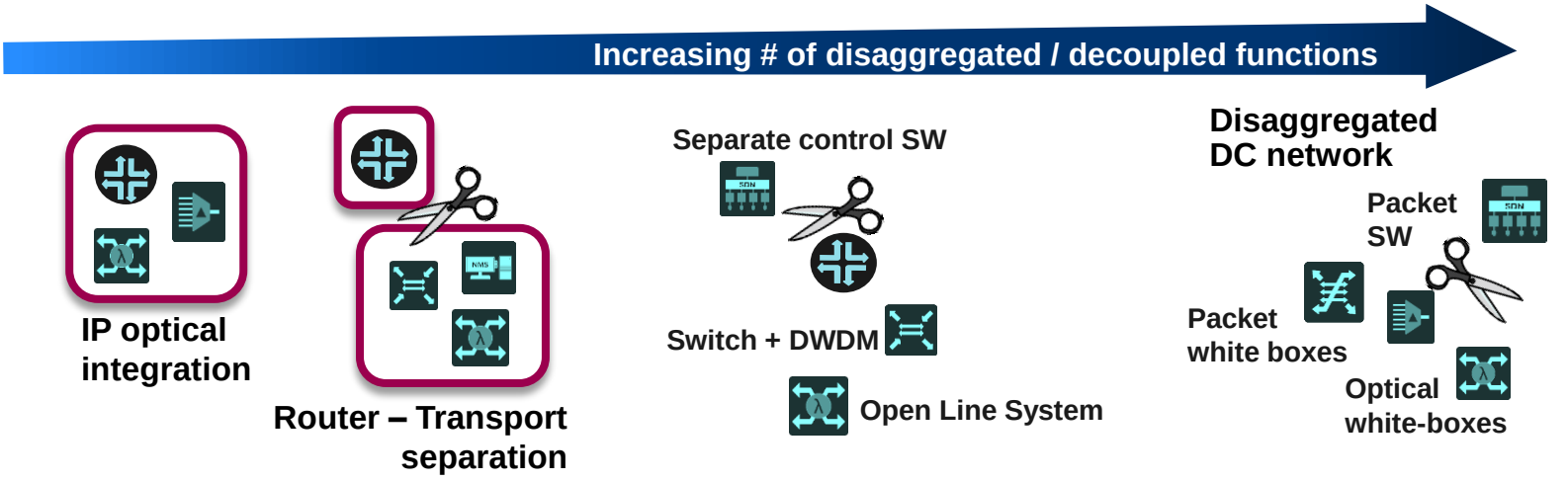
4,5 cm x **4,5 cm**
packaging





Whitebox debate

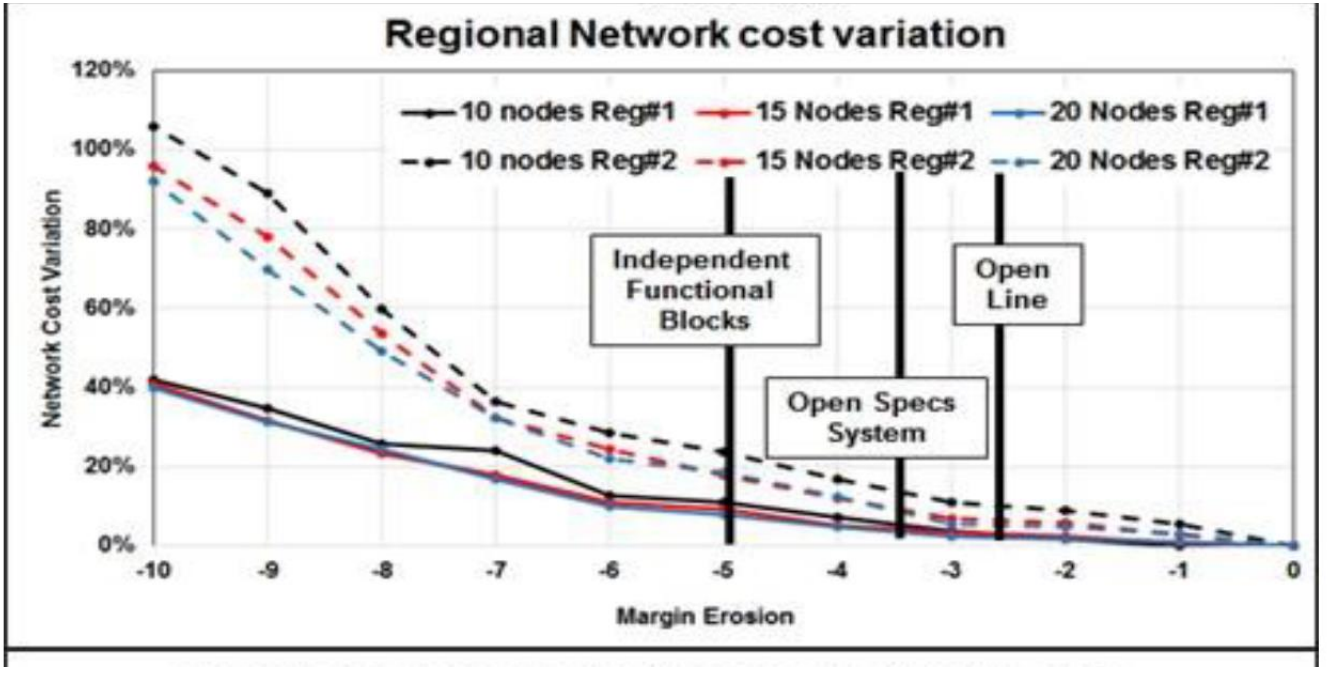
Determined by replacement & innovation cycles, financials, operational environment



Key need:
new control environment to handle complexity

ONDM discussion on this theme

Disaggregation penalty not significant in metro

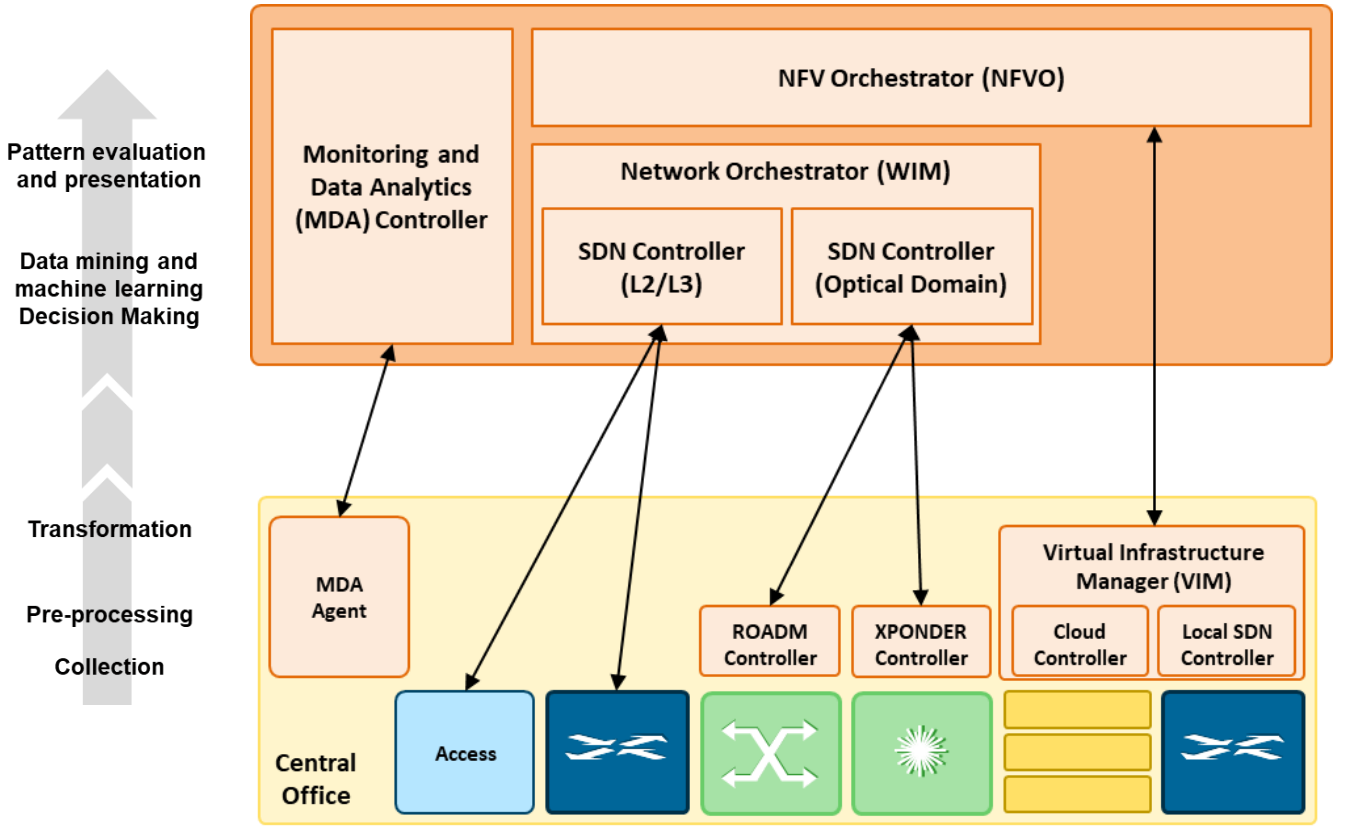


M1E.2 OFC 'Margin requirement of disaggregating the DWDM transport system and its consequence on application economics' Ciena

Telemetry and monitoring

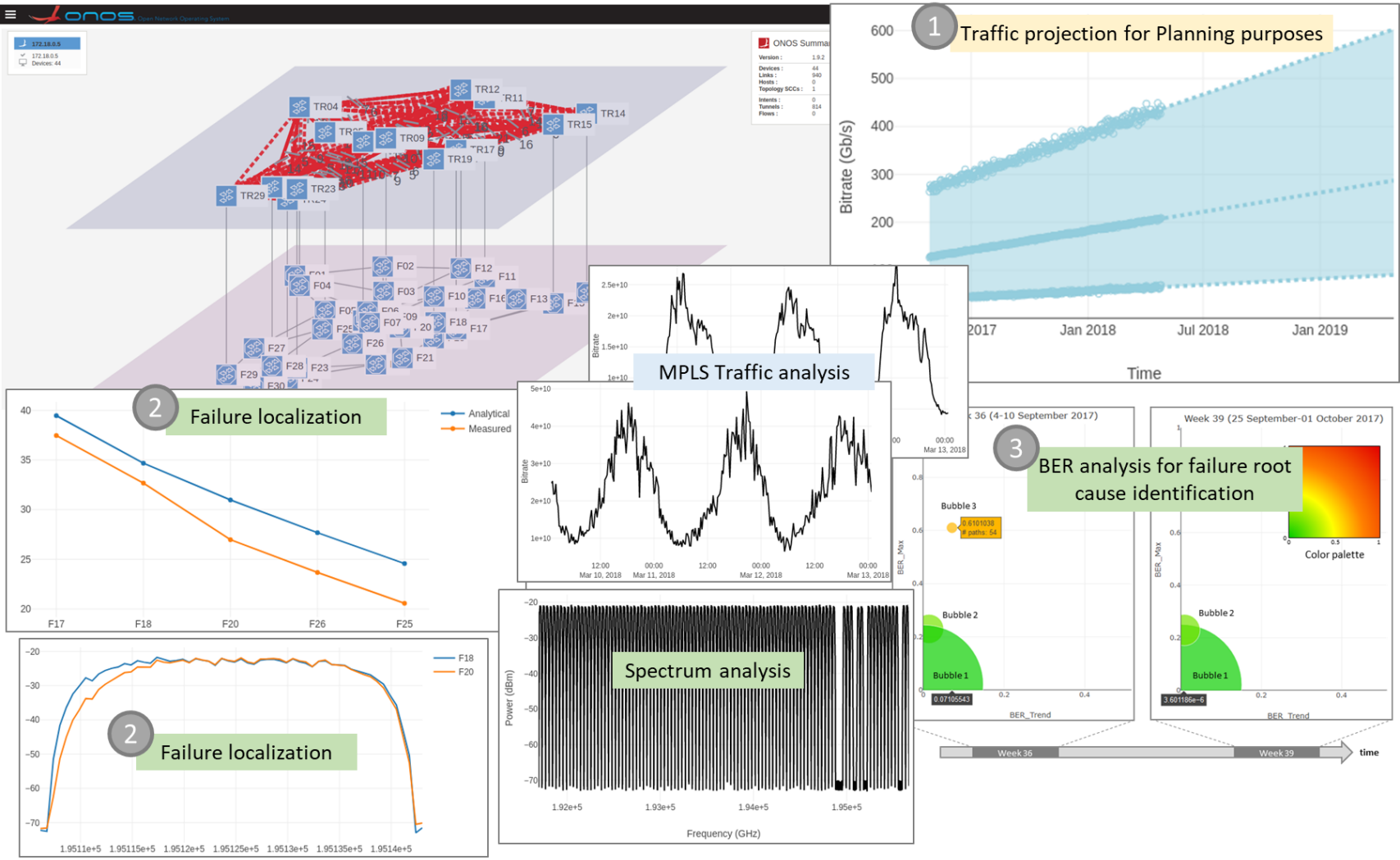
- Management of complex systems requires appropriate monitoring
- In 5G networks, KPI assurance is required, and so monitoring takes on an even more critical role
- Wide range of resources need monitoring
  - Optical layer, Packet layer (L2, 3)
  - 5G clients
  - Data Center functions
- Monitoring requirement becomes real time
- Fast decisions need to be made to respond to dynamic situations (new services or performance variations)
- Monitoring needs to be incorporated into the overall Control architecture
- Metro-Haul has a large topic studying this – headed up by **UPC (Universitat Politècnica de Catalunya)**

Conceptual COM Architecture



- MDA agent collects monitoring data from all the different sources, process them locally and conveys data to the MDA controller.
- COM = Control, Orchestration and Management

Typical results



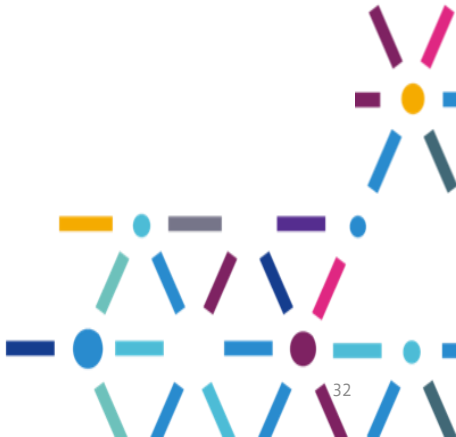
Machine Learning?

- Huge current hype around this subject
- Concept relates to huge, unpredictable data sets
- Networks have potentially hundreds of nodes, each generating a huge amount of monitoring data
  - Every optical and electrical component on every board
  - Every sub-system, transceiver, EDFA, WSS…
  - Every network component, equipment card, rack, shelf…
- Can all this data be harnessed together to analyse and predict overall network performance
- Potentially TOO much data for a 'linear' analysis ?
- Machine Learning could assist in optimising performance and providing warnings of future problems
- Issues –
  - Is there sufficient data for the ML algorithm to learn?
  - Is the data available from the DCN control that manages the network
  - If the algorithm makes a wrong prediction, that might be catastrophic for a Carrier Class network
  - Vendors don't have networks to trial the algorithms they have developed
  - There is no explanation 'why' a specific decision is arrived at

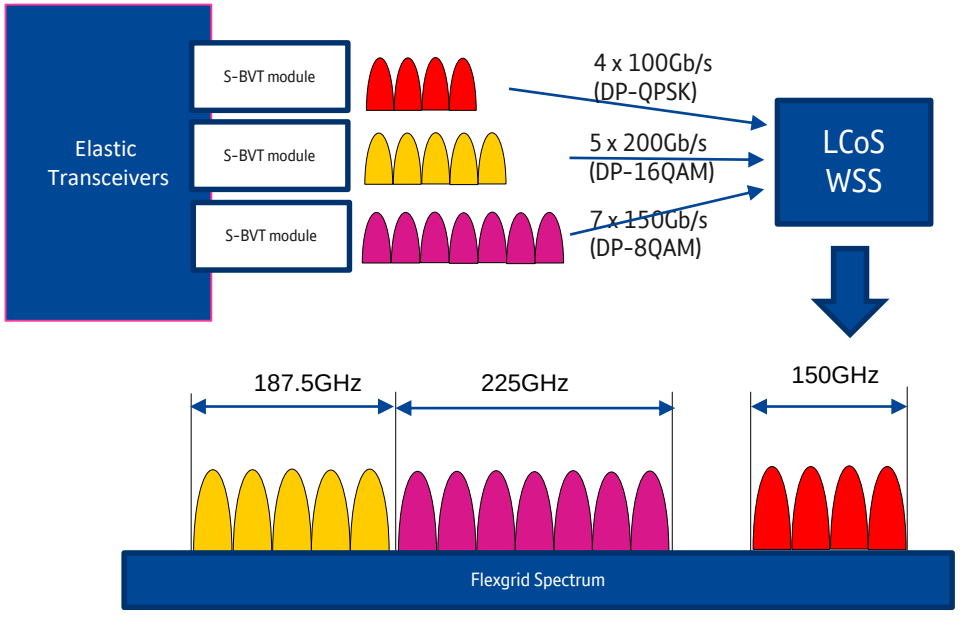
Area needs some careful analysis to see if conventional 'linear' analysis isn't sufficient

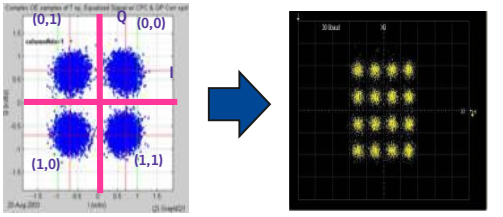
Physical Layer – the core network

- Core network changes for 5G?
  - More capacity
  - Possibly more dynamic – although many of the short time scale variations from 5G might average out
  - Edge DC functions (compute, storage etc) intended to reduce latency but also reduce core network load
    - Core might not grow as quickly as the metro
  - BT flat core has been a challenge –
    - 100 + metro-core nodes fully meshed
    - Complex Routing and Spectrum Assignment
    - Stranded bandwidth
  - Scope for more integrated optical + packet layers
    - SDN based orchestration



Metro-Core Edge – Elastic Optical Networks





Future transponders capable of 100Gb – 600Gb in 50Gb increments

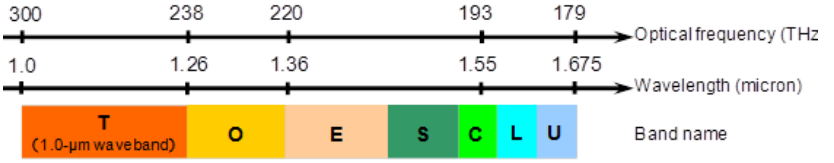
32Gbaud carrying 25Gb + FEC:
25Gb x BPSK x 2 pol = 50Gb
25Gb x QPSK x 2 pol = 100Gb
25Gb x 16QAM x 2 pol = 200Gb
25Gb x 64QAM x 2 pol = 300Gb

64Gbaud carrying 50Gb + FEC:
50Gb x QPSK x 2 pol = 200Gb
50Gb x 16QAM x 2 pol = 400Gb
50Gb x 64QAM x 2 pol = 600Gb

And many other options

Beyond the ‘C’ band

Optical Fibre Spectrum



- Stacking many parallel fibres =
  - Cost, power consumption and space requirements rise linearly with equipment
- Extension beyond ‘C’ band – to L, then S etc now receiving significant research attention in the industry
  - Require new amplifier and switch technologies and improved transmission modelling
  - Now getting real attention in the industry
  - No real work on optimised optical architectures for C + L
- Beyond traditional Single Mode Fibre?
  - Multicore fibre offers enormous potential but with a huge barrier to entry

Conclusions

- Continued bandwidth growth means continued pressure on optical networks
- Focus moved discernibly from core to metro – though both need attention
- 5G requires radical changes to networks
  - Intelligence to handle KPIs
  - Dynamic capability
  - Extended monitoring
  - Deep fibre – cost effective transport
- Whitebox could definitely have a role in the metro
- Machine Learning – still not certain

- One thing IS for certain – plenty of optical network research still left to do!

THANK YOU