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BEYOND 5G – OPTICAL NETWORK CONTINUUM
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Deliverable D2.1

Definition of use cases, requirements, and reference network architecture

Editor A. Rafel (BT)

Contributors TID, UC3M, TIM, BT, CTTC, CNIT, UPC, OLC-E, ELIG, PLF, INF-P, INF-G

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DISCLAIMER

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LIST OF AUTHORS

Name	***Partner***
Albert Rafel	BT
Emilio Hugues Salas	BT
Luis Velasco	UPC
Marc Ruiz	UPC
Jaume Comellas	UPC
Davide Careglio	UPC
Salvatore Spadaro	UPC
Filippo Cugini	CNIT
Ramon Casellas	CTTC
Laia Nadal	CTTC
Jose Alberto Hernández	TID/UC3M
Óscar González de Dios	TID/UC3M
Pablo Pavón Mariño	ELIG
Jose Manuel Martínez Caro	ELIG
António Eira	INF-P
João Pedro	INF-P
Antonio Napoli	INF-G
Carlos Castro	INF-G
Marco Quagliotti	TIM
Laura Serra	TIM
Lorenzo Magnone	TIM
Annachiara Pagano	TIM
Paolo Pellegrino	TIM
Emilio Riccardi	TIM
Alexandros Stavdas	OLC-E
Rui Bian	PLF

Abbreviations and Acronyms

Acronym	Expansion
5G	Fifth Generation
5GPPP	5G Infrastructure Public Private Partnership
AAU	Active Antenna Unit
ADM	Add/Drop Multiplexer
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
AR	Augmented Reality
B5G	Beyond 5G
BER	Bit Error Ratio
BNG	Broadband Network Gateway
BSS	Business Support System
BVT	Bandwidth/bit rate Variable Transceivers
Capex	Capital Expenditure
CAGR	Compound Annual Growth Rate
CBR	Constant Bit Rate
CDN	Content Delivery Network
CN	Core Node
CNF	Cloud-native Network Function
CO	Central Office
CP	Control Plane
CPRI	Common Public Radio Interface
C-RAN	Centralized-Radio Access Network
CSG	Cell Site Gateway
CU	Central Unit
DC	Data Centre
DCI	Data Centre Interconnection
DSC	Digital Subcarrier
DSCM	Digital Subcarrier Multiplexing

DSLAM	Digital Subscriber Line Access Multiplexer
DSP	Digital Signal Processing
DSR	Digital Signal Rate
DT	Digital Twin
DTC	DT City
DU	Distributed Unit
DWDM	Dense Wavelength Division Multiplexing
E/O	Electrical to Optical
E2E	End-To-End
EC	European Commission
eCPRI	Enhanced CPRI
EDFA	Erbium Doped Fibre Amplifier
ENP	E-Lighthouse Network Planner
EPA	Enhanced Platform Awareness
Eth.	Ethernet
ETSI	European Telecommunication Standards Institute
ETSI MANO	ETSI NFV Management and. Orchestration
FCAPS	Fault, Configuration, Accounting, Performance, Security
FTTA	Fibre-To-The-Antenna
FTTH	Fibre-To-The-Home
FWM	Four-Wave Mixing
gNB	gNodeB
GTW	Gateway
HD	High Definition
HLS	High Layer Split
HSI	High Speed Internet
HTC	Holographic-Type Communications
IBN	Intent-Based Networking
IETF	Internet Engineering Task Force
IIoT	Industrial IoT with cloudification
INT	In-band Network Telemetry
ION	Intelligence Operation Network
IoT	Internet-of-Things

IP	Internet Protocol
ISRS	Inter-channel Stimulated Raman Scattering
IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
KVI	Key Value Indicator
LiFi	Light Fidelity
LLS	Low Layer Split
MAC	Media Access Control
MAN	Metropolitan Area Network
MAS	Multi-Agent System
MB	Multi-Band
MBH	Mobile Back-Haul
MBN	Multi-Band Network
MB-OXC	Multi-Band - Optical Cross-Connect
MCF	Multi-Core Fibre
MCS	Multicast Switch
MDA	Monitoring and Data Analytics
MFH	Mobile Front-Haul
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
MMH	Mobile Mid-Haul
mMIMO	Massive MIMO
MPLS	Multiprotocol Label Switching
NBI	North Bound Interface
NCC	Network and Computing Convergence
NE	Network Element
NFV	Network Function Virtualization
NG	Next Generation
NGC	Next Generation Core
NMS	Network Management System
NOS	Node Operating System
NR	New Radio

O/E/O	Optical to Electrical to Optical
OADM	Optical Add/Drop Multiplexer
OD	Origin-Destination
ODN	Optical Distribution Network
OFC	Optical Networking and Communication Conference & Exhibition
OIF-ENMI	OIF External Network to Network Interface
OLA	Optical Line Amplifier
OLT	Optical Line Terminal
ONF	Open Networking Foundation
ONT	Optical Network Termination
ONU	Optical Network Unit
OpEx	Operational Expenditure
OSNR	Optical Signal-To-Noise Ratio
OSS	Operation Support Systems
OTN	Optical Transport Network
OTT	Over-The-Top
OXC	Optical Cross-Connect
P2MP	Point-To-MultiPoint
PCE	Path Computational Engine
PCEP	Path Computation Element Communication Protocol
PE	P-Edge
PM	Project Manager
PMD	Physical Medium Dependant
PO	Project Officer
PoC	Proof of Concept
PON	Passive Optical Network
POP	Point Of Presence
PPP	Point-to-Point Protocol
PtoMP	Point-to-Multi-Point
PtoP	Point-to-Point
QMR	Quarterly Management Reports
QoE	Quality of Experience

QoS	Quality of Service
QoT	Quality of Transmission
R&D	Research and Development
RAN	Radio Access Network
RAT	Radio Access Technology
RL	Reinforcement Learning
RMSA	Routing, Modulation and Spectrum Assignment
ROADM	Reconfigurable OADM
RoF	Radio Over Fibre
RRH	Remote Radio Head
RRU	Remote Radio Unit
RTT	Round-Trip Time
RU	Radio Unit
S-BVT	Sliceable Bandwidth/bitrate Variable Transceiver
SC	Steering Committee
SDM	Space Division Multiplexing
SDN	Software Defined Networking
SDO	Standards Developing Organization
SD-WAN	Software Defined WAN
SL	Supervised Learning
SLA	Service Level Agreement
SME	Small and Medium-sized Enterprises
SoA	State of the Art
SOA	Semiconductor optical Amplifier
SONiC	Software for Open Networking in the Cloud
SRS	Stimulated Raman Scattering
STIN	Space-Terrestrial Integrated Network
TCO	Total Cost of Ownership
TDM	Time Division Multiplexing
TIP	Telecom Infra Project
TIRO	Tactile Internet and Remote Operations
UE	User Equipment
UNI	User Network Interface

UP	User Plane
uRLLC	Ultra-Reliable Low-Latency Communication
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualized Network Function
VoD	Video on Demand
vOLT	virtual OLT
vPON	virtual PON
VR	Virtual Reality
VV	Volumetric Video
WAN	Wide Area Network
WB	White-Box
WDM	Wavelength Division Multiplexing
WiFi	Wireless Fidelity
WIM	WAN Infrastructure Manager
WP	Work Package
WSS	Wavelength Selective Switch
XR Optics	Infinera Technology for point to muti-point optics
ZTN	Zero Touch Networking

EXECUTIVE SUMMARY

This deliverable reports on the activities of WP2 during the first year of the project. The work was split into two activities with the following objectives:

- Defining use cases, service requirements and the network architecture in a generic way and more specific cases that will be used as guidelines to the project.
- Providing reference network topologies and architecture to be used in the project for experimentation and performance evaluation.

These objectives have been fully achieved and the B5G-OPEN network concept has been fully defined, thus providing a clear framework upon which to base and steer the activities in the other technical work-packages. One of the major aspects is the definition and clarification of the project key features, i.e. multi-band (MB) operation, optical continuum (closely related to the concept of domain-less network), integrated access, E2E network orchestration, and autonomous operation.

A High-Level network view has proved very useful for many of the activities done within WP2 and a mapping of the 3 operators' networks has been carried out along with terminology convergence. This document briefly reports on future types of services relevant to the B5G-OPEN network concept and related performance KPIs that are described around the dimensions of bandwidth, time, security, AI, and multi-network integration. Two specific Use Cases have been analysed and used to derive traffic matrices. The first one is a network service and related to access integration and describes how to use LiFi as an access technology along with WiFi and fixed line optical access. The second one develops a volumetric video service in a Digital Twin use case, which can potentially require an extremely high network capacity connectivity.

A layered architecture where IP/MPLS termination and processing is performed at relevant central offices has been defined showing the relevant network technologies enhanced thanks to the introduction of the optical multi-band technology that allows optical bypass and thus the optical continuum. Two network architectures have been specifically proposed and preliminary investigated, based on either vertical or horizontal organization of resources. The former vertical approach appears, at this stage, as the most relevant one since it includes features that might be anyway required also for the alternative horizontal approach. This includes the need for new models and procedures for standardized multi-domain impairment-aware path computation, provisioning, and recovery, also encompassing packet-optical white boxes.

The document reports on an analysis made of different access technologies and how they may fit into the B5G-OPEN network concept leading to an initial proposal of short-, medium, and long-term node architectures. The control plane is a key part of the B5G-OPEN concept and a starting point architectural fundaments are presented. The control plane is based on an architecture that performs service and network operations E2E from the Access Point to the Cloud node, which might include monitoring and AI/ML, and is also based on IBN and zero-touch networking paradigms, with autonomous operation built using closed-control loops at various levels, from device to network. The control plane, empowered by a distributed AI/ML-based engine, which performs data collection and intelligent aggregation, analysis, and autonomous operation acting on the network components, will enable coordinated decision-making across domains.

The biggest piece of work in WP2 has been the definition of the reference network topology and traffic characterisation. A reference network topology has been defined that can be used for the validation studies. A traffic characterization methodology is also defined that can be used for different activities such as planning, dimensioning, and techno-economic studies. The methodology provides a procedure to generate traffic scenarios combining mass market services with other innovative services foreseen in the B5G-OPEN scope.

A preliminary traffic analysis study on a realistic operator network example has been carried out. Total traffic volumes conveyed by different CO types under different adoption scenarios for both mass market and B5G-OPEN services are evaluated from short to long-term scenarios.

The final activity reported in this deliverable tries to clarify the performance KPIs of the project and investigate how it relates to the KPI's cartography of the 5G-PPP.

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1 INTRODUCTION

Work in WP2 started at the beginning of the project and was the only active technical WP during the first three months. The WP2 comes to a close at the end of Month 12 of the project with the submission of this deliverable and its outputs might be used by the rest of technical WPs, i.e. WP3, WP4, and WP5. The main objectives of WP2 are:

- Defining use cases, service requirements and the network architecture in a generic way and more specific cases that will be used as guidelines to the project.
- Providing reference network topologies and architecture to be used in the project for experimentation and performance evaluation

This is the only deliverable document planned at the end of the activities. However, there have been two important milestone documents that have been available by the end of Month 3 and Month 7 of the project that are being used by WP3 and WP4. Therefore, an excerpt of these two reports is briefly presented in this introduction.

1.1 HIGH-LEVEL VIEW OF THE NETWORK ARCHITECTURE

An important contribution of WP2 has been the definition of a high-level view of the B5G-OPEN network (Fig. 1.1). This view is agnostic with respect to the actual architecture and technologies used for its implementation (optical, packet and IT-data centre) and it was used among other things to map the traffic flows involved in service Use Cases (Section 1.2).

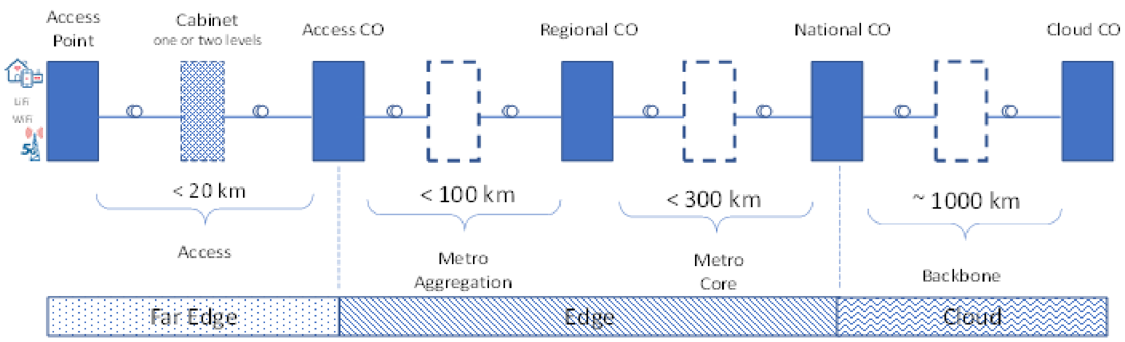

Fig. 1.1. High-Level Network Diagram

The infrastructural boundary points present in the diagram of Fig. 1.1 are: the Access Point, the Cabinet and the various kind of Central Offices (CO). This boundary points comply with the characteristics as in the following description.

The **Access Point (AP)** is a physical entity acting as a termination point of a full optical network architecture, exploiting Fibre-To-The-Home (FTTH) or Fibre-To-The-Antenna (FTTA) architectures in the last mile segment. In most scenarios the AP is closely connected to, or integrated with, more specific devices enabling fixed, nomadic, and mobile users & IoT devices to be connected to any kind of digital services, such as:

- a Residential Gateway located at the home premises, connected to the Optical Network Termination (ONT) of x-PON technology, and providing 3-Play services to the final customer;

- a Customer Edge router providing SD-WAN service to business premises via a ptp/coherent optical connection;
- a 5G/6G site equipment collecting MFH or MMH or MBH traffic from mobile users over a macro/small/femto cell site, and connected to the mobile network via an optical link;
- a WiFi-x Hotspot covering a limited public area or indoor space to provide HSI services to nomadic users, and connected to the Core Network via an optical link;
- a cluster of LiFi lamps covering a street or a building and connected to the Core Network via optical links.

These devices, when co-located with the Access Point, should be considered as connected to it via an Ethernet based UNI physical interface.

The **Cabinet** is a protected space, typically placed outdoor in the street, where fibres coming from the Access CO can transit or can be terminated on a device. It can host passive devices (e.g., splitters) and, if power supply is available, active devices (ONUs, switches, mini servers etc.). For its nature, the Cabinet does not ensure neither a high level of physical security nor a high level of reliability and survivability against adverse events (accidents, vandalism, bad weather etc.).

Population covered by each Cabinet can be of the order of hundreds of people. The maximum physical distance from an Access Point to the nearest Cabinet is of the order of 200 m, resulting in a two-way propagation time (RTT) of the order of microseconds.

The **Access CO** is a small size building that can host Telco applications and, more rarely and not necessarily, IT applications. It includes Telco equipment (packet and optical) of the aggregation part of the Metro-Regional network and some (up to tens) servers for Telco Virtualized Network Functions and IT applications. Access CO is the closest Central Office to the customer and requires a good level of physical and logical security and a good level of reliability and survivability. The number of Access COs in a National network can range from one thousand to a few thousands, while the population covered by each Access CO ranges from few thousands to a few tens of thousands. The maximum physical distance from an Access Point to the nearest Access CO is of the order of 20 km, resulting in a maximum RTT of 0.2 ms.

The **Metro-Regional aggregation network** interconnects Access COs together and with one or, preferably, more (usually two) Regional COs. Metro-Regional aggregation networks are organized at optical transport layer in a mesh, ring, or horseshoe topology. At packet/IP level, for reliability and survivability reasons, the logical connections are typically double homed from the Access COs to a couple of Regional COs.

The **Regional CO** is a medium size building that hosts Telco applications and possibly IT applications. It includes Telco equipment (packet and optical) of the Metro-Regional network and hundreds of servers for Telco virtualized Network Functions and IT applications. A Regional CO is an important network node and requires high degree of physical and logical security and also a high level of reliability and survivability.

The number of Regional COs in a National network ranges from one hundred to a few hundreds. The population covered by each Regional CO can be in the order of one hundred thousand. The maximum physical distance from an Access CO to the furthest Regional CO is in the order of 100 km, resulting in RTT from an Access point to a Regional CO of the order of 1.2 ms in the worst case, but typically this distance is lower, resulting in a propagation RTT of sub ms.

Some of the Regional COs of a Metro-Regional network are linked to a National CO to allow the exchange of traffic between the metro-regional and the national-international levels.

The Metro-Regional core network interconnects Regional COs together and with one or, preferably, more (usually two) National COs, and it's organized at optical transport layer as a meshed network. At packet/IP level the logical connections are predominantly hubbed, from the Regional COs to the National COs. IP survivability is maintained by ensuring dual-homed flows are not sharing common optical links (i.e. flows sourcing from different Regional COs may have optical-layer constraints between them). For the metro-regional aggregation dual-homing is used to different Regional COs.

In a medium-big size EU country, the number of Metro-Regional networks can be of the order of ten to twenty, each one covering an administrative region, a part of it or even more regions. The population covered by each Regional CO can be of the order of one to a few million people. The maximum physical distance between a Regional CO to the furthest National CO is of the order of 300 km, resulting in a two-way propagation time (RTT) in the order of 4 ms

The **National CO** is a big building that hosts Telco and, possibly, IT applications. It includes packet and optical equipment of the National Backbone and hundreds to few thousand servers for Telco virtualized Network Functions and IT applications. National CO include also dedicated packet and optical equipment to ensure the interconnection of the Backbone with the Metro Regional Networks. The number of National COs within an operators' network can be between ten and one hundred. National COs are neuralgic point of the network and require very high levels of physical and logical security and very high reliability and survivability.

The **Backbone network** interconnects National COs, and at the optical transport layer it is organized as a flat mesh network, while at the packet level it can be logically organized in one or more tiers. In the last case, usually, no more than two tiers of logical connections are present: for instance, a meshed inner core with few nodes and a star outer core with nodes double-hubbed to the inner core ones. Gateways to interconnect the backbone network with peers (other operators' networks) or to the Internet are co-located with nodes at this hierarchical level.

In a medium-big size EU country, the number of National COs could be between ten and a few dozen. The population covered by each National CO can be in the order of one to a few million people. The maximum physical distance from an Access Point to the nearest National CO is in the order of 400 km, resulting in a maximum two-way propagation time (RTT) in the order of 4 ms.

The **Cloud CO** is a very big infrastructure that hosts National level Datacentres. It can include thousands to tens of thousands of servers and provides IT applications for the operator and services to both residential and business customers. It can also include services for the network (Telco services). It is a strategic point of the Telco network infrastructure and requires extremely high levels of physical and logical security and reliability. Normally, but not necessarily, it is co-located with a node of the National Backbone. If not, it is connected to the network through dedicated circuits.

In a typical country there are usually less than ten datacentres at this hierarchical level. In a medium-big size European Country the maximum physical distance from an Access point to the nearest Cloud CO is in the order of 1500 km, resulting in a RTT in the order of 15 ms, but on average this distance is lower (a few hundred km with a propagation RTT of 5 ms).

In terms of covered population, a Cloud CO can cover from one to ten o few tens million people.

Table 1-1 summarises the CO network infrastructure that has been described.

Table 1-1. Summary of the network COs infrastructure

	Access CO	Regional CO	National CO	Cloud CO
Number of CO in a National network	Thousands (<10k)	Hundreds (<1k)	Tens (<100)	A few (<10)
Population covered	≈10k	≈100k	1 to a few million	≈Ten million
Max distance from the Access Point	20 km	120 km	420 km	≈1420 km
Reliability/availability	High	Very high	Extremely high	Extremely high
RTT (propagation only)	0.2 ms	1.2 ms	4.2 ms	14.2 ms
RTT (total: propagation + transmission + switching + processing)	1 ms	A few ms	20 ms	50 ms

Fig. 1.2 shows the mapping of the current networks of the three operators belonging to the consortium onto the High-Level network view (Fig. 1.1). This mapping shown is to be taken as a reference and a starting point in an evolutionary view for the solutions identified by the project, having as a target the achievements of the project KPIs (Section 8).

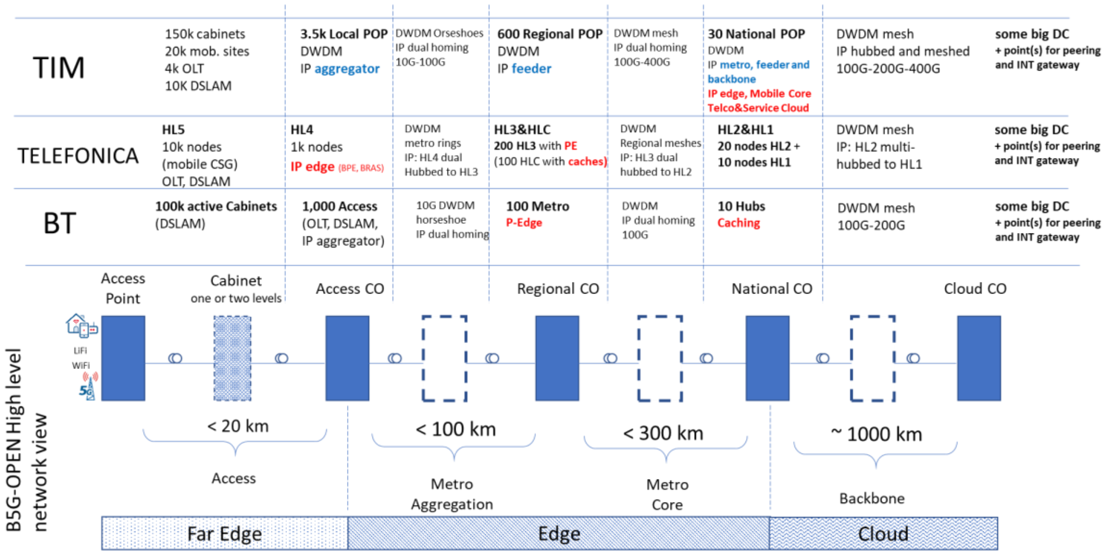

Fig. 1.2. Mapping of number of Central Offices, technologies, and functionalities of the Operators' networks on the B5G-OPEN High-Level network view

The mapping in Fig. 1.2 is indicative and approximate because each operator's network has its own particularities that cannot be reduced to the simplified model defined in B5G-OPEN. However, some general considerations can be made.

The first one is that Telefonica's network has more distributed IP edge functionalities: at Access level there are one thousand nodes with BNG functionality for residential customers and at Regional level 200 nodes with Provider Edge functionality for business customers, with 100 nodes also hosting caches. TIM network has the most centralized functions: only 30 nodes, at National level, for IP edge of both residential and business customers and for hosting Telco and Service functions including caches. BT's case lies in between, with the IP Edge at Regional level in 100 nodes and caches at National level in 10 hubs.

In terms of overall number of Central Offices (any level, excluding cabinets), TIM has the greater number of active COs (about four thousand), while BT and Telefonica have a total of Central Offices just over one thousand. This is due both to architectural choices of each operator (e.g., BT has around 100 thousand active cabinets) and to different territorial geography and distribution of population.

1.2 Use Cases and Key Services

The summarised project innovations in the data plane and control plane from which the project key features are extracted are shown in Table 1-2.

Table 1-2. Key features of B5G-OPEN

Key Feature	Description
Multi-Band operation	Availability of bands O, E, S, C, L to provision: a) the required capacity, and b) service based on requirements
Optical continuum	Operate connectivity extending the principles of optical bypassing of nodes in the Multi-Band B5G-OPEN network, allowing optical slicing based on service requirements and crossing network segments (i.e. access, metro, core, etc.)
Integrated access	Operate and control service regardless of the access technology (Mobile, Fixed, WiFi, LiFi)
E2E network orchestration	Operate service and network operations from the Access Point to the Cloud node, which may include monitoring and AI/ML
Autonomous operation	Based on Intent-based and zero-touch networking paradigms, autonomous operation is built using closed-control loops at various levels, from device to network. Empowered by a distributed AI/ML-based engine providing data collection and intelligent aggregation, analysis, and acting on the network devices, autonomous operation enables coordinated decision-making across domains

B5G-OPEN looked at [FG30] to frame the service use cases and analysed the evolution of network capabilities. The conclusion was that the most relevant ones will be qualitative communications, high precision communications and holographic teleports. These capabilities will enable low latency services and the delivery of different types of video-based services, which will range from 4K/8K HD video to VR/AR and to Hologram transmission. The performance requirements [Eck21] are shown in Table 1-3.

Table 1-3. Performance parameter values for Video, VR/AR and hologram [Eck21].

	4K/8K HD Video	Virtual / Augmented Reality	True Holograms
Data rate	35 - 140 Mbps	25 Mbps – 5Gbps	2 Tbps -5 Tbps
Latency	15 ms – 35 ms	5 ms – 7 ms	Sub ms – 7 ms
# of parallel streams	2 (Audio / Video)	12 (multiple tiles)	≈1000 (view angles)

The FG-NET2030 identified several challenging Use Cases [FG-R1], which may comprise a large portion of the total traffic carried by network operators. Similar trends have happened in the past, where web/email traffic was dominant in the 90s, followed by PtP traffic in the 2000s and VoD in the 2010s. Having said that, network designers must be ready to have the network prepared for supporting some (possibly all) these Use Cases and applications, which include:

- Holographic-Type Communications (HTC)
- Tactile Internet and Remote Operations (TIRO)
- Intelligent Operation Network (ION)
- Network and Computing Convergence (NCC)
- Digital Twins (DT)
- Space-Terrestrial Integrated Network (STIN)
- Industrial IoT with Cloudification (IIOT)

These Use Cases will require network capacity, latency, and availability requirements taken to the next level, including resource availability and resiliency. The advent of Satellites, Edge computing and AI/ML will enhance existing fibre-based networks to reach users everywhere, provide computing and caching resources for enhanced QoE perception and improve service provisioning and network operations in a close-to-autonomous way.

There are five dimensions where network innovations are required:

Bandwidth	Time	Security	AI	ManyNets

- ➢ The Bandwidth dimension includes aspects of bandwidth capacity, QoE, QoS, flexibility, and adaptable transport
- ➢ The Time dimension includes aspects like latency, synchronisation, jitter, accuracy, scheduling, coordination, and geolocation accuracy
- ➢ The Security dimension spans aspects like security, privacy, reliability, trustworthiness, resilience, traceability, and lawful intercept
- ➢ The AI dimension includes aspects like data computation, storage, modelling, collection and analytics, autonomy, and programmability
- ➢ The ManyNets [FG-R1] dimension includes addressing, mobility, network interface, and heterogeneous network convergence

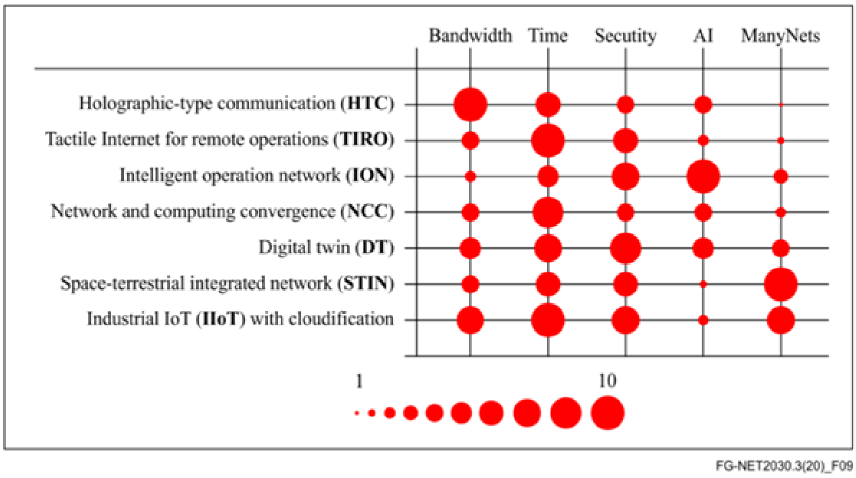

Fig 1.3. Use cases Abstracted KPI Dimensions [FG-R1]

Fig. 1.3 graphically presents the requirements of each use-case per dimension in a qualitative scale from 1 to 10.

WP2 also developed a methodology to analyse the main characteristics of service use cases that will be used to derive the requirements of the B5G-OPEN network concept.

Different research projects look at service use cases and applications from different perspectives and use different classifications that are best suited for their project objectives. WP2, in addition to the work in ITU-T by the FG-NET2030 looked at the EU H2020 5G-SOLUTIONS and HEXA-X Projects, as well as the New European Media initiative and NETWORLD EUROPE Use Cases. B5G-OPEN looks at the LiFi technology as an attractive access technology that will be integrated with other technologies in the access network segment, and at AR/VR in the Digital Twin service use case. Both use cases are briefly presented and analysed following the methodology developed and explained in the same document.

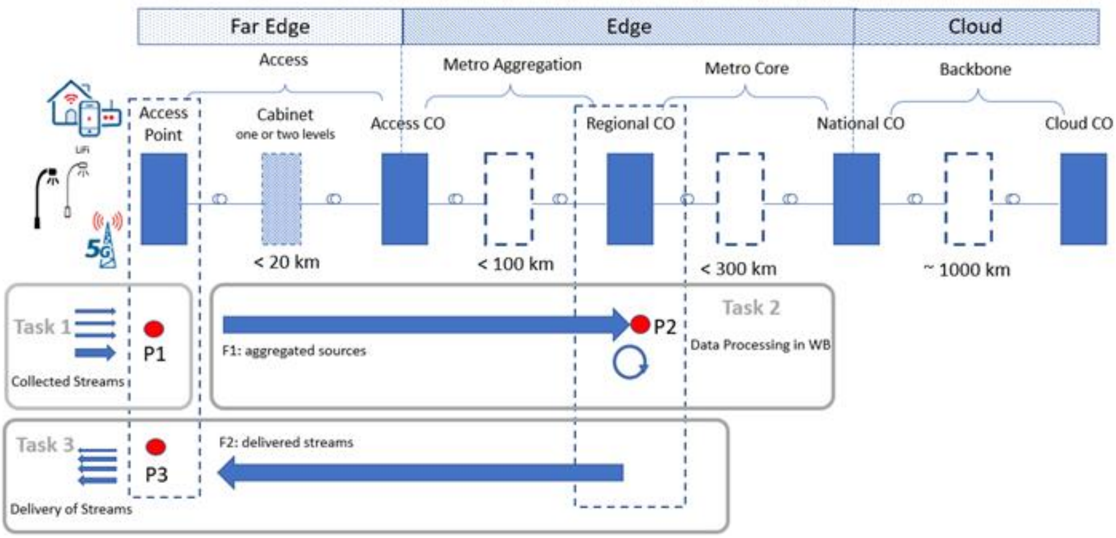

Fig. 1.4. LiFi Access Integration Use Case tasks mapped over the High-level Network diagram

The LiFi access integration Use Case illustrated in Fig. 1.4 has three tasks identified:

- Task 1 considers the uplink streams and data collection from multiple users and different applications. For the case of home applications (VR, video streaming, etc.), a 10 Gb/s data exchange would be required per home, while for the streetlight case, a 50 Mb/s throughput is considered.
- Task 2, where the aggregated data is transported to the assigned White-Box (WB) and processed. Data processing includes data management, AI based prediction and resource allocation, etc. In addition, communication between WBs happen if required which will involve the MB metro network.
- Task 3 covers the transportation of data from WB to the access technologies, the distribution of streams among the multiple access points, and data delivery to end users.

These tasks are then related to the abstracted dimensions and the B5G-OPEN key features as shown in Fig. 1.5.

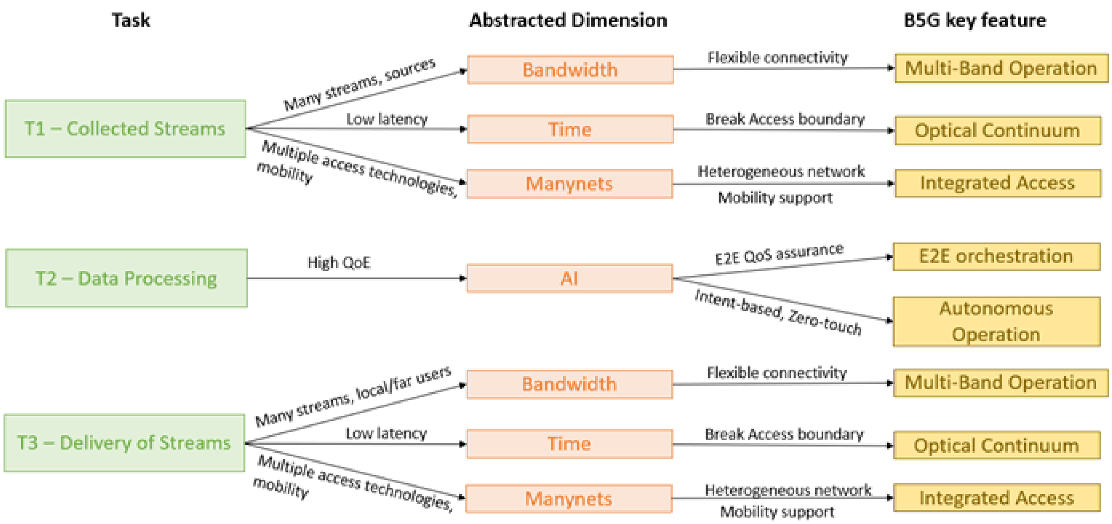

Fig. 1.5. LiFi Access Integration Use Case: abstracted dimensions and B5G key features

A Digital Twin (DT) is a digital representation of a physical asset, process or system based on real-time, real-world data and is also bidirectional, i.e. any change to the physical asset is reflected in the digital twin and vice versa. Connection of DTs enables new research around collections of DTs connected at different levels of interoperability. This interconnection of regional DTs will enable more complex scenarios such as Digital Twin Cities (DTCs) [FG-R1].

In B5G-OPEN, several applications of DTs are considered, such as DTs for work offices, living spaces, buildings, etc. These applications could include technologies such as AR/VR, volumetric video, etc.

Five tasks have been identified for this Use Case:

- Task 1 considers the collection of data stream from different sources with diverse technologies (e.g. AR/VR, Volumetric Video, etc.). For instance, for the case that several VR technologies are used, and each technology demands 10 Mb/s of data exchange for sufficient quality of experience, a gigabit per second aggregated capacity will be required within the network (e.g. 100 x 10 Mb/s = 1 Gb/s).
- Task 2 includes transporting the aggregated data to the digital model. A key feature in this Task 2 is the aggregation of resources (F1) which means that all the traffic from the collection of streams is combined and sent towards the digital processor unit (model). Another key feature is the delivery of streams to the model (F2). This F2 feature will receive the data aggregated streams and deliver to the model unit.
- Task 3, where the data is processed considering data management, prediction based on AI and resource allocation to deliver the data to the model unit. Key feature F3 (Processing of Digital Data) entails the required processing for further enhancement of the physical asset in the digital twin process. The digital data processing can be carried out in any point between the regional and the cloud CO. The location of the process will depend on the implementation of the digital twin application.
- Task 4, where data is supplied to the physical asset (e.g. AR/VR technologies) providing feedback from the digital model for enhanced performance. A key feature F4, delivery of streams to physical asset, will hand over the processed digital data to Task 5.
- Task 5 distributes the data streams to the suitable source.

Fig. 1.6 shows the high-level network diagram where the tasks for this DT Use Case have been mapped.

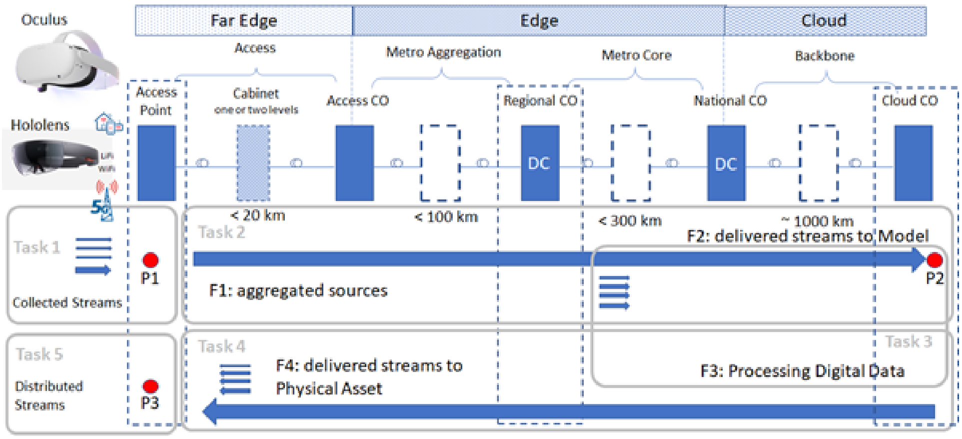

Fig. 1.6. Digital Twin Use Case tasks mapped over the High-level Network diagram

Figures 1.7, 1.8, and 1.9 related the different tasks with the abstracted dimensions and the B5G-OPEN key features.

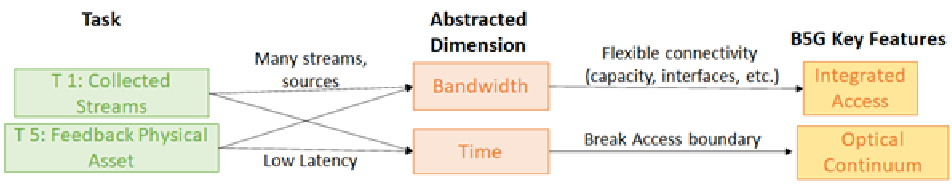

Fig. 1.7. DT Use Case tasks 1 and 5 relation with the abstracted dimensions and B5G key features

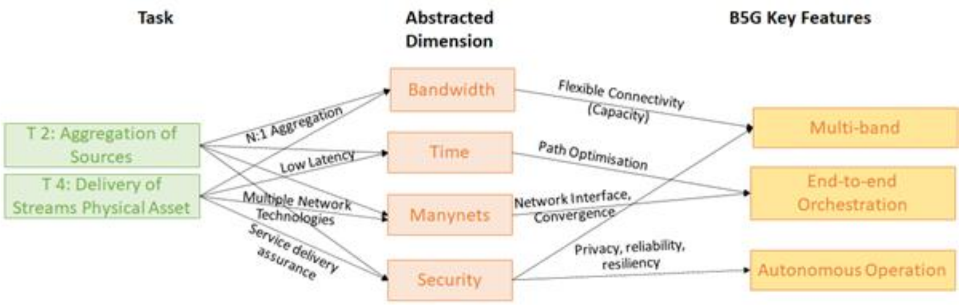

Fig. 1.8. DT Use Case tasks 2 and 4 relation with the abstracted dimensions and B5G key features

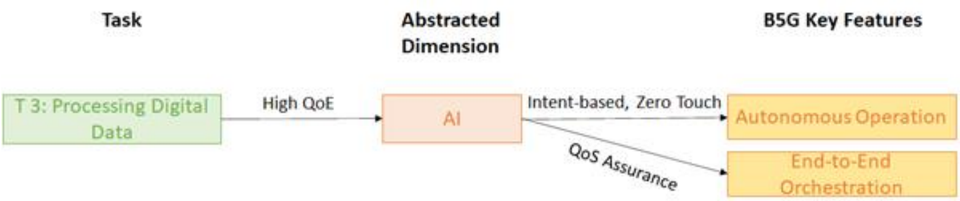

Fig. 1.9. DT Use Case task 3 relation with the abstracted dimensions and B5G key features

1.3 PROPOSED B5G-OPEN NETWORK ARCHITECTURE

1.3.1 Layered architecture

A telecommunications network is a very complex technology platform, and many aspects are not in scope of the project. In order to help contextualising which network technologies are important for the project, WP2 defined a layered network architecture shown in Fig. 1.10.

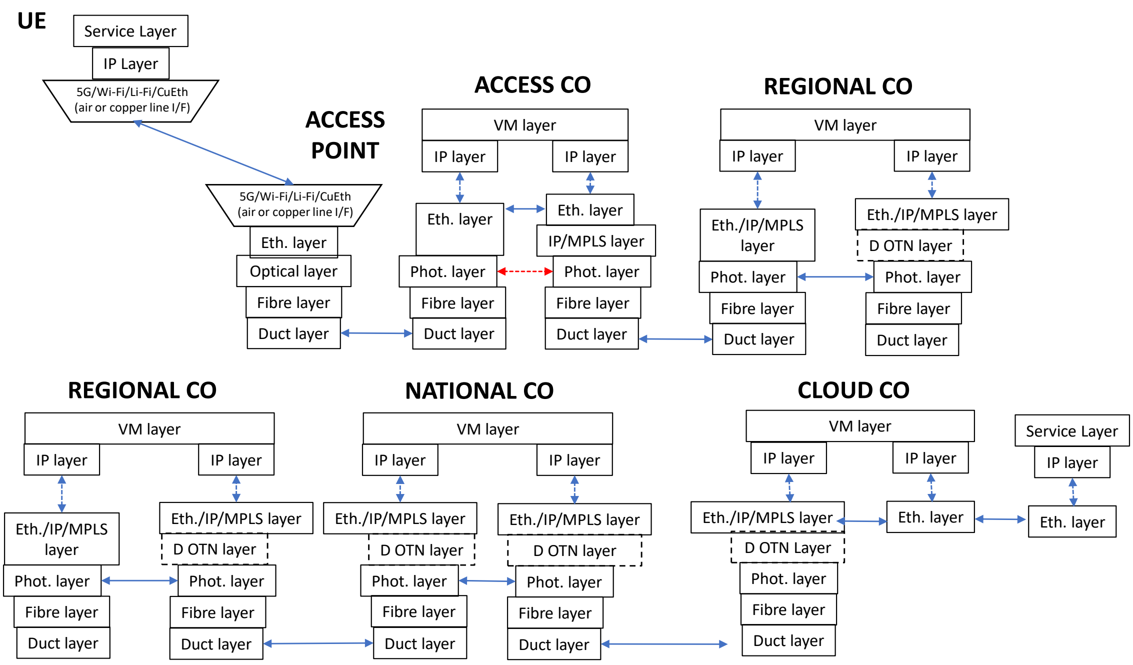

Fig. 1.10. Proposed Layered Network Architecture

B5G-OPEN aims at demonstrating five key features (Table 1-1) and the main network layers to achieve this goal, are shown in Fig. 1.10 along with other network layers (e.g. duct layer, D-OTN layer, etc.) that help putting those into context, i.e. for completeness reasons without aiming at being exhaustive. The “D-OTN layer” refers at the functionality of the OTN technology in the electrical domain except the cross-connecting function (irrelevant in any case as OTN is out of scope in this project).

Starting from the left hand-side, an integrated access is shown between the UE and the Access Point, where services can be configured and managed regardless of the specific access technology. The optical network starts at the Access Point, which is connected to an access node in the Access CO (note that in some cases the Access Point is directly connected to a Regional CO illustrated by an optical bypass at the Access CO.

The optical cross-connecting or switching options in each node are represented by the horizontal doubly pointed arrows inside each CO while the routing option is represented by the bridging VM layer box between incoming and outgoing traffic flows. Note that B5G-OPEN will focus on packet switching only inside the Access CO and the Cloud CO (although the latter is out of scope), while in the rest of nodes the Packet Optical Node will perform the routing function.

1.3.2 Multi-domain architecture

Fig. 1.10 shows a network scenario where the interconnection among segments can be implemented using the traditional approach of electronic regeneration and processing at the

IP/MPLS layer. However, the introduction of MB technologies has the potential to facilitate the implementation of an optical by-pass at the central office for selected traffic, leading to the concept of optical continuum.

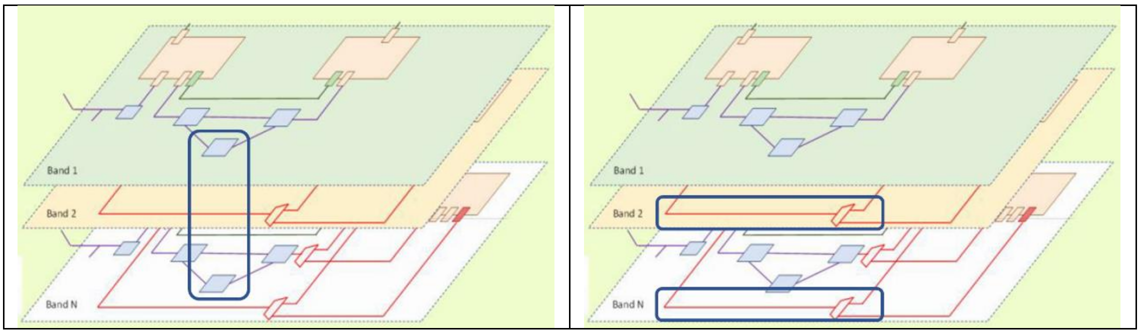

Fig. 1.11. Vertical and horizontal approaches to design and control MB optical infrastructures.

Fig. 1.11 shows a possible implementation of optical by-pass and continuum. The data plane is represented with multiple transmission layers. Each layer can be mapped onto a specific optical fibre spectrum band. Components such as transmission systems and optical switches/ROADMs may operate in one or multiple bands. For example, Fig. 1.11 left shows a node that operates in band 1 and N but it is bypassed in band 2. This way, a single fibre could be simultaneously used to provide different services on different bands (see Fig. 1.11 right). For example:

- direct customer access to edge computing resources in the O band (e.g. high speed Ethernet 802.3cn and beyond);
- high-capacity direct access to a regional Data Centre in the E band (bypassing the edge node)
- segment interconnection in the S band
- low granularity flex-grid connections in the L band
- pluggable-based P2MP in the C band for converged metro and X-haul

The proposed architecture goes beyond the traditional approach of network segmentation with clear electronic demarcation points. This has the potential to significantly reduce the number of opto-electronic conversions but poses new challenges in the design and control of the overall infrastructure.

To address these challenges, two innovative approaches have been considered by B5G-OPEN. The first approach, shown in Fig. 1.11 left, applies and extends the traditional vertical organization of network resources, where each domain is designed and controlled according to its physical location (e.g. region). In this case, an SDN Controller maintains unique access to all resources under its visibility domain. However, the Controller must interact with other controllers for provisioning and recovery of multi-domain transparent interconnections, since the border among regions/segments will not always encompass opto-electronic regeneration. Impairment-aware path computation across different transparent domains is yet an open issue which requires standardization of impairment models and common procedures for control and management.

The second approach, shown in Fig. 1.11 right, applies an alternative, horizontal organization of network resources. In this case, an SDN Controller has a *per-band visibility domain* and has access to all resources within that domain of "transparency". On the one hand this may imply multiple concurrent access to MB network components from different Controllers, each operating in a different band. On the other hand, this horizontal approach aims at limiting/avoiding multi-domain interconnections. This approach was named *domain-less* in the B5G-OPEN Description of Action to highlight the fact that each geographical region has no clear domain border.

Each of the two approaches presents pros and cons in terms of scalability and definitions of procedures and operations for management and control. Both approaches will be further investigated in the project. However, the need to handle multi-domain transparent interconnection appears as a key feature also for the horizontal approach to cope with potential scalability issues. For this reason, both WP3 and WP4 will consider standardized impairment-aware multi-domain connectivity as a key innovative technology to be introduced by B5G-OPEN.

1.3.3 Packet-optical infrastructure

Traditionally, the interconnection among COs is typically achieved using dedicated transponders. On the plus side, transponders guarantee optimized transmission performance, but on the down side, they introduce additional power-hungry opto-electronic regeneration.

The introduction of cost-effective coherent transmission solutions as pluggable modules equipped within packet switching nodes has the potential to drastically reduce the amount of electronic processing in intermediate nodes, particularly in the context of metro-aggregation where the optimization of transmission performance is normally not a key requirement. Furthermore, potential benefits should be achieved in terms of CAPEX/OPEX as well as in the tight integration between optical and packet infrastructures.

In B5G-OPEN dedicated studies are in progress within WP3 and WP4 to support network architectures and solutions encompassing packet-optical white boxes.

2 Reference Topologies

One of the aims of WP2 was to identify one or more reference networks with which to carry out network studies and perform techno-economic analysis. One of the reference networks that has been selected to be used in B5GOPEN for studies focused on metro segment is the metro network that was defined in the Metro-Haul project which is described in [MHD2.4]. The network is based on geotype classification of nodes and includes 63 nodes organized in two layers, a six-node meshed metro core network and five aggregation horseshoes double hubbed to the nodes of the metro core. The Metro-Haul reference network, extended to include a small backbone segment (to be used in studies which include both the metro and backbone segments), is used for the implementation of an example of the traffic characterization model described in Section 7.1.

A further larger network that includes both the metro and access segments was provided by TIM and is described in this section.

The reference network provided by TIM shows many similarities with networks of the other two participant operators and this is the reason why it was considered suitable to be chosen as the reference network for the studies to be carried out in B5G-OPEN.

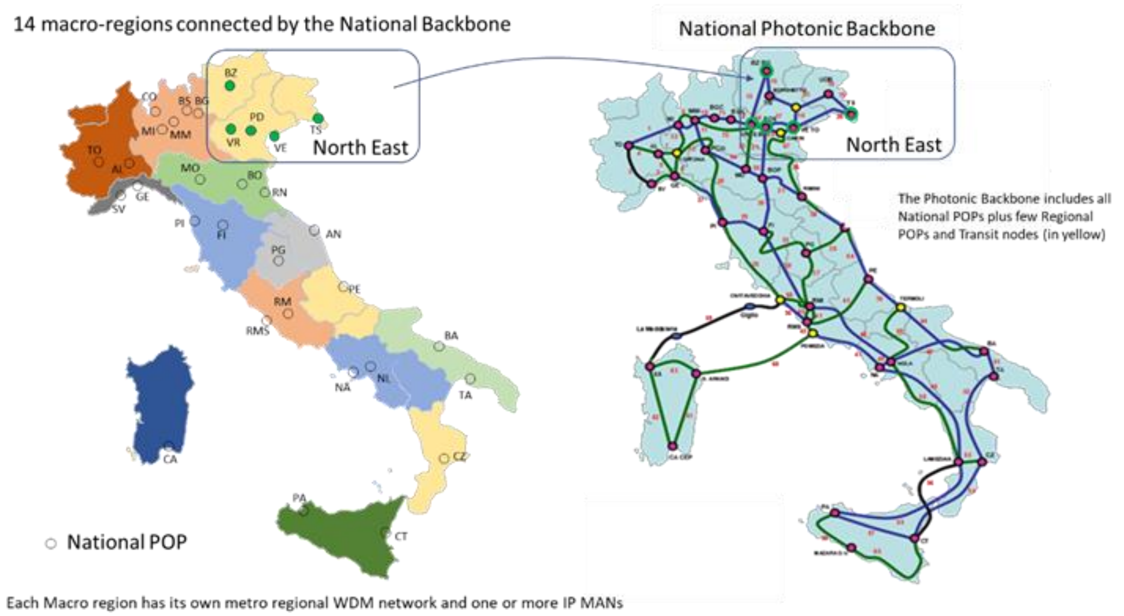

Fig. 2.1. Macro Regions and National Photonic backbone of TIM

The reference network topology is divided into two, one being the National Backbone and the other one of fourteen Metro Regional networks corresponding to the WDM macro regional network serving the North-East of Italy. Left side of Fig. 2.1 shows the partitioning of Italy in fourteen macro regions. Each macro-region has its own Metro-Regional WDM network, and one or more IP MANs on top of it. The macro-regional networks include one to five National POPs. The National Backbone (right side of Fig. 2.1), which includes all the National POPs plus some other nodes (regional or pure transit), is used for traffic exchange between macro regions and to carry traffic to be exchanged with National data centres, peer interconnected networks and Internet.

The provided network topologies are the Metro-Regional for the North-East and the National Backbone. The common nodes and points of traffic exchange between the two networks are the green coloured/circled nodes in Fig. 2.1. For confidentiality reasons, the data is provided with a perturbation on their values, and the nodes are anonymized and not geo-referenced. The model is however still representative of the network in the field.

The Photonic Backbone network has more than 40 nodes, the majority (around 30) are National POPs while some Regional POPs and few pure transit nodes take part of the backbone as well. The links are more than 70 in total. Fibres on each link of the graph are either G.652 or G.655 (with only few exceptions of links with G.653 fibre), and the distance between OLAs ranges approximately from 50 to 100 km (80 km on average). Table 2-1 shows the topological data.

Table 2-1. Node degrees and link length statistics of the National Photonic Backbone

Backbone Node Degree			Link Length Statistics	
Topological degree	Occurrence		Link length L	% of links
1	0		0 < L ≤ 50 km	15.5 %
2	10		50 < L ≤ 100 km	16.9 %
3	18		100 < L ≤ 200 km	33.8 %
4	12		200 < L ≤ 400 km	25.4 %
5	4		400 < L ≤ 600 km	8.5 %
6	0			

The Metro-Regional reference network covers the North-East of Italy and includes three regions and 13 administrative provinces. Population in the macro region amounts to 3.4 million people with 2.9 million households, and about 1.4 thousand mobile sites (macro cells) are covered by this macro regional network.

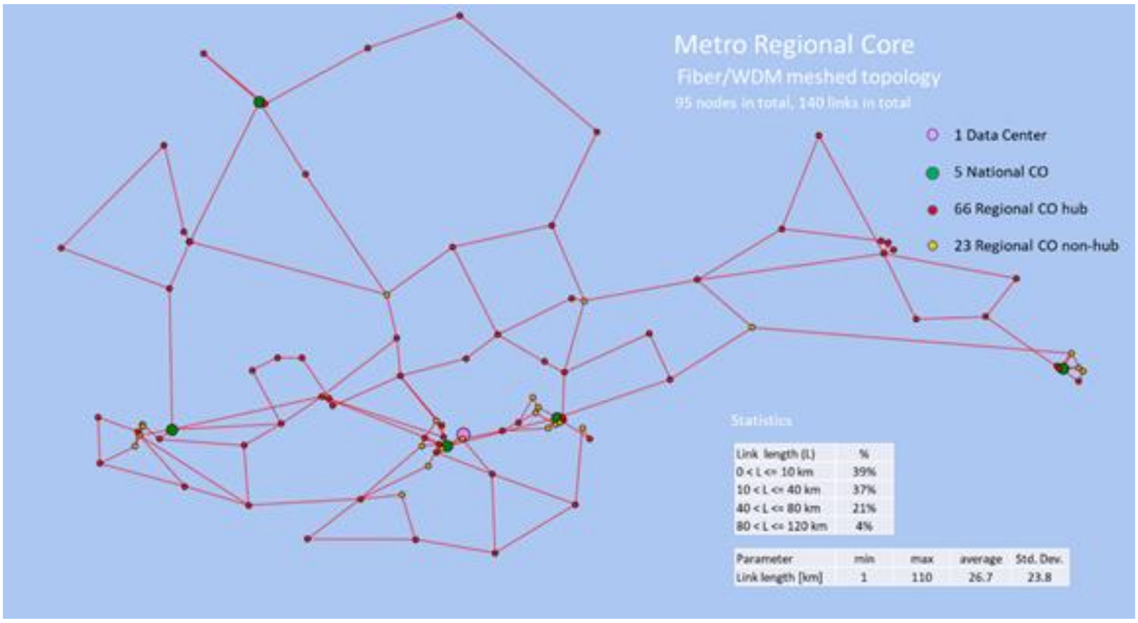

Fig. 2.2. Topology of the Reference Metro Core network

The network is organized into two tiers. A lower tier, the Metro-Aggregation, which interconnect Access COs to Regional and National COs using hubbed horseshoe topology, and a higher tier, the Metro Core, which interconnects Regional COs, National COs and a DC, using a mesh topology.

Fig. 2.2 shows the topology of the reference Metro Core network, which has been taken from the macro region network in the North-East of Italy. Statistics on link lengths are given as table insets at the bottom right of the figure.

Table 2-2 shows the symbols used for the network representation together with the number of nodes and roles of nodes for both the WDM and Packet layers. Details on functions and services hosted in different types of COs are also given in the table.

Table 2-2. Symbols, number of nodes and current main characteristics of each type of node used in the Reference Metro Core network (Fig. 2.2 and 2.3)

Symbol	Node	# of Nodes	Role in WDM network	Role in MAN and Packet backbone	Functions/Services
	Data Centre	1	WDM Metro Core	None (gateways to DC infrastructure)	IT services for business App.
	National CO	5	WDM National Backbone, WDM Metro Core, and WDM Metro Aggregation as Hubs	Metro, Feeder and Backbone routers	BNG, Mobile Core, Telco NFV-I, Service Cloud (CDN), alien caches (OTT)
Hub non-Hub	Regional CO	89	WDM Metro Core; 66 CO in WDM Metro Aggregation; 23 as non-Hubs	Feeder routers	L2/L3 transport
	Access CO	342	WDM Metro Aggregation	Aggregation routers	L2/L3 transport

Fig. 2.3 shows some typical examples of horseshoe structures of Metro Aggregation network. Horseshoes are made of Access COs (the leaves) connected to two hubs that can be a Regional CO (hub, in red) or a National CO (in green). Some Regional CO are not hubs for any Horseshoes, in that case they are classified as non-hub (in orange), they take part of the Metro core mesh and collect local traffic only. Horseshoes can be very different from each other in terms of number of nodes and total length. In general, in rural and suburban areas, lengths are greater and also the number of nodes is higher, but there are many exceptions.

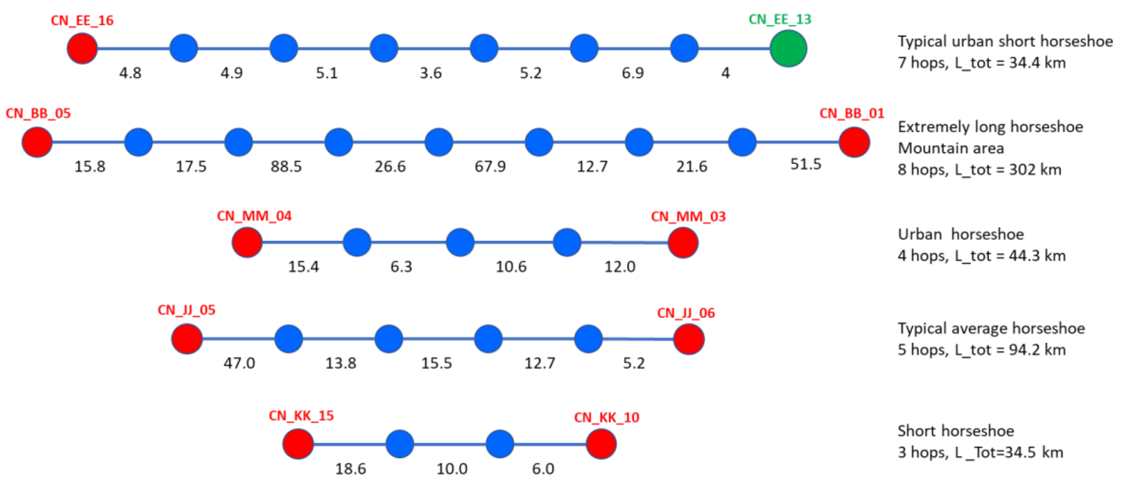

Fig. 2.3. Examples of Horseshoe aggregation networks

Table 2-3, 2-4 and 2-5 show statistical data about the Metro Aggregation horseshoes structures of the reference network. Similar values hold for the other thirteen metro regional networks of the TIM network.

Table 2-3. Statistical data of the Metro Aggregation horseshoe structures

	Min	Max	Average	Standard Deviation
# Hops	2	8	4.5	1.5
Link length (km)	0.6	166.4	21.4	22.2
Total horseshoe length (km)	15.2	301.9	95.6	61.7

Table 2-4. Horseshoe length pdf

Horseshoe length	
0 < L ≤ 50 km	25%
50 < L ≤ 100 km	40%
100 < L ≤ 200 km	29%
200 < L ≤ 302 km	6%

Table 2-5. Horseshoe hops pdf

Horseshoe hops	
2	10%
3	19%
4	21%
5	27%
6	14%
7	5%
8	4%

Fig. 2.4 shows schematically both the fibre/WDM and logical/IP topologies as they are organized in TIM's metro regional networks. On the bottom-left side, the horseshoes at WDM level are shown organized as chains of Access COs doubly hubbed to nodes that can be either Regional or National COs. At higher levels, still on the left side of Fig. 2.4, the Regional CO, National COs and the Data Centre are part of the metro core WDM mesh. On the right of Fig. 2.4 the IP topology and location of main IP Edge, Mobile core and Telco and Service functions is shown as they are organized today in TIM network. Functions are centralized at National CO level and the IP network is used as pure transport bearer from the Access COs to the National POPs. IP topology (dotted lines between IP equipment, i.e. routers) is very simple and it implements the principle of dual homing of routers belonging to a given level in the hierarchy to a couple of routers in the next higher level (i.e. from local aggregator router in the Access CO to a couple of feeder routers in two distinct Regional COs and from a feeder router in the Regional CO to a couple of Metro routers both located in this case in one single National CO). The two connections ensure the dual homing is implemented on the WDM network with two physical disjoint paths guaranteeing a sufficient degree of network survivability against failures.

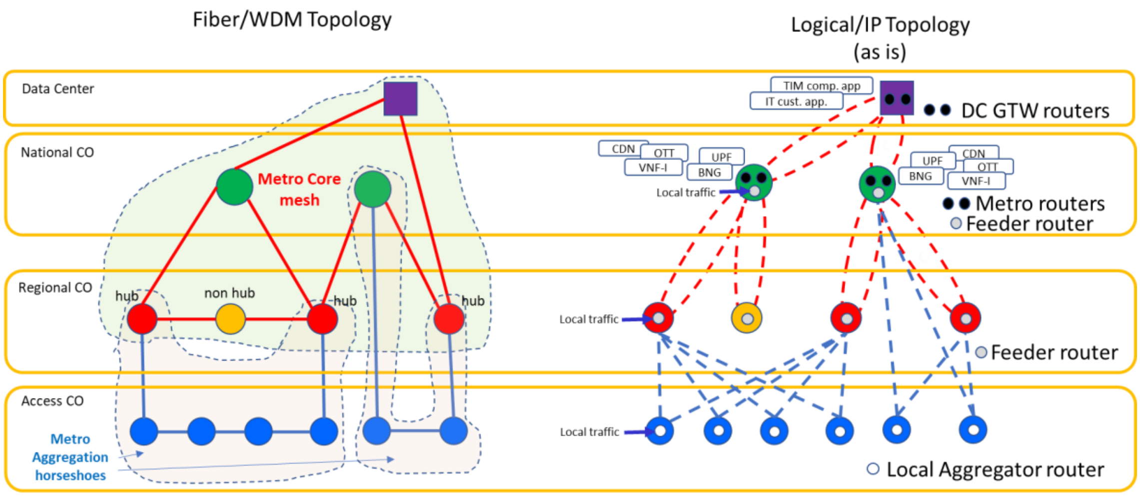

Fig. 2.4. Basic scheme of Fibre/WDM and Logical/IP topologies of the Metro Regional networks of TIM.

It is not required that the solutions for architecture of the packet network and the positioning of the network functions and services proposed by B5G-OPEN reflect the example of Fig. 2.4 which is a typical example of the TIM network. However, the topological constraints of the fibre (no further fibre deployment) and the hierarchy of the exchanges as defined according to the high-level model defined in Section 1.1 should be respected. In addition, the concept of network segmentation, and in particular the presence of a metro segment and a backbone segment, implies that the exchange of traffic must take place in a hierarchical way, i.e. in the transition from a metropolitan network domain to a different metropolitan network domain traffic must pass through the backbone network. In the transition between the metro domain and the backbone domain, it is necessary to move between separate devices belonging to the two domains. If the passage of traffic flows is carried out directly at the optical level bypassing the packet level, the solution to be applied is particularly critical, especially if you want to ensure the optical transparency of the signal.

3 Analysis of Access Network Architectures in the Context of B5G-OPEN

Revisiting medium- and long-term possible access architectures, the question is how the current access systems will connect with a network that uses an end-to-end control plane, fibre multi-band, and optical continuum concepts. WP2 have defined three access architectures from current to longer-term possibilities, but apart from the physical layer implementation challenges, what system protocols aspects are challenges or easy, or show-stoppers. Here we want to investigate the answer to these questions.

First, we will describe the main relevant characteristics of access technologies and see the implications. Analysing these implications will lead to a) an understanding on how these access systems can be used and b) what would be the requirements for future access systems exploiting the concepts of multi-band and optical continuum.

We start with a look at the mobile Radio access networks with an analysis of its functional decomposition and interfaces, and the different possible architectures.

3.1 Radio Access Networks

Most of the material in this section has been extracted from [NGMN18] and from a BT internal presentation.

Mobile network technologies play an important role in modern telecommunications, which will only increase with the development of 5G NR and future generations. A Radio Access Network (RAN) implements a Radio Access Technology (RAT) and connects a device or User Equipment (UE) with its Core Network (CN). The 5G NR base station is called gNB (or gNodeB).

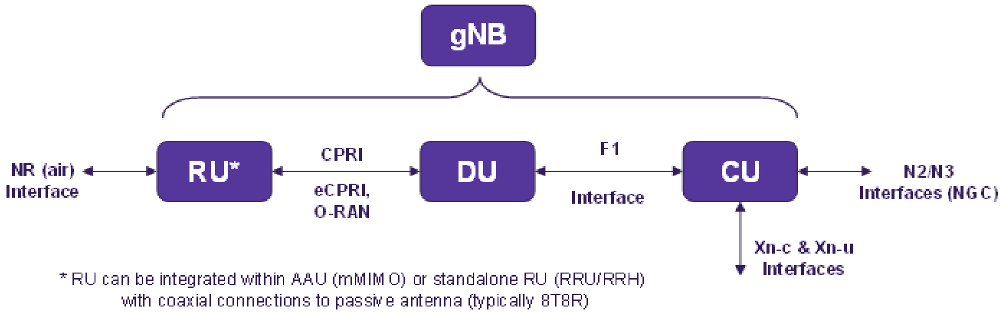

Fig. 3.1. gNB and RAN functional decomposition

Interfaces based on the RAN functional decomposition shown in Fig. 3.1 may be classified into three classes:

- Low Layer Split (LLS) between radio and central RAN functions:
  - Specified in various forums and standards bodies (i.e. IEEE 1914, CPRI forum and O-RAN)
- High Layer Split (HLS) between distributed and central RAN functions:
  - Specified in 3GPP as F1 for gNB
- CU-CP and CU-UP: control/user plane functionality split within central RAN (Fig. 3.2)
  - Specified in 3GPP as E1 for gNB
- RAN-core interface:

  - Specified in 3GPP as N2/N3 or NG for 5GC

The interfaces between RAN nodes are:

- Xn: Between CU functions in different gNB (Fig. 3.2)
  - In practice, split into Xn-c and Xn-u control plane and user plane interfaces

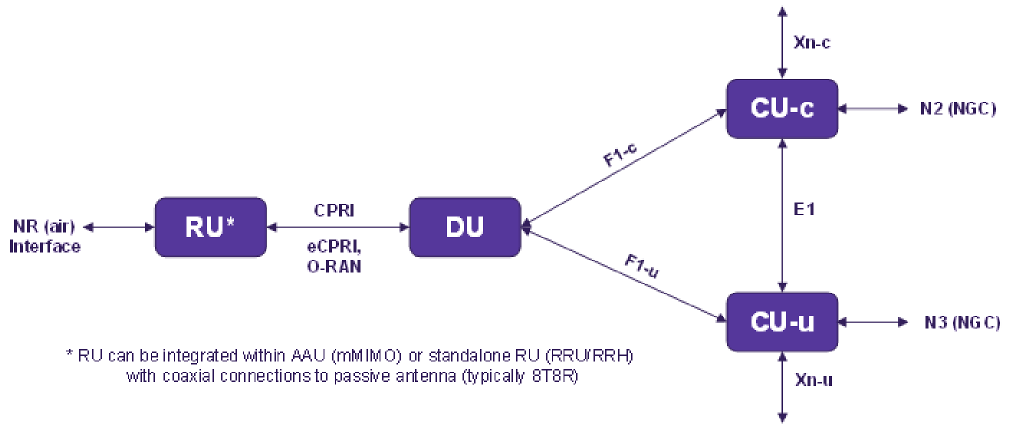

Fig. 3.2. CU control and user plane separation

As shown in Fig. 3.3, the transport to connect functional units has a range of names, such as fronthaul, midhaul, and backhaul (together referred to as x-haul). For clarity, when discussing the transport for the various interfaces in a disaggregated RAN, fronthaul transport connects the functionality between RU and DU. The transport for the F1 interface is the midhaul connecting the DU functionality with the control CU functionality (CU-C) and the use plane CU functionality (CU-u). Finally, the transport between the CU functionality and the 5G core functionality (5G NC) is known as backhaul transport.

Fig. 3.3. RAN functional decomposition

The terminology to describe LLS and HLS functional splits is as follows:

- RU: Radio unit. Contains all RAN functions placed below LLS interface
  - CPRI Forum uses the terms “RE” and “eRE”
  - O-RAN Forum and TIP use the term “RRU”
  - The Small Cell Forum (SCF) uses the term “PNF”
- DU: Distributed Unit. Contains all RAN functions placed between LLS and HLS interfaces
  - 3GPP uses the same term “DU” to refer to all functions below HLS interface and hence refers to both RU and DU
  - CPRI Forum uses the terms “REC” and “eREC” to refer to all functions above LLS and hence refers to both DU and CU
  - O-RAN Forum uses the same term “DU”
  - SCF uses the term “VNF” to refer to all functions above LLS
  - TIP uses the term “vBBU” to refer to all functions above LLS for DU and CU, and “ECU” for DU

- CU: Centralized unit. Contains all RAN functions above HLS interface and terminates inter-RAN interfaces (Xn)
    - For the gNB, 3GPP splits this function into a single CU-CP control plane and one or more CU-UP user plane functions

Only the CU and some of the DU functionality above LLS is susceptible to be virtualised. This has implications in the context of B5G-OPEN. Functionality that needs to be implemented in hardware cannot be easily moved from location. Therefore, once the system has been commissioned, all the traffic to and from the RU needs to be terminated at the CU. When the CU functionality (either control or user planes) is implemented in software there is the possibility that depending on the type of services being supported over the RAN, the location of the functionality might be moved, which means the traffic will need to be re-routed accordingly.

Fig. 3.4 shows the functional blocks of 5G RAN with the association to the architectural functionality for the different split options corresponding to the different split interfaces.

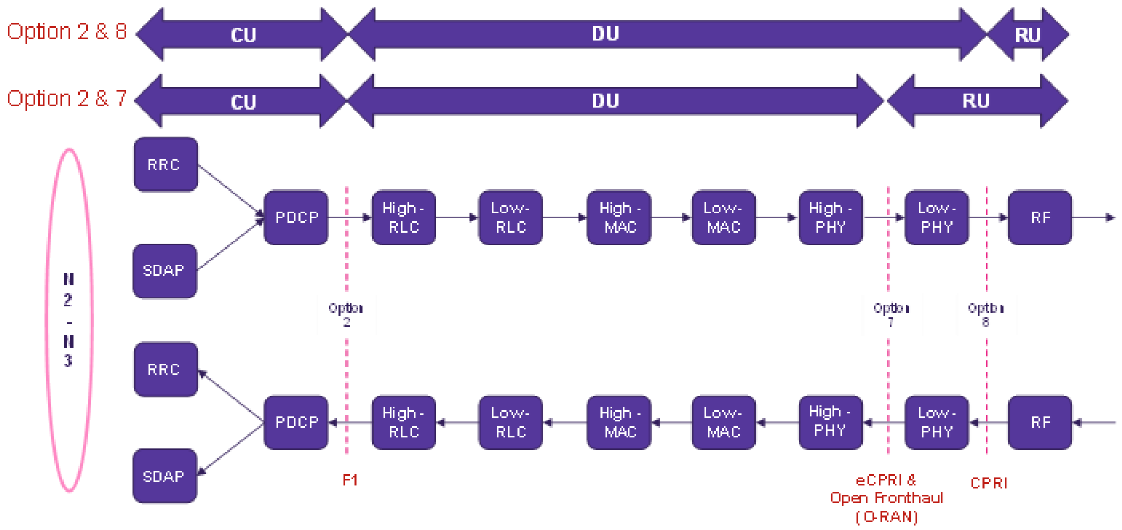

Fig. 3.4. 5G RAN functional entities and interfaces

The new disaggregated RAN architecture gives the network architects a lot of flexibility depending on the location of the different functional blocks. Fig. 3.5 shows different potential mapping over the B5G-OPEN high-level network view.

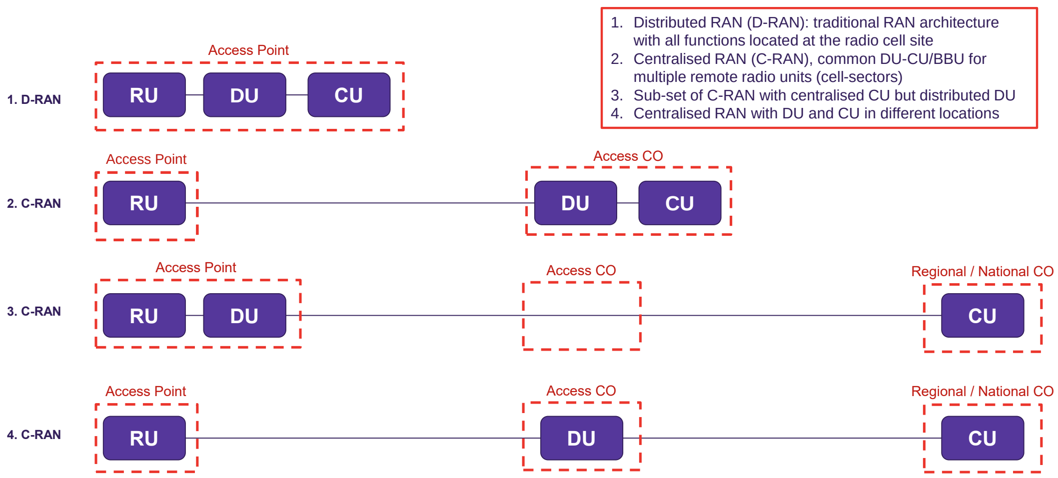

Fig. 3.5. RAN architectures

Simplifying a little, only the CU functionality might be located either at an access node to support low latency services, or at a more centralised location such as a regional/national node for other time non-sensitive services.

3.2 Fibre Access Technology Types

The fibre access networks physically connect the (optical) access points to a network node (typically the access node or the regional/metro node). We can classify the types of access technologies according to the type of ODN they use:

- P2MP ODN based on power splitters
- P2MP ODN based on wavelength splitters (multiplexers/demultiplexers)
- PtP ODN (or fibre PtP)
- PtP WDM ODN

To understand how access systems fit into the B5G-OPEN network concept we need to look into some of their technical characteristics like for example the wavelength plans. Fig. 3.6 shows the wavelength plan of the main ITU-T TDM-PON systems.

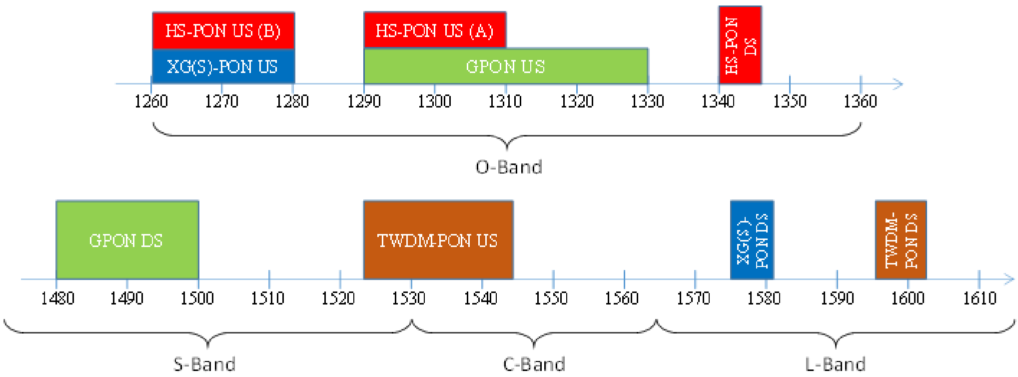

Fig 3.6. ITU-T TDM-PON wavelength plans

The reason the channel bands are so wide is because of the need to control the costs that leads to some choices like the use of no temperature-controlled laser diodes in the ONUs for the upstream transmissions. Co-existence between PON generations is also very important for operators. PON co-existence means that the different generations can simultaneously coexist in the same ODN. This feature allows seamless upgrade of PON systems.

The HS-PON is the High-Speed PON that has started by specifying the 50G-PON. It has two possible options for the upstream channel, option A makes it able to coexist with XG-PON and option B makes it able to co-exist with GPON.

IEEE TDM-PONs also use the same wavelength plans (e.g. EPON same as GPON, 10G-EPON same as XG(S)-PON).

All other fibre access systems have a well-defined wavelength plan. While we have shown the wavelength plan of the ITU-T TDM-PONs in Fig. 3.6, the specifications will define it for each technology and the reader is referred to those.

Next, we look into some characteristics of different common systems used over the different types of ODN.

3.2.1 Fibre P2MP access systems based on power splitters

- ITU-T TDM-PON (GPON, XG(S)-PON, and 50G-PON)
  - GPON (G.984) wavelength channels: O-Band (Up), S-Band (Down)
  - XG(S)-PON (G.9807.1) wavelength channels: O-Band (Up), L-Band (Down)
  - 50G-PON (G.9804.3) wavelength channels: O-Band (Up & Down)
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified.
  - Transmission Convergence tightly specified
  - MAC with Dynamic Bandwidth Assignment (dynamic scheduling)
- ITU-T TWDM-PON (G.989)
  - Wavelength channels: C-Band (Up), L-Band (Down)
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified.
  - Transmission Convergence tightly specified
  - MAC with Dynamic Bandwidth Assignment (dynamic scheduling)
- ITU-T PtP-WDM-PON (G.989)
  - Wavelength channels: L-Band (Up & Down)
  - OLT MAC control (Closed loop control protocol)
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified.
  - Transmission Convergence tightly specified
- Open XR Forum DSCM-PON (XR system)
  - Wavelength channels: C-Band (Up & Down)
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), clearly specified
  - Transmission Convergence (e.g. FEC, control channel, etc.) specifications under development

All these systems have clear and avoidable termination points with optical interfaces well specified. Albeit it might be possible to move the OLT/Hub location provided the system specifications are still met by duplicating all the functionality (including the hardware), it is not possible without changing the service characteristics of all remote nodes.

3.2.2 Fibre P2MP access systems based on wavelength multiplexers/filters

- ITU-T G.metro (G.698.4)
  - PtP DWDM system: C-Band (Up & Down)
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified
  - ONU Wavelength control (Closed loop control protocol)
  - Partial, no Transmission Convergence specification, but the wavelength control protocol
- ITU-T WDM-PON (G.9802.2)
  - C-Band (Up & Down)
  - System control layer specification
  - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified
  - ONU Wavelength control (Closed loop control protocol)
  - No Transmission Convergence specification

The systems specified in G.698.4 and G.9802.2 have control functionality over the remote nodes optical transmitters. This control functionality needs to be common for all ONUs in the same ODN and needs a control channel with low latency. This means that re-configuring the OLT termination (provided the physical specifications of the optical transceivers are still met and duplicating the whole OLT) would need to be implemented for all ONUs in the same ODN thus impacting all service traffic characteristics.

3.2.3 Fibre PtP access systems

- IEEE PtP Ethernet
    - O-, S-, C-Bands
    - Optical Interfaces specification
    - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified
    - No Transmission Convergence specification
- ITU-T PtP Ethernet (G.9806)
    - O-, S-, C-Bands
    - Uses IEEE Optical Interfaces specification
    - Physical Layer parameters (wavelength channel, Transmitted power, etc.), tightly specified
    - No Transmission Convergence specification
- Open XR Forum DSCM-PON (XR system)
    - Wavelength channels: C-Band (Up & Down)
    - Physical Layer parameters (wavelength channel, Transmitted power, etc.), clearly specified.
    - Transmission Convergence (e.g. FEC, control channel) specifications under development.

These systems define a unidirectional (IEEE) or bidirectional (ITU-T) connection in each fibre, and one of or both termination points can be re-located (by duplicating them) provided they still meet the physical parameters specs.

The Open XR Forum system can be used over both a P2MP and PtP ODN.

3.2.4 Fibre PtP WDM systems

The ITU-T defines the WDM channels that may be used in a PtP fibre in different channel spacings (G.694.1 and G.694.2).

- CWDM (G.694.2): O-, E-, S-, C-, L-Band (Up & Down)
- DWDM (G.694.1): C-, L-Band (Up & Down)
- Optical transmission fibre channels allocation
- No optical interfaces specification
- No Physical Layer specification
- No TC layer specification

When designing a system using these channels, each connection needs tight physical layer specifications to avoid impairments on, or from, the other connections in the same fibre.

It is possible to dynamically add/drop optical connections at intermediate locations along the way provided the optical physical specifications are still met. Changing the physical characteristics of one connection requires the knowledge of the physical characteristics of the other connections in the fibre.

3.3 Summary and Some Conclusions

Access systems need to manage and control different aspects of the system itself and be able to properly handle the service traffic it is supporting. Optical access systems are specified in ITU-T by Question 2 of Study Group 15 and the functionality needed to manage and control the system is known as Transmission Convergence (TC).

The next table summarises the listed access technologies above highlighting some relevant features for the purposes of this study.

Table 3-1. Optical access technologies and some relevant features

ODN Type	Access System	Fibre Bands	Phy. Layer Spec.	TC Layer Spec.	MAC DBA Scheduler
Fibre P2MP w/ power splitter	TDM-PON	O, S, L	Yes	Yes	Yes
	TWDM-PON	C, L	Yes	Yes	Yes
	PtP WDM-PON	L	Yes	Yes	No
	DSCM-PON	C	Yes	Partial	No
Fibre P2MP w/ wavelength splitters	G.metro	C	Yes	Partial	No
	WDM-PON	C	Yes	Yes	No
Fibre PtP	IEEE PtP Eth.	O, C	Yes	No	No
	ITU-T PtP Eth.	O, C	Yes	Yes	No
Fibre PtP WDM	PtP C/DWDM	O, E, S, C, L	No	No	No

Now we can answer some questions to understand how we can use the different optical access systems in the B5G-OPEN architecture.

1. Can the access system termination be reconfigured/moved to a different location by optically bypassing the access node?

Systems based on P2MP fibre must manage all connections together, so making it not possible to decouple one of them by terminating it at a different location. If the terminations need to be moved, both physical layer and protocol layer functions need to be moved, which implies a duplication of equipment, with only one of them being active at any given time. System specifications need to be met regardless of the location (e.g. maximum transmission distance).

Systems based on PtP fibres carry only one connection, and therefore, the access node termination can be reconfigured to a different location provided the physical layer parameters are still met. This means the duplication of termination equipment and the need to reconfigure the other network segments to connect the service end-to-end.

Systems based on PtP fibre WDM have the potential to reconfigure one of the connections to a different location provided the physical layer requirements are still met. Some connections can be dropped at some intermediate location and another connection added to the WDM bundle.

2. Can the access system termination be reconfigured/moved to a different location based on the type of service being supported?

Centralised access systems will generally benefit of better economics and in some cases technical and service advantages (e.g. mobility). However, more centralised architectures will inherently suffer from higher latencies when closed control loops are involved (e.g. RAN Front-Haul, TDM-PON, etc.) or because of longer transmission latencies. While in most cases this not an issue, the service application platforms need to be near the service user when supporting low latency services, which drives a more distributed architecture. The need to reconfigure the access system between a centralised and a distributed architecture and the potential benefits against the drawbacks will depend on many factors that are outside the scope of the project.

4 MAPPING ACCESS SYSTEMS OVER B5G-OPEN CO ARCHITECTURES

The access system analysis in the previous Section 3.3 has shown that access systems already use different fibre bands. The technical decision specified in the system Standards is normally based on best PMD Layer options that minimise the system cost.

Another observation is that optical bypass at the access node is already being implemented to reach a more centralised location (e.g. regional node). This is usually the case when using PtP fibre connection e.g. for mobile backhauling, to centralise certain equipment such as e.g. Mobile 4G EPC (Evolved Packet Core) nodes. Fig. 4.1 shows a somewhat typical access architecture and its typical connection to a regional node. The figure is not depicting the metro aggregation network topology, but only the systems used to interconnect both nodes. Also, ROADM may part of the optical equipment in regional nodes in some cases, which is not shown in the figure.

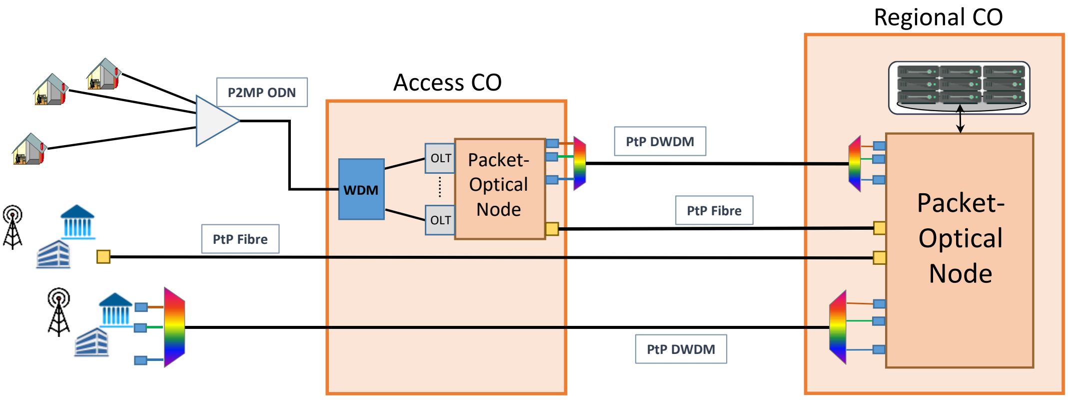

Fig. 4.1. Current typical fibre access architecture

In general, access networks are not protected. Only some PtP Fibre access cases are protected, normally for big corporate businesses customers, financial institutions, or some administration critical services (not shown in Fig. 4.1).

The aggregation metro network is protected using diverse duct routes from each Access CO to two Regional COs, but it is not shown in the figure either.

4.1 SHORT-/MEDIUM-TERM EVOLUTION

As the application services evolve and higher capacities are needed, new technologies will be deployed both in the access and metro/aggregation segments of the network such as for example the DSCM-PON. Additionally, the support of low latency services may force the application functionality be moved closer to the user such as the access node, and therefore some compute and storage resources will need to be accommodated (Fig. 4.2).

In order to quickly configure/reconfigure optical connections between the access point and the service functionality an optical ADM may be located in front of the packet-optical node intercepting those connections susceptible of being routed/re-routed (Fig. 4.2).

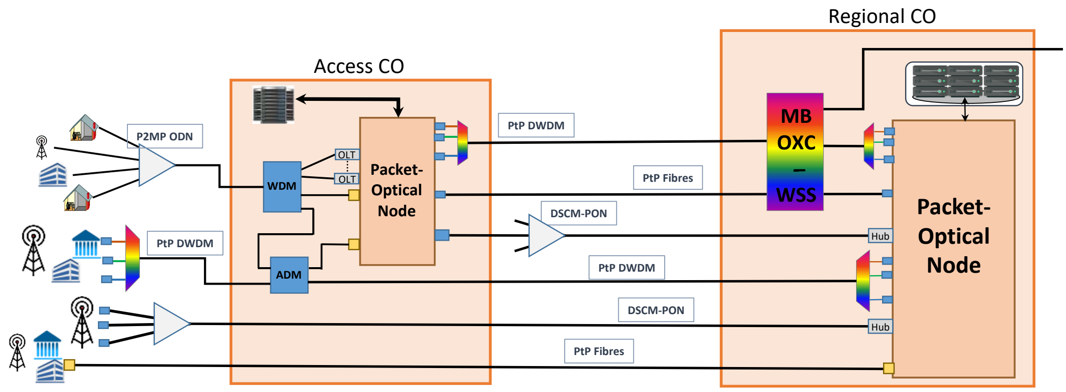

Fig. 4.2. Short to medium term access/regional architecture

Fig. 4.2 also shows a Multi-Band OXC (or WSS) in the regional node as needed for optical bypass. Note that in some cases the optical node may consist of a ROADM or a patch-panel after demultiplexing. It can be argued that whether called OXC or ROADM it basically performs the same optical functionality. In any case, Multi-Band support is part of the B5G-OPEN concept and we can refer to this node as MB-OXC.

Protection is not shown. Some of the services in the access networks (beyond the ones already being protected in the current architecture) should start implementing protection. The aggregation/metro network must be protected.

4.2 Medium-/Long Term Evolution

In the longer-term, network service operators may want more flexibility reconfiguring the connections through the access node. A MB-WSS could be used to intercept access systems to redirect some connections to either resources locally hosted for low latency services, or to more centralised service application resources when latency is not an issue, by optically bypassing the access node (Fig. 4.3).

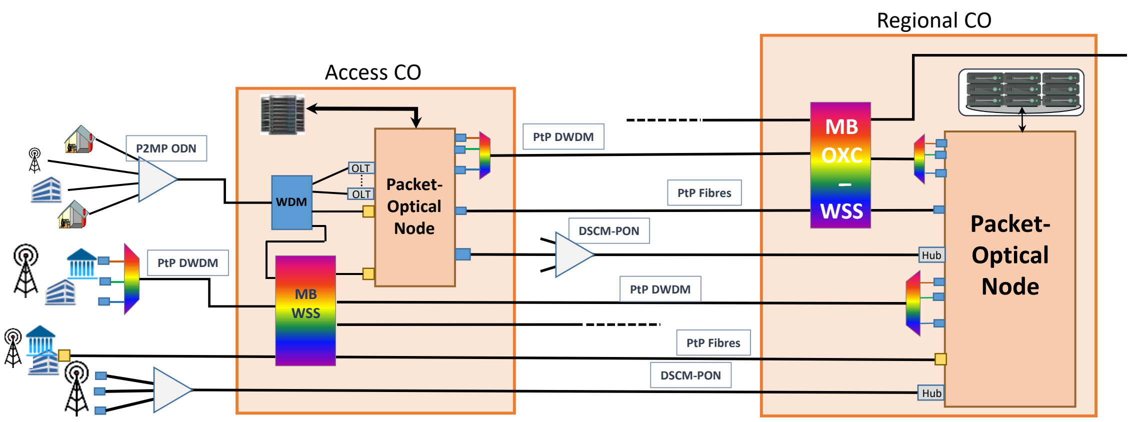

Fig. 4.3. Medium to long term access/regional architecture

In the same way as with the previous figures, Fig. 4.3 does not show network protection.

5 Relationship With Control Plane Architectural Aspects

5.1 Control Plane Services

The considered use case, related requirements and detailed network architecture has been used as a starting point to identify a set of *Control Plane Services*, to be elaborated in the scope of WP4. In this scope, a *control plane service* is understood as a network service whose lifetime is managed by the B5G-OPEN control plane – in other words, it is responsibility of the B5G-OPEN control and orchestration system – and it is stablished via one or more NBIs, dynamically and upon demand. The following subsections summarize such services, presenting a brief description and applicability statement.

5.1.1 S1 point to point optical connectivity

The first basic service addresses point to point connection between optical ports, corresponding to, for example, the packet/optical devices line ports or ROADM add/drop ports (see Fig 5.1). It typically involves the provisioning of a media channel (provisioning of raw optical spectrum) within a given optical band, and it is characterized by its effective frequency slot. The dynamic provisioning and deployment of the service involves different elements of the control plane architecture (see Section 5.2).

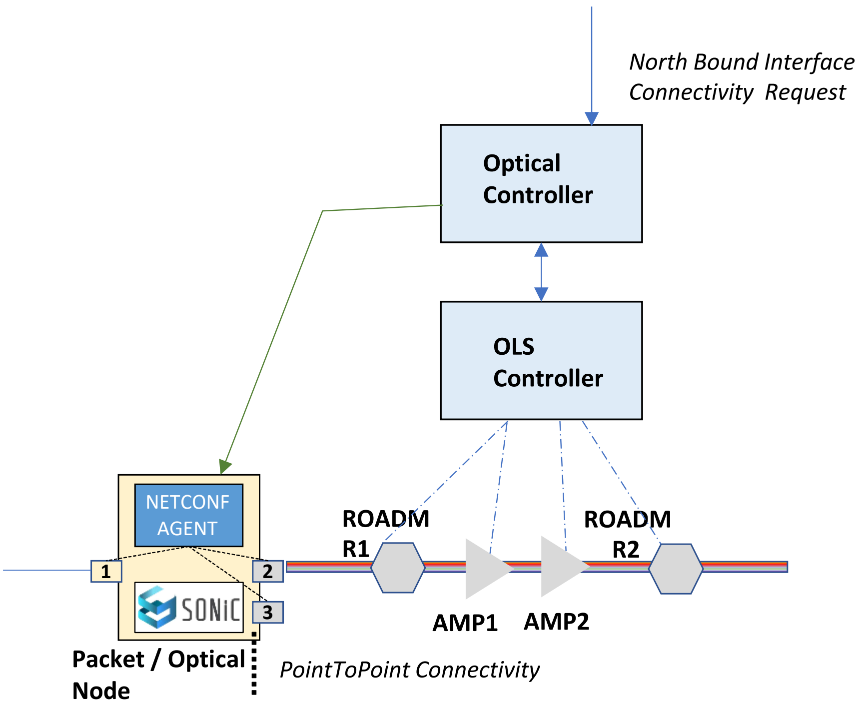

Fig. 5.1. Point to Point Optical Connectivity Service

5.1.2 S2 point to point digital connectivity

This service extends the previous one by considering point to point connectivity at the packet/electrical level. It considers packet switching at the Packet/Optical nodes (relying on IP forwarding or in more advanced SDN-based solutions, such as those based on P4)

This service may require extending the scope to additional network segments, such as optical access. The main goal is to demonstrate packet/optical interworking at the network level.

5.1.3 S3 point to multi-point optical connectivity

Given the increasing importance and benefits of P2MP transceivers, this service extends S1 to consider P2MP optical connectivity (see Fig. 5.2). In the scope of B5G-OPEN, this involves managing a P2MP optical tree (unidirectional and/or bidirectional). This service may need to be constrained by the underlying data plane (e.g. not all ROADM devices support service split/merge) and may be only considered in the scope of specific deployments (e.g. for filter-less networks).

From the point of view of initial requirements, this service assumes that the P2MP connectivity is provisioned between a transceiver (the hub) and one or more leaves (the destinations) and that the optical spectrum reserved towards the leaves is the same and contiguous (in other words, a P2MP single media channel).

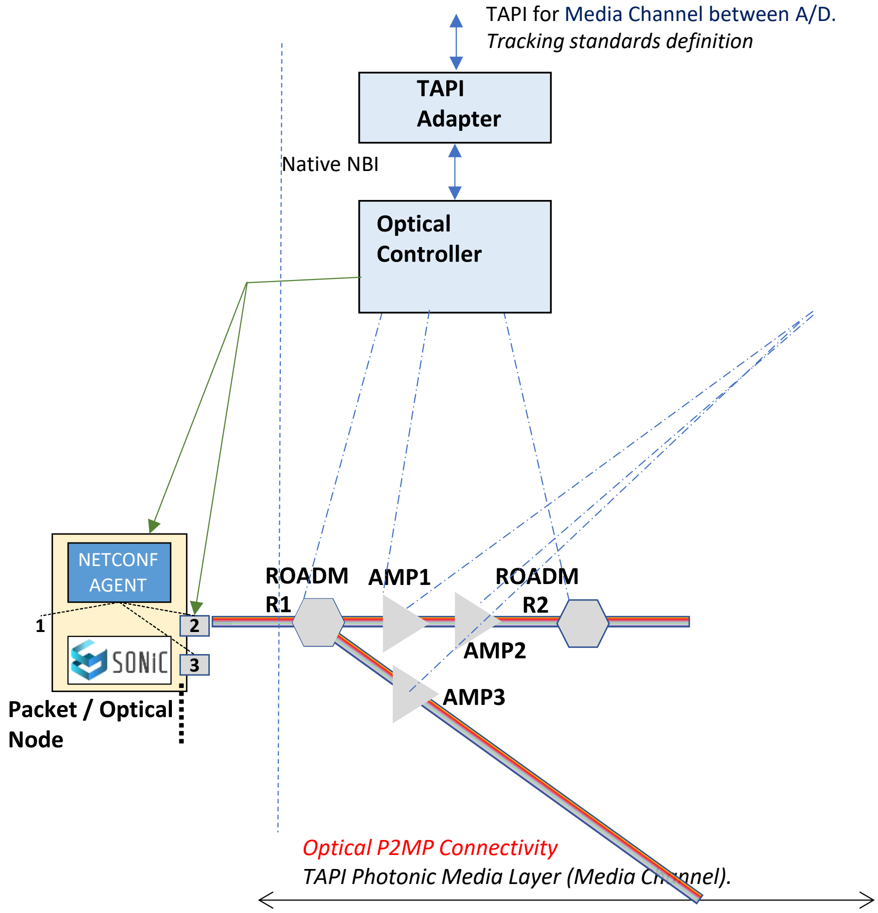

Fig. 5.2. Point to Multipoint Point Optical Connectivity Service

5.1.1 S4 B5G-OPEN slice

In this context, a B5G-OPEN slice is defined as a set of interconnected computing and storage functions, deployed within the B5G-OPEN infrastructure, and which involves the orchestration of heterogeneous computing, storage, and networking resources.

Computing functions are instantiated within computing servers or nodes, and they are interconnected using dynamic network connectivity (thus relying on the previously mentioned services). They may correspond to containers (e.g. Cloud Native Functions, CNF) or Virtualized Network Functions (VNF).

Such service information model shall contain a list of functions, their interconnection, and related constraints in terms of bandwidth and delays and the control plane shall address a placement function that fulfils the requirements.

5.2 Control Plane Functional Architecture

The functional architecture of the B5G-OPEN control plane, targeting single domain networks, is currently being developed in the scope of WP4. The Milestone M4.1 has considered an initial architecture for single domain networks, and it is currently being developed in the project deliverable D4.1. This section presents the most relevant elements of the architecture. The different functional elements (often referred to as components) are identified for the purposes of service orchestration and device configuration (incl. resource control).

5.2.1 Device configuration and control

The definition of the architecture relies on a set of initial assumptions, the devices are client agnostic (they export several configuration endpoints, based on separation of concerns, functionality, or administrative assignment), export several telemetry endpoints, with the same considerations since configuration and Telemetry endpoints may have different access requirements, visibility, and interfaces should be homogeneous. For devices that export multiple configuration endpoints, it is expected that the scope of each endpoint is clearly defined, and/or side effects are well-known (i.e. no overlapping models).

The architecture targeting two main models: i) partial disaggregation with a 2-level control hierarchy, where there is a dedicated OLS controller, responsible for the ROADM and ILA nodes (note that ROADM/ILA nodes MAY export other interfaces (e.g. streaming telemetry) towards other entities, and ii) Full Disaggregation, with a single SDN controller. Both models may include additional functional elements, notably in support of path computation, resource allocation, or function placement.

As addressed in the previous section, the control plane architecture assumes several key services, such as the provisioning of DSR or Media Channel connectivity services and contemplates two main blocks: MB Optical Network SDN control and Domain Telemetry Collector. The MB Optical Network Control is fully decomposed on TAPI adapter, Path Computation Servers, and Optical Controllers (e.g. in the case of partial disaggregation additional OLS controllers will be considered). For the packet domain, different options are addressed. Packet controllers can cover one or multiple packet domains and rely on pure SDN (e.g. P4) or hybrid SDN/IP in which the SDN control plane is mostly used to configure IP processes running in the packet/optical boxes. In the case of multi-OLS scenarios, B5G-OPEN will consider B2B deployments with Transparent Configuration.

5.2.2 Service orchestration and planning

Service orchestration for provisioning, planning, network analysis, and acting as orchestrator, the B5G-ONP element sits on top of the Kubernetes controller, the SDN controllers and the Domain Telemetry collector. IBN Applications implement Knowledge Sharing and rely on the services offered by the different functional elements (see Fig 5.3).

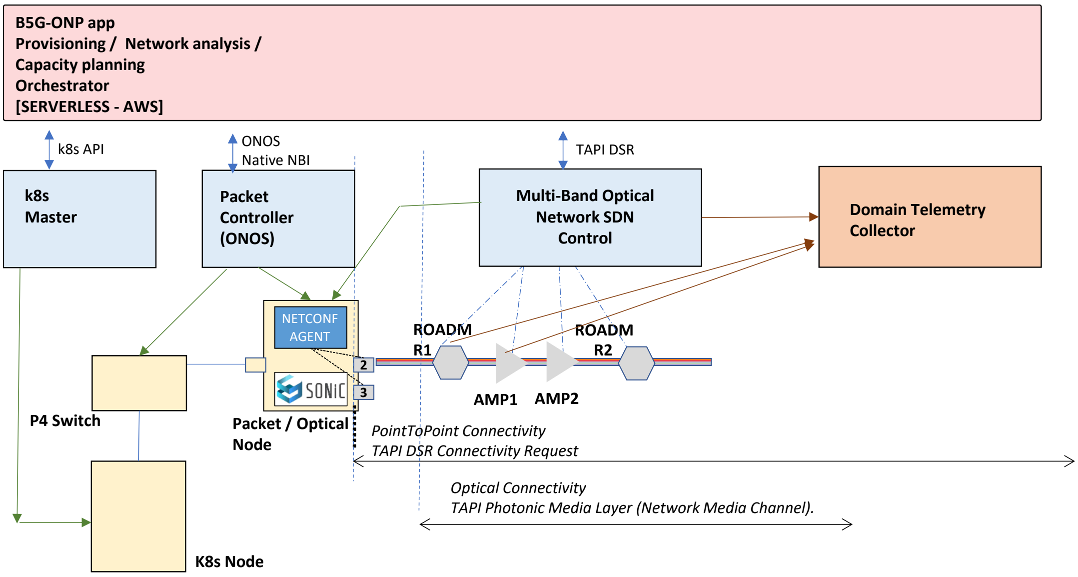

Fig. 5.3. B5G-OPEN Control and Orchestration architecture.

5.2.3 Telemetry and intent based networking

The domain telemetry collector architecture has also been defined (see Fig 5.4). It involves a Telemetry Manager with its own repository as well as telemetry agents that sit on different elements, using the REDIS database. The architecture will be presented in detail in D4.1

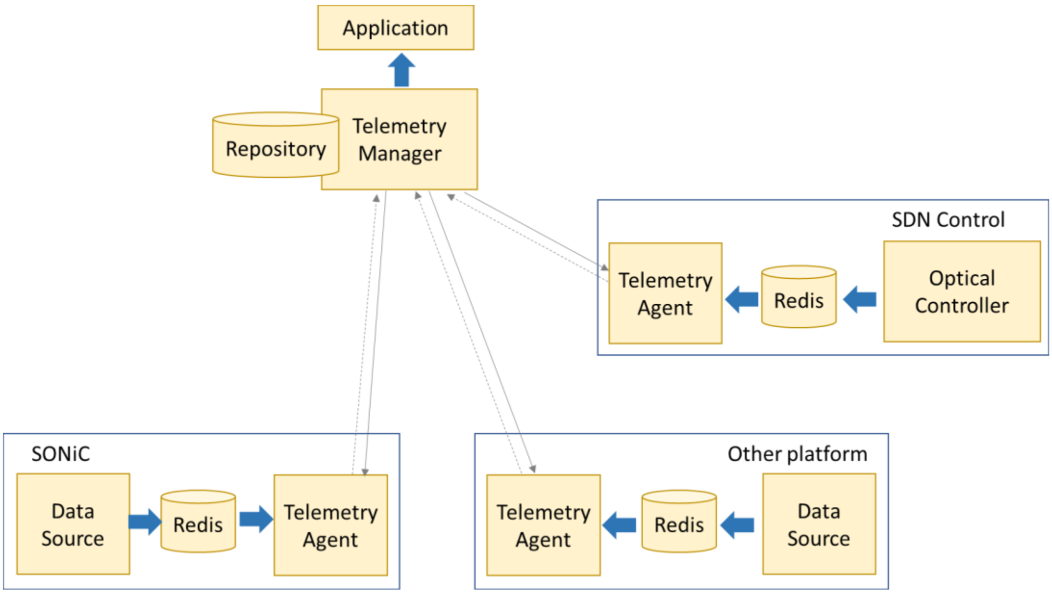

Fig. 5.4. B5G-OPEN Control and Orchestration architecture.

Finally, the B5G-OPEN architecture operates service and network operations from the Access Point to the Cloud node, which might include monitoring and AI/ML

Based on IBN and zero-touch networking paradigms, autonomous operation is built using closed-control loops at various levels, from device to network. Empowered by a distributed AI/ML-based engine providing data collection and intelligent aggregation, analysis, and acting on the network devices, autonomous operation enables coordinated decision-making across domains (see Fig. 5.5).

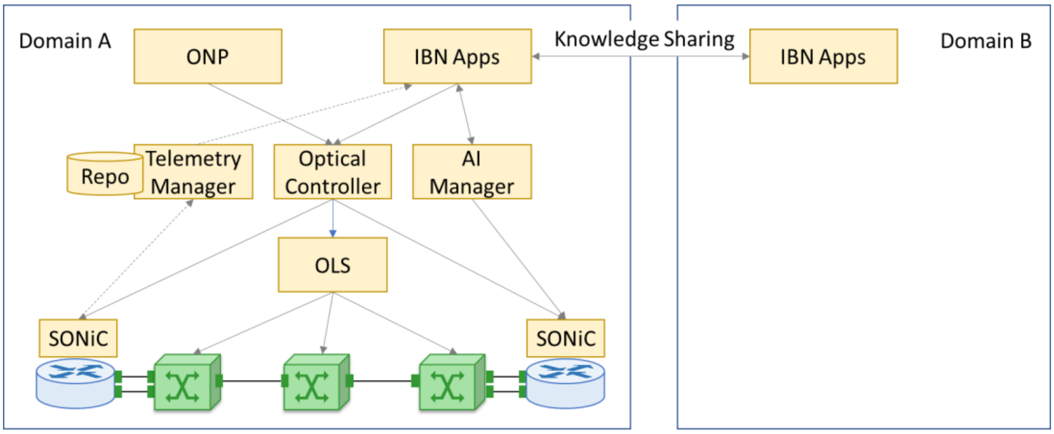

Fig. 5.5. B5G-OPEN Intent Based Applications (IBN) and Knowledge-Sharing.

6 Traffic Characterization

6.1 Introduction

The purpose of this section is to present a traffic characterization methodology to be further used for different activities such as planning, dimensioning, and techno-economic studies. This methodology focuses on characterizing traffic volumes with flow-based metrics i.e., Origin-Destination (OD) matrices (in b/s) in the peak hour. It is specifically tailored to match the proposed high-level architecture in Fig 1.1, excluding the “Far Edge” segment. Therefore, flows between COs in the “Edge” and “Cloud” segments (metro-aggregation, metro-core, and backbone) will be the target of the methodology.

The ambition of this methodology is to provide a comprehensive procedure to generate traffic scenarios combining legacy and well-known mass market services such as web browsing, direct communication, and content delivery, with other innovative services foreseen in the B5G-OPEN scope such as those derived from DT services e.g., high-bitrate flows generated by virtual and augmented reality services. Moreover, it aims to be agnostic to network solutions in terms of technologies, equipment and, in part, on architecture.

Since traffic flows conveyed within and among the different segments and routed/switched/bypassed at different COs depend on many assumptions and parameters such as the placement of telco and service functions (BNG, UPF, caches, servers) or the percentage of cached contents in every CO, the number and variety of potential scenarios is unmanageable. For this reason, the methodology also proposes a reduced number of relevant traffic scenarios to focus on, as well as key assumptions that make this activity practical and relevant for answering key questions in the scope of B5G-OPEN e.g., where and under which scenarios the expected benefits of MB technologies are going to be fully exploited.

Finally, it is important to recall that this methodology is going to be used as a reference procedure to guide and help further activities in the framework of the project related with planning, dimensioning, and techno-economic studies to be carried out in WP5. In this regard, extensions to cope with different assumptions and objectives can be produced (if needed) before the end of the project in other WPs.

6.2 Proposed Methodology

As already mentioned in the introduction, the network model considered in this methodology is based on the B5G-OPEN high-level architecture. Fig 6.1 illustrates an example of the technology-agnostic network model, that is going to be used to enumerate the different components. Thus, the elements in this example are: *i*) two metro-aggregation networks with 2 and 3 access COs, respectively, and 2 regional COs each; *ii*) a metro-core network that interconnects all regional COs with two national COs, *iii*) a national backbone network that interconnects all national COs, and *iv*) a gateway node, directly connected to one national CO (III in the example), which allows connectivity with other networks including Internet. Note that, since far edge segment is excluded, continuity between access and aggregation is not considered. In fact, access COs are considered as origin/destination nodes of the traffic flows.

Fig 6.1 also depicts few examples of traffic flows that could be identified and characterized using the proposed methodology. Let us assume that the depicted flows are generated by users from different access networks and services, all terminating at access CO B. Thus, traffic from some of those services might require processing or accessing contents placed at regional CO (labelled as flow A), whereas others can require a similar processing at national CO (flow B), thus generating flows that cross different segments (this is a potential motivation to exploit optical continuum). In addition, the need to reach other termination points (including others beyond the gateway) creates traffic flows within metro-core (flow C) and backbone (flow D) networks. Finally, note that the activity in a given CO (say access CO B) can generate incoming traffic in other access COs (e.g., access CO D), which obviously generate extra-flows to allow such kind of direct communication (flow E).

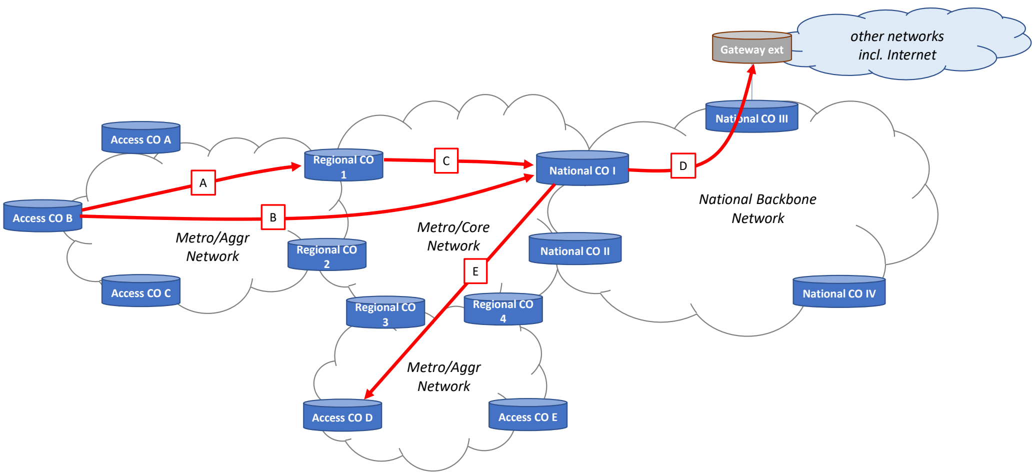

Fig. 6.1. Example of network model with traffic flows

Although not depicted in Fig. 6.1, COs can hold two types of functions in the form of virtualized/containerized nodes: *i*) *telco functionalities* (*telco node*), comprising functions like DU, CU, UPF, and BNG; and *ii*) *service functionalities* (*service node*), containing functions like processing, access to contents, and caching capabilities, just to mention a few. Among telco functionalities, BNG/UPF are those that terminate user sessions and enable traffic to be routed toward destinations (service applications or other users). Therefore, its placement is critical to determine which flows, and their magnitude, are generated in the network.

In view of the above, one can realize how the number of flows that can be generated if several telco/service node placements are considered at the same time for different services, can increase up to an unmanageable dimension. To reduce such complexity, we suggest limiting the traffic scenario selection to one of the following three alternatives for the placement of telco functions (BNG /UPF), called *break-out* point:

- Centralized: break-out point located at National CO, for all services.
- Semi-distributed: break-out point located at Regional CO, for all services.
- Distributed: break-out point located at Access CO, for all services.

These alternatives are sufficiently varied to generate different traffic flow scenarios using the same topology and list of services. However, additional assumptions need to be done to completely build the scenarios. In this project, we are considering the following ones:

- Each access CO has its own reference regional CO plus one additional for backup. In the example of Fig 6.1, access CO B has regional CO 1 as reference and regional CO 2 as backup.

- Each access CO has its own reference national CO plus one additional for backup. In the example of Fig 6.1, access CO B has national CO I as reference and national CO II as backup.
- For the traffic generated by a given access CO the reference national CO and the reference regional CO are the places where break-out is performed in the cases of centralized and semi-distributed scenarios, respectively.

At this point, we can introduce the proposed multi-step traffic characterization methodology, which can be applied once a network topology and a traffic scenario is selected. It consists of four main steps:

***Step 1* –Sets and input parameters definition**: this step consists in defining the parameters of the three major sets that need to be identified to generate traffic flows. These sets are:

- *U*: containing those parameters identifying the number and type of users whose activity generates traffic entering/leaving the network at every access CO. This set is independent from the traffic scenario chosen but depends on the considered topology.
- *F:* containing the set of specific flows to be generated between different COs. This set depends on both the topology and the network scenario.
- *P:* containing those required parameters that, combined with the user parameters in *U* and flows in *F*, allow computing the desired traffic volumes. Typical parameters in *P* are the traffic generated by a single user in both uplink (UL) and downlink (DL) and the percentage of traffic in every flow (or flow type) in *F*. This set *P* is dependent on the network scenario but typically independent from the specific topology.

Note that a group of sets <*U*, *F*, *P*> is required to be defined for every single service considered for traffic computation.

***Step 2* – Service flow traffic computation:** this step consists of describing the simple equations that are needed to compute a traffic volume (peak traffic) for every flow in *F* according to the parameters defined in both sets *U* and *P*.

Step 3 – OD matrix computation: this step is devoted to aggregate (sum) the values of traffic obtained in the previous step in order to compute OD matrices for the desired objective e.g., to compute the traffic exchanged between COs in a given segment or compute the total traffic exchanged between different segments.

Step 4 – Extended traffic outcomes: this step aims at complementing step 3 and produce additional outputs for traffic analysis. For instance, normalized daily profiles can be used to convert a single peak traffic in a cell of an OD matrix into a curve showing the expected daily traffic variation.

In Section 7, a numerical example based on Metro-Haul network will be presented to illustrate the application of the described methodology.

In the remaining of this chapter, we focus on briefly describing the main characteristics of sets *F* and *P* for both background and B5G services considered in this work.

6.3 Background Services

In this section we present some significant examples of services that generate background traffic without claiming to be exhaustive. In a very similar way, other services can be modelled. The Web browsing service, the direct communication service, and the use of content on a Content Delivery Network (CDN) are taken into consideration and illustrated hereafter.

6.3.1 Web browsing

In the case of Web browsing, a user, fixed or mobile, benefits from various types of content (web pages, text, sound, images) that can be accessed on DC (servers) at various levels of the network (local, regional, national, or external to the operator's network). The accessibility of the contents, and the formation of the related traffic flows, depend on the architectural scenario (centralized, semi-distributed and distributed) and on the content caching strategy, which is modelled through the percentage of content accessible at various levels. In Web browsing, flows seen from the user's side are quite unbalanced, in the sense that the Downlink component is typically much greater than the Uplink.

In typical content web browsing services, we can assume that traffic can be exchanged (when needed) with local caches in the reference Regional CO only (not with other regional COs). On the contrary, at National level traffic is exchanged with caches in all the National COs. Moreover, web traffic is exchanged also with external networks through a gateway. The amount of traffic will depend on the percentage of traffic exchanged at different levels (Local, Regional National, External). The set *P* to be defined in step 1 of the proposed methodology for content web browsing service contains the following parameters:

- ***p1.*** Uplink (UL) traffic per user (in b/s) and type (fixed, mobile)
- ***p2.*** Downlink (DL) traffic per user (in b/s) and type (fixed, mobile)
- ***p3.*** % of traffic exchanged within local access CO
- ***p4.*** % of traffic exchanged within reference regional CO
- ***p5.*** % of traffic exchanged within reference national CO
- ***p6.*** % of traffic exchanged with other national CO
- ***p7.*** % of traffic exchanged with external network (gateway)

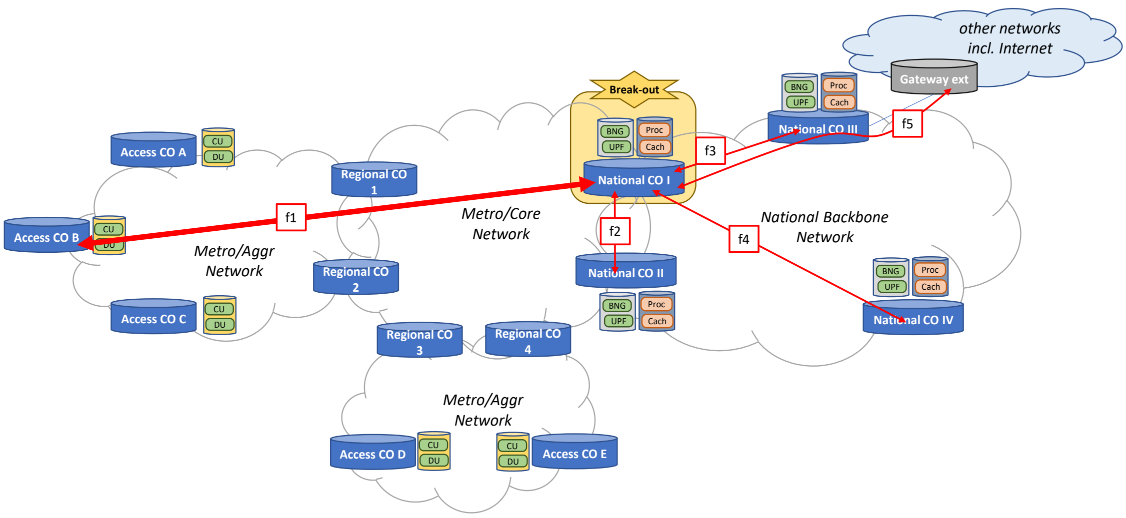

Fig. 6.2. Web browsing – Centralized

The set of flows *F* generated under the centralized scenario are depicted in Fig. 6.2. For simplicity, the traffic flows that remain within a CO i.e., to reach telco and/or service nodes, are not shown. First, all the traffic must reach the break-out point at reference national CO (labelled as flow *f1*). Then, part of the traffic remains in the national CO (not represented) and part is exchanged with other national COs (*f2* to *f4*). Finally, part of the traffic reaches the gateway (*f5*).

When a semi-distributed scenario is considered, flows are generated as shown in Fig. 6.3. With respect to the centralized scenario, now *f1* terminates at the reference regional CO, as well as new flows from such break-out point to all national COs (from *f2* to *f5*) are created.

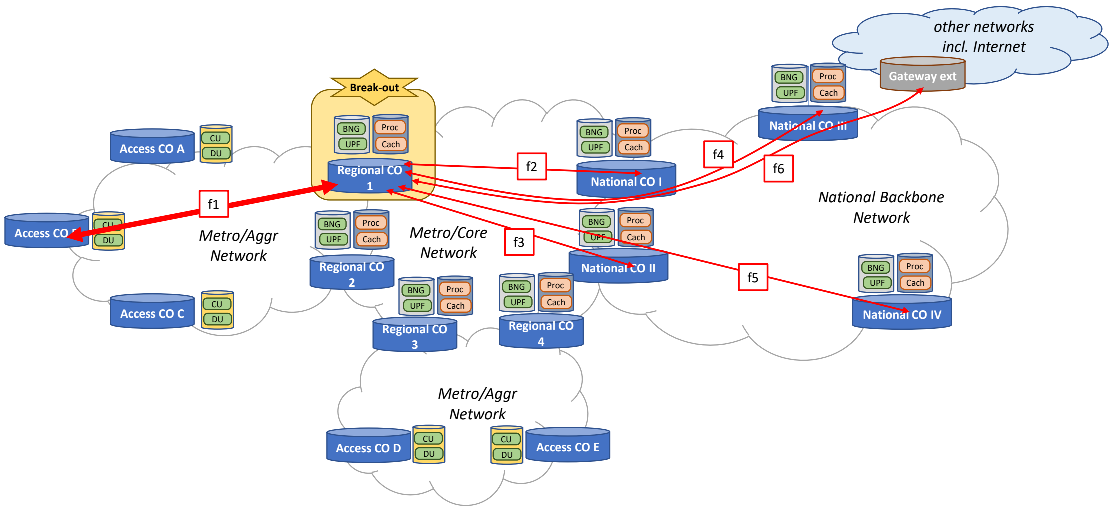

Fig. 6.3. Web browsing – Semi-distributed

Finally, under a distributed scenario, flows are generated as in Fig. 6.4. Since typically most of the traffic remains within breakout CO (this happens in all the scenarios for web browsing) the total traffic exchanged between remote COs is smaller than in previous scenarios. However, flows between reference access and all National COs are generated and therefore, they cross three different segments.

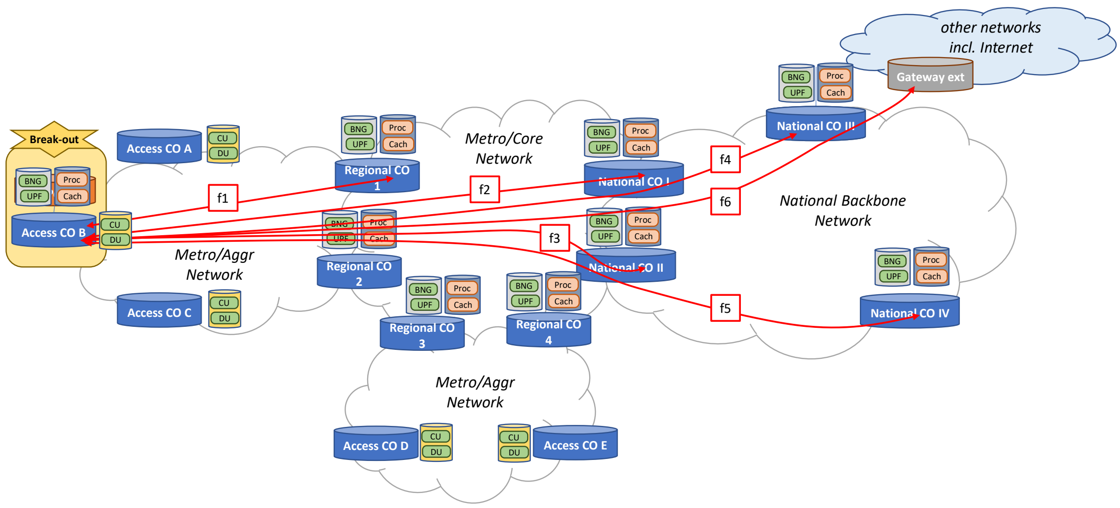

Fig. 6.4. Web browsing – Distributed

6.3.2 Direct communications

The generic direct communication service concerns the direct interaction of customers who communicate with each other to exchange data or for multimedia communication such as videoconferencing (in the future holoconference). In this case the hypothesis is that the Uplink and Downlink flows are balanced. Note that regardless of the position of the interlocutors, the traffic must be processed at the closest break-out point of the network, so that for the same traffic exchanged between end users, the scenarios (centralized, semi-distributed and distributed) contribute to determine the distribution of traffic in the various network segments.

Independently from the position of break-out point, all traffic exchanged outside the Metro Core network is assumed processed at packet level in the Reference National CO (no bypass allowed). This simplifies the model and can also be considered reasonable from a general point of view for traffic management between metro domains.

Then, the specific parameters *P* for direct communications service are:

- ***p1.*** Uplink (UL) traffic per user (in b/s) and type (fixed, mobile)
- ***p2.*** Downlink (DL) traffic per user (in b/s) and type (fixed, mobile)
- ***p3.*** % of traffic directly sent to same metro-core network
- ***p4.*** % of traffic directly sent to reference regional CO
- ***p5.*** % of traffic exchanged between reference regional CO and other regional COs
- ***p6.*** % of traffic exchanged between reference regional CO and reference national CO
- ***p7.*** % of traffic directly sent to reference national CO
- ***p8.*** % of traffic exchanged between reference and other national COs
- ***p9.*** % of traffic exchanged between reference national CO and gateway

The set of flows *F* for centralized, semi-distributed, and distributed scenarios are depicted in Fig. 6.5, Fig. 6.6, and Fig. 6.7, respectively.

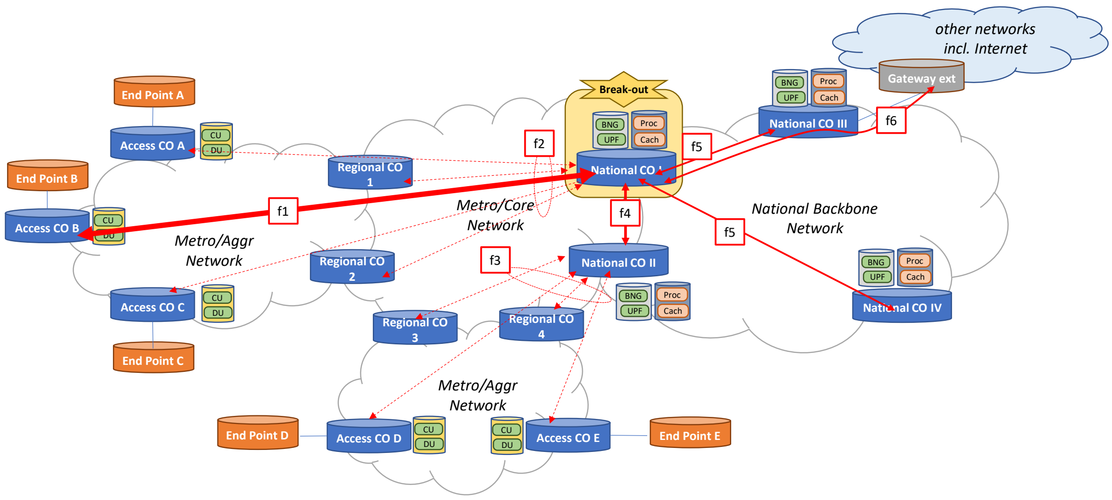

Fig. 6.5. Direct communications – Centralized

In a centralized scenario (Fig. 6.5) all traffic collected by an Access CO (Access CO B, flow f1) must reach the break-out at National level (National CO I, the Reference National for Access CO B). Traffic reaching the reference National CO I is split into many parts: the component exchanged with other COs of the metro that have the same National Reference CO (National CO I, flows f2), the traffic directed to other COs of the metro that have as a reference National node the other National Reference CO (National CO II, flow f4), the traffic exchanged with other National COs (flows f5) and with the gateway (flow f6). Traffic that reaches National CO II (flow f4) is in turn exchanged with Access COs that have National CO II as a National Reference node (flows f3), apart the component terminating in National CO II (the difference between flows f4 and f3). Please note that in building the traffic matrix for the metro network not all the contributions generated by an Access CO and depicted in Fig. 6.5 must be considered. In the example, flow f2 and f3 associated to Access CO B have not to be considered as contributions for the traffic matrix because they are already considered by the model through flows of type f1 generated by other Access COs of the metro network. As far as the contribution of f4 to the traffic matrix, it is assumed to be 50% of the value of the flow because, according to the model, there is a correspondent contribution from access nodes that have National CO II as the National Reference node and that are directed to National CO I to reach Access COs associated with it. The assumption is that 50% of each flow of type f4 from National CO I and National CO II is an approximation deemed acceptable or a model with much more complicated flow weighting calculation would have been required otherwise. The same rule applies for the contribution to the traffic matrix of the backbone of the flows of type f5 from a certain National node, i.e. their contribution is for 50% of their value since there are the contributions of the corresponding flows originating in the others nodes of the backbone and directed to the node in question (in the example the National CO I node). Contribution of flow f8 to the traffic matrix is 100% as external networks connected with gateway does not generate traffic like metro networks attached to National CO nodes (they act simply as external destination; they are not modelled with Access COs generating traffic).

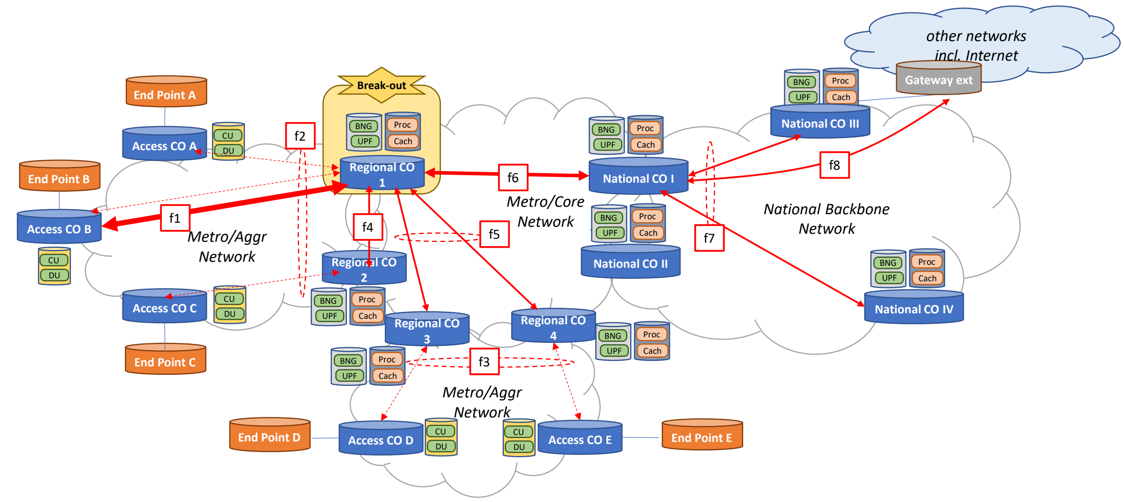

Fig. 6.6. Direct communications – Semi-Distributed

In a Semi-Distributed scenario (Fig. 6.6) all traffic collected by an Access CO (Access CO B, flow f1) has to reach the break-out at Regional level (Regional CO I) and from there routed to the destinations. Flows of type f2 are the components exchanged with Access COs of the same aggregation network, may they belong to Regional CO 1 or Regional CO 2. Flow 4 is the component exchanged between a Regional CO to the other Regional CO taking part of the same aggregation network (in the specific case Regional CO 1 to Regional CO 2) and it concerns, in the example shown, the transit of traffic components from Access COs associated to Regional CO 1 to Access COs associated to Regional CO 2. Then there are flows of type f5 which consider the exchange of traffic between metro aggregation subnetworks of the same metro network: this takes place between regional nodes where the break-out points are located. From them, flows of type f3 are the ones terminated at Access COs end points of the traffic within the aggregation networks. Flow f6 accounts for traffic directed to national backbone and to the gateway which is assumed to transit through the National Reference node. It includes the component of metro traffic from access nodes which have National CO 1 as a Regional Reference node. In the end f7 and f8 have the same meaning as flows f5 and f6, respectively, of a centralized scenario case. For similar reasons as to the ones already exposed above for a centralized scenario, the contribution from flows to the traffic matrix is 100% for flows f1, f6 and f8, while, according the approximation made, the contribution is only 50% for flows f4, f5 and f7. (f2 and f3 do not contribute as they are modelled by traffic generated by Access COs other than Access CO B).

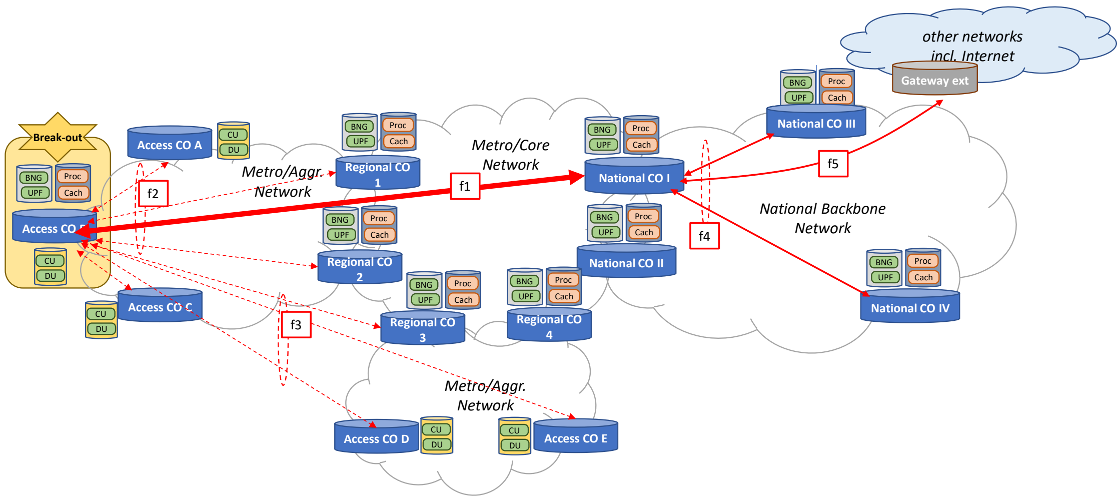

Fig. 6.7. Direct communications – Distributed

In a distributed scenario (Fig. 6.7), all traffic collected by an Access CO (Access CO B, flow f1) is processed by the local break-out point at Access level (Regional CO I) and directly routed from there to the destinations. Flows f2 and f3 model the direct exchanges between Access COs belonging to the metro network: flows of type f2 are the exchange within Access COs of the same aggregation network while flows of type 3 are the exchange with Access COs from other aggregation networks within the metro network domain. Flow 1 between the Access CO and its National Reference node bears all the traffic exchanged with other metro networks (attached to National CO III, National CO IV, etc.) and with the external networks through the gateway. For similar considerations already done for the other two scenarios described above, contributions from flow types to the traffic matrix are 100% of the traffic flow for f1 and f5, and, according to the introduced approximation, 50% of the traffic flow for f2, f3 and f4.

6.3.3 Content delivery network

The CDN service is the typical service for accessing multimedia contents (today typically high-definition video, tomorrow other multimedia formats, including holographic ones) from caches placed at various levels of the network. The CDN service adopts a model similar to that of Web browsing (Section 6.3.1) and differs from it essentially in parameter values (Web and CDN cache have specific distributions and also the flow is markedly at a higher bit rate and more unbalanced in favour of downlink stream for the CDN case).

6.4 B5G-OPEN Services

6.4.1 Digital twin (DT)

A digital twin is the representation of a physical asset, process or system that spans its lifecycle updated from real-time data. The real-time data for the DT can be provided by different objects, such as historical records, sensors, etc. DT is bidirectional as any change to the physical asset should be reflected in the digital twin and vice versa.

One specific example of how a DT can be implemented is by integrating VR/AR devices to generate data which is gathered and sent towards a model to process the information received. Once processed, the data is retransmitted towards the equipment to achieve the optimisations required. If a large number of these devices is used (e.g. >50), the amount of traffic generated will be in the order of gigabits per second for a single node.

The set of parameters *P* that characterise DT traffic are:

- p1. Uplink (UL) traffic per user (in b/s) and type (sensor, AR/VR)
- p2. Downlink (DL) traffic per user (in b/s) and type (computing process, interface, etc.)
- p3. % of traffic directly sent to same metro-core network
- p4. % of traffic directly sent to reference regional CO
- p5. % of traffic exchanged between reference regional CO and other regional COs
- p6. % of traffic exchanged between reference regional CO and reference national CO
- p7. % of traffic directly sent to reference national CO
- p8. % of traffic exchanged between reference and other national COs
- p9. % of traffic exchanged between reference national CO and gateway

The set of flows *f* for this B5G service is sketched in Fig. 6.8, where large UL traffic is generated in access COs where factories are located and forwarded towards the location (or locations) where processing operation (or modelling) is undertaken. In addition, the DL traffic that reaches all the access COs is for control/feedback purposes. The traffic generated by factories and access COs A, B, C and D is aggregated and sent towards the regional CO 1 (flow 1), where possible processing (or modelling) can be undertaken (flow 2). However, the processing can be also undertaken in a national CO, therefore, the aggregated traffic (flow 2) can be sent towards this national backbone area. Once the processing of the data occurred, feedback is sent towards the regional CO 1 (flow 3) and distributed across different Regional and Access COs (flow 4).

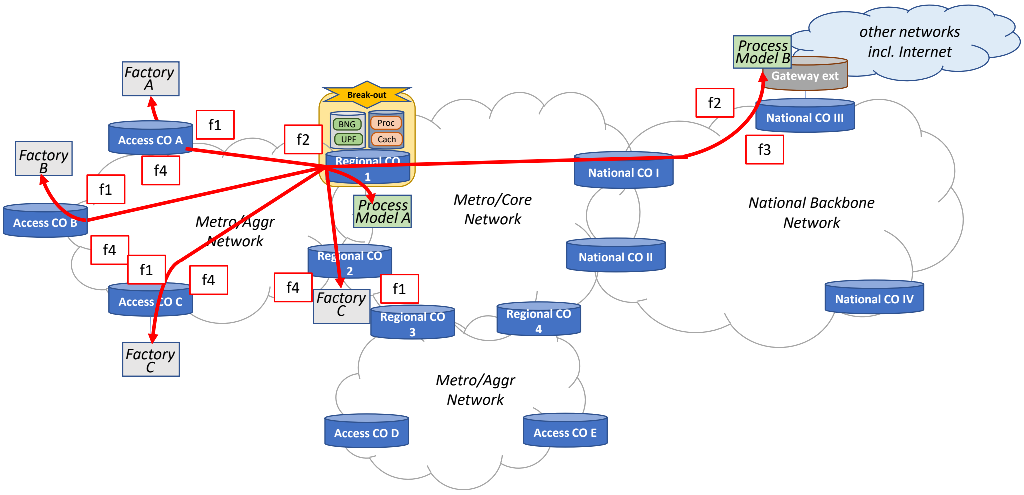

Fig. 6.8. DT traffic Flows in a semi-distributed scenario

6.4.2 Volumetric video (VV)

Volumetric video is a technique that captures a three-dimensional space object. Rather than having a flat image built using two axis, volumetric video captures the light from all angles. Using technology advancements, 3D video can be captured by using 3 axes rather than the 2 used in regular video (X, Y and Z, defining the volume of the image) hence the name volumetric video.

VV involves setting cameras or sensors at different positions over a “capture stage”, covering it from as many different angles as possible. The reconstruction process uses algorithms to produce a set of 3D models that can be arranged as a sequence. There are multiple different workflows that can be used to generate volumetric videos. In addition, equipment used to produce a volumetric capture can vary on different factors (quality, cost, storage space etc.). VV generates large amounts of data from hundreds of Megabits to Terabits per second.

The set of parameters *P* that characterise a volumetric video are:

p1. Uplink (UL) traffic per video area rig (in Mb/s).
p2. Downlink (DL) traffic per video user (in Mb/s).
p3. % of traffic exchanged within local access CO
p4. % of traffic exchanged within reference regional CO
p5. % of traffic exchanged within reference national CO
p6. % of traffic exchanged with other national CO
p7. % of traffic exchanged with external network (gateway)

The scenario considered in this VV delivery service (depicted in Fig. 6.9) is suited for an enhanced user experience in events such as e.g. live sport. The scenario of this B5G-OPEN service includes the collection of data traffic in the Access CO where 2K/4K cameras are used for the volumetric video production chain (Access CO B, flow f1). The processed encoded traffic is sent towards the National CO III for compute processes, such as rendering and encoding (flow f2) and after this stage, the traffic is sent to the Regional CO 1 (flow 3) for delivery distribution to different access and end points (flow 4). This scenario is similar to the CDN mass market service described in Section 6.3.3. However, the values of the parameters will be different, since parameters for DL are expected to be higher. Therefore, this scenario represents a highly unbalanced use case since DL traffic is much bigger than UL traffic.

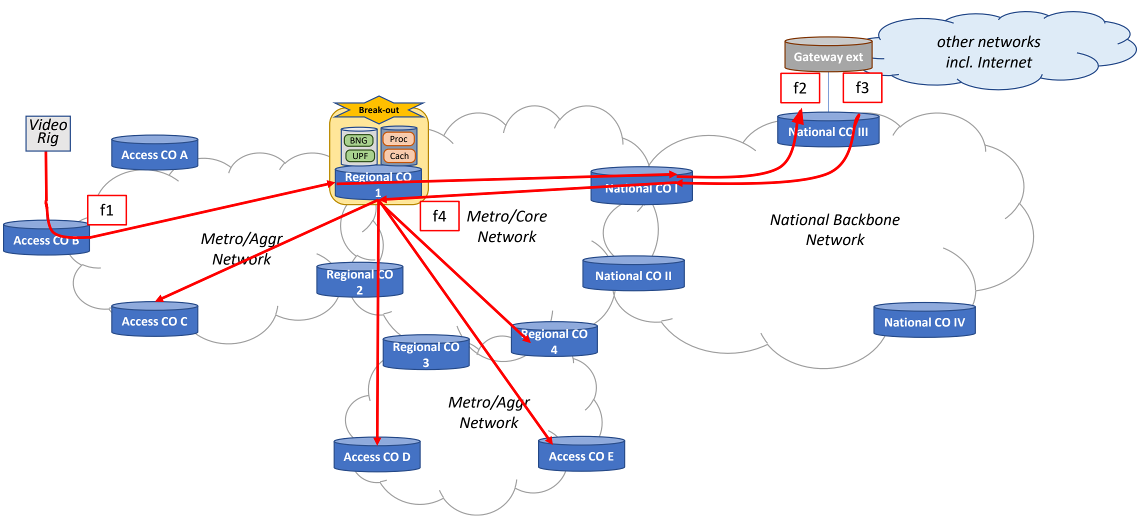

Fig. 6.9. VV traffic Flows in a semi-distributed scenario

7 DIMENSIONING DATA

7.1 REFERENCE NETWORK TOPOLOGY

Fig 7.1 shows the topology used for the ongoing numerical study, in line with the description and assumptions in Section 2. Specifically, it consists of 4 MAN networks, each consisting of: *i*) 6 horseshoe subnetworks connecting a number of access COs with both ends in either a regional or national CO; *ii*) a mesh subnetwork interconnecting regional and national COs (Fig 7.1a).

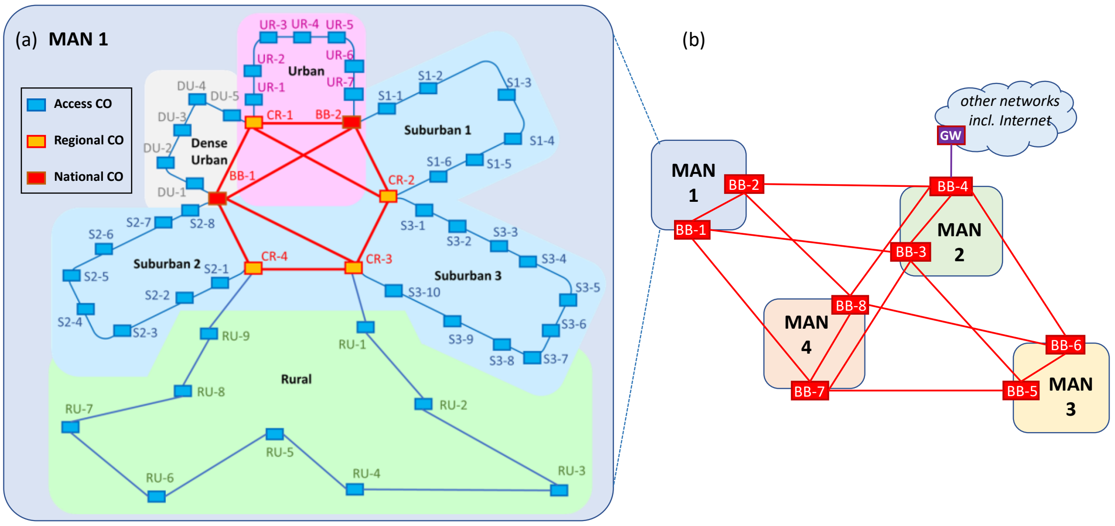

Fig. 7.1. Reference network topology

MAN details in terms of number of nodes, links, and other characteristics are provided in Table 7-1. The interconnection between MANs is assumed to be done at the core level by means of a mesh topology connecting national COs (Fig 7.1b).

Table 7-1. MAN parameters

	Subnetwork	Type	Number of nodes	Number of links	Average link length [km]	network diam. / horseshoe length [km]
	Metro Core	**Mesh**	**6**	**9**	**10.6**	**21.6**
Metro Aggregation	*Dense Urban*	*Horseshoe*	7	6	2.5	15.1
	Urban	*Horseshoe*	9	8	4.2	34.0
	Suburban 1	*Horseshoe*	8	7	8.0	55.8
	Suburban 2	*Horseshoe*	10	9	9.5	85.1
	Suburban 3	*Horseshoe*	12	11	9.6	105.3
	Rural	*Horseshoe*	11	10	16.4	163.6

7.2 REFERENCE NETWORK AND MASS MARKET TRAFFIC PARAMETERS

The numbers presented in this subsection have been obtained from current available information provided by operators, properly anonymized. Moreover, some of the parameters are conveniently scaled to illustrate the expected situation when the main technological advances to be demonstrated and prototyped in B5G-OPEN project will be commercially available. In addition, parameters that define the amount of traffic processed at a given level of

COs (Scenario parameters, Tables 7-3 and 7-4) are assigned to balance the cost of the caching and of the transport but without performing an actual optimization.

Table 7-2 shows an extract of input parameters characterizing few representative COs in Fig. 7.1 in terms of its role, geotype and access network items collected: households for fixed, cell sites for mobile (divided between macro and small cell sites).

Table 7-2. CO characterization

Node Code	CO type	Geotype	Households	Macro cells sites	Small cell sites
BB_01	National CO	Dense Urban	14700	13	52
CR_01	Regional CO	Urban	17500	9	36
DU_01	Local CO	Dense Urban	10600	11	44
S1_06	Local CO	Suburban	8800	7	28
RU_04	Local CO	Rural	4100	4	0

The number of Households associated with a node (each node has its own) drives the amount of fixed traffic generated by the node. To compute the traffic generated by mobile users, we define the number of cell sites collected by a node and the mobile active users per site. Mobile active users represent the mobile users registered on a mobile site that potentially generate traffic in the busy hour.

In the example reported in this Deliverable, 200 and 50 active users are considered for each macro cell site and small cell site services, specifically. The percentages of active users, defined for each service (Table 7-3), allow to compute the active users that generate traffic for the specific service.

Table 7-3. Mass market service parameters

Service	Access type	% of active users	*p1* [Mb/s]	*p2* [Mb/s]
Web browsing	*household*	20%	10	100
	macro cell	50%	2.5	25
	small cell	75%	2	20
Direct communication	*household*	10%	100	100
	macro cell	20%	20	20
	small cell	30%	20	20
CDN	*household*	25%	2	100
	macro cell	15%	0.5	25
	small cell	10%	0.5	25

Finally, the following tables present the relevant parameters of every mass market service for each considered scenario.

Table 7-4. Scenario parameters – Web browsing

Scenario	*p3*	*p4*	*p5*	*p6*	*p7*
Centralized	0%	0%	50%	30%	20%
Semi-Distributed	0%	40%	10%	30%	20%
Distributed	30%	10%	10%	30%	20%

Table 7-5. Scenario parameters – CDN

Scenario	p3	p4	p5	p6	p7
Centralized	0%	0%	70%	30%	0%
Semi-Distributed	0%	50%	20%	30%	0%
Distributed	20%	30%	20%	30%	0%

Table 7-6. Scenario parameters – Direct Communications

Scenario	p3	p4	p5	p6	p7	p8	p9
Centralized	0%	0%	0%	0%	100%	30%	20%
Semi-Distributed	0%	100%	40%	50%	0%	30%	20%
Distributed	50%	0%	0%	0%	50%	30%	20%

7.3 Assumptions for B5G-OPEN Services Traffic Generation

7.3.1 Digital twin (DT)

For the sake of simplicity, hereafter we assume that parameters from p3 to p9 can be assumed to be the same that that of direct communications services (Table 7-6). Regarding UL and DL traffic values (i.e. p1 and p2), we consider video-cameras as reference device. Then, we can assume different levels of service penetration by assuming a different number of factories and quality of the streams. As an illustrative example, we could consider:

- *Low penetration*: one digital factory per 10,000 inhabitants, each factory with 300 cameras operating and recording 24x7, that is, generating and injecting 300 x 8 Mb/s video streams (Full HD quality, 1080p) into the network, i.e. 2.4 Gb/s deterministic (no variability). This implies 0.24 Mb/s per inhabitant.
- *High penetration*: one digital factory per 1,000 inhabitants, each factory with 500 cameras operating and recording 24x7, that is, generating and injecting 500 x 40 Mb/s video streams (4K quality) into the network, i.e. 20 Gb/s deterministic (no variability). This implies 20 Mb/s per inhabitant.

7.3.2 Volumetric video (VV)

Similar to DT, we assume that parameters from p3 to p7 are the same as those of CDN services (Table 7-5). Then, p1 and p2 can be obtained assuming that this service behaves similarly to other well-known entertainment video services, such as IPTV. Following EU estimates, the average amount of IPTV content watched per household is 235 minutes per day (i.e. 4 hours), or one sixth of the day (i.e. 1/6 is also the probability that a user is active in the service). Under the assumption that users are uncorrelated and may be using that service at any time of the day, and following the assumption of an ON/OFF process which is active (ON) with probability 1/6 and inactive (OFF) with probability 5/6, the average and standard deviation for IPTV traffic per user (DL) would be 0.8 Mb/s and 1.86 Mb/s, respectively.

Following the same methodology as for DT, we can generate different levels of service penetration for the VV case:

- *Low penetration*: 10 minutes per day per user on average, with a service bitrate of 1,000 Mb/s (high-quality VV with 32 cameras recording at 4K). Assuming a reference value of 18,000 users, average and standard deviation of DL traffic is 0.45 Tb/s and 11.1 Gb/s, respectively.
- *High penetration:* 100 minutes per day per user on average, with a service bitrate of 1,000 Mb/s (high-quality VV with 32 cameras recording at 4K). Assuming a reference value of 18,000 users, average and standard deviation of DL traffic is 4.5 Tb/s and 34.1 Gb/s, respectively.

7.4 Case Study: Node Traffic Dimensioning

A quantitative case study was developed to identify the traffic handled by nodes at various network levels and in different scenarios using as reference network for the numerical evaluation the network presented in Section 7.1.

The analysis was conducted considering the centralized (BNG-UPF at National CO) and semi-distributed (BNG-UPF at Regional CO) architectural scenarios since the distributed scenario was deemed at this stage unsuitable for DT and Volumetric Video services. Subsequent analyses will be extended to also consider the distributed scenario.

The traffic offered to the network is assumed to be generated by a mix of mass market services and B5G-OPEN use cases. With respect to the mass market traffic, the reference numbers presented in Section 7.2 are considered for the short-term period. Aiming at generating traffic increasing beyond that short-term, a reasonable CAGR of 30% is considered.

For DT and VV, the parameters used are the ones presented in Table 7-7 and Table 7-8, respectively. These numbers were obtained combining the assumptions introduced in Section 7.3 with the number of residential users as considered in the reference example.

Table 7-7. VV parameters for different adoption scenarios

Adoption scenario	% of Rig sources	*p1* UL [Mb/s]	% of users	*p2* DL [Mb/s]
Low Penetration Standard Bandwidth	40%	100,000	10%	420
High Penetration Standard Bandwidth	100%	100,000	100%	420
High Penetration High Bandwidth	100%	200,000	100%	1,200

Table 7-8. DT parameters for different adoption scenarios

Adoption scenario	% of factories	*p1* UL [Mb/s]	*p2* DL [Mb/s]
Low Penetration - Low bitrate	10%	2,400	24
High Penetration – Standard bitrate	100%	20,000	200
High Penetration - High bitrate	100%	100,000	1000

Adding mass market and B5G-OPEN adoption scenarios, we considered the following three combinations for the Volumetric Video and Digital Twin for the following dimensioning studies:

- Combination 1 (Short-term)
  - Mass market Y0, i.e., values in Section 7.2
  - VV: Low Penetration – Standard bitrate
  - DT: Low Penetration – Low bitrate
- Combination 2 (Medium-term)
  - Mass market Y3 = Y0 x $(1.30)^3$
  - VV: High Penetration – Standard bitrate
  - DT: High Penetration – Standard bitrate
- Combination 3 (Long-term)
  - Mass market Y6 = Y0 x $(1.30)^6$
  - VV: High Penetration – High bitrate
  - DT: High Penetration – High bitrate

Table 7-9 shows the amount of traffic generated at each access CO. With the assumptions made in the three scenarios and for the services considered, the nodes collect from access about 0.5-2.4 Tb / s of traffic in the first combination, 3-12 Tb / s of traffic in the second and 8-33 Tb / s in the third. Between UL and DL the dominant component is the DL one (about 90% of the total) since the services that have the greatest impact on the overall traffic are web browsing and CDN for mass market and Volumetric Video for B5G services, and all of them are very unbalanced in favour of DL component.

Table 7-9 Traffic generated by a node (averaged per geotype) in three combinations of MM; VV and DT traffic scenarios.

	Combinations of traffic scenarios					
	Combination 1		Combination 2		Combination 3	
Geotype	DL + UL [Tb/s]	% DL	DL + UL [Tb/s]	% DL	DL + UL [Tb/s]	% DL
Dense Urb.	1.65	87%	8.37	91%	22.93	90%
Urban	2.39	87%	12.19	91%	33.44	90%
Suburban	1.17	87%	6.01	91%	16.48	90%
Rural	0.58	87%	3.05	91%	8.38	90%

To show the impact of the traffic in case of the combinations of traffic on the entire network architecture some diagrams are reported in Fig 7.2, Fig. 7.3 and Fig. 7.4. The diagrams show the amount of traffic exchanged at Access, Regional, National and gateway level for the two architectural options characterized by centralized UPF-BNG and semi-distributed UPF-BNG.

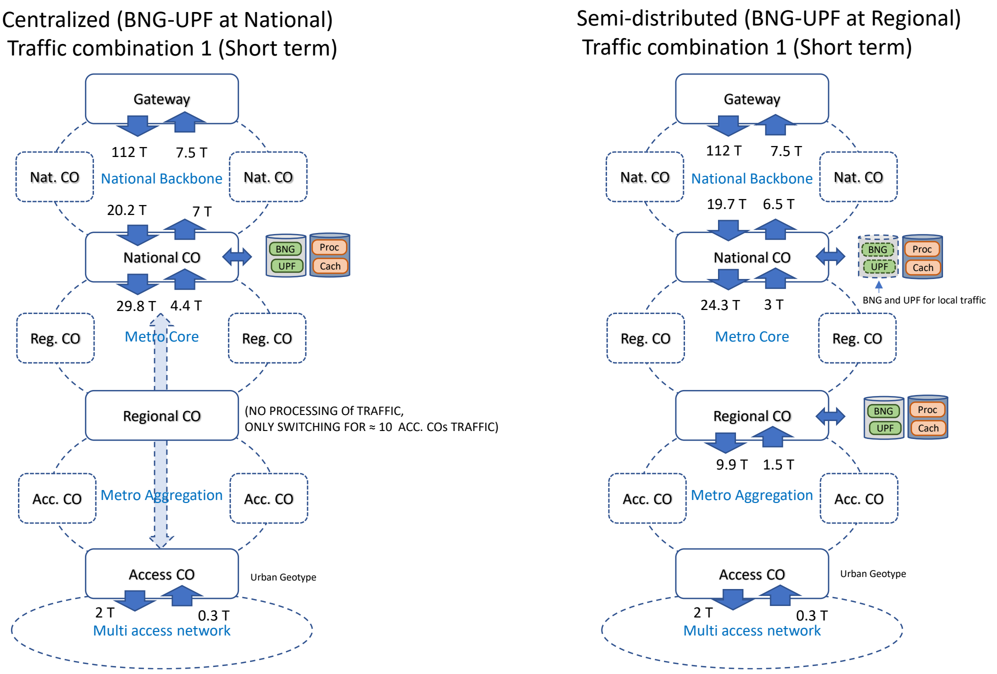

Fig. 7.2. Traffic exchanged at different network-segments for traffic combination 1 (Short term) and for the two architecture options centralized and semi-distributed.

On the left side of Fig. 7.2 the values of total traffic processed by the nodes in centralized case (UPF-BNG at National) and with the traffic scenario corresponding to combination 1 (short term) are represented.

The traffic collected in the multi access network including fixed and mobile for residential and business customers is 2 Tb/s in UL and 0.3 Tb/s DL (according to geotype classification the values shown are the average values of an urban node).

The traffic collected in access in this case must reach the national nodes where it is processed before being forwarded to the destinations. In this case, the regional node does not process the traffic and it must ensure only the switching of the transiting flows. The switching can be done at the electrical or optical layer, depending on the amount of traffic and networking implementation choices not considered here. In this scenario, the traffic processed by the national nodes, on average, is about 30 Tb/s DL and 4.4 Tb/s UL on the metro side and 20 Tb/s UL and 7 Tb/s DL on the national backbone side. In total, the gateway pushes into the backbone network about 112 Tb/s and receives 7.5 Tb/s of traffic.

On the right side of Fig. 7.2 the traffic values for flows in the semi distributed architecture (BNG-UPF at Regional). The traffic collected by the access is the same but in this case the traffic is processed at the Regional CO before reaching its destination. The amount of traffic exchanged with the Access nodes (metro aggregation) by Regional nodes and to be processed by UPF-BNG functions is about 10Tb/s UL and 1.7 Tb/s DL. Part of the traffic processed by Regional Nodes is not forwarded to the national nodes (it is served by the processing and/or caching components of the local service node) and this is the reason why the National nodes exchange about 24 Tb/s DL traffic (3 Tb/s UL) instead of 30 Tb/s of the centralized architecture case. The values of traffic exchanged by the National CO Backbone side is about the same as in the centralized case (the small difference is due to the direct interaction of the regional nodes with the national ones in the semi-distributed case) while the traffic to and from the gateway in the backbone is exactly the same for the two architectural hypotheses.

In Fig. 7.3 and Fig. 7.4 the values of total traffic at different level of the topology are reported for traffic combination 2 and 3 respectively. For Centralized scenario the value of DL traffic of National nodes at the metro core side grows from 30 Tb/s of Combination 1 (short term) to 160 Tb/s of Combination 2 (medium term) and to 430 Tb/s of Combination 3 (long term). Similarly, the UL traffic at the national backbone side grows from 30 Tb/s of Combination 1 to 140 Tb/s of Combination 2 to reach 400 Tb/s for Combination 3. This means that National nodes should be able to switch and process traffic of the order of many tens of Tb/s in the short term, hundreds of Tb/s in the medium term and one or few Pb/s in the long term.

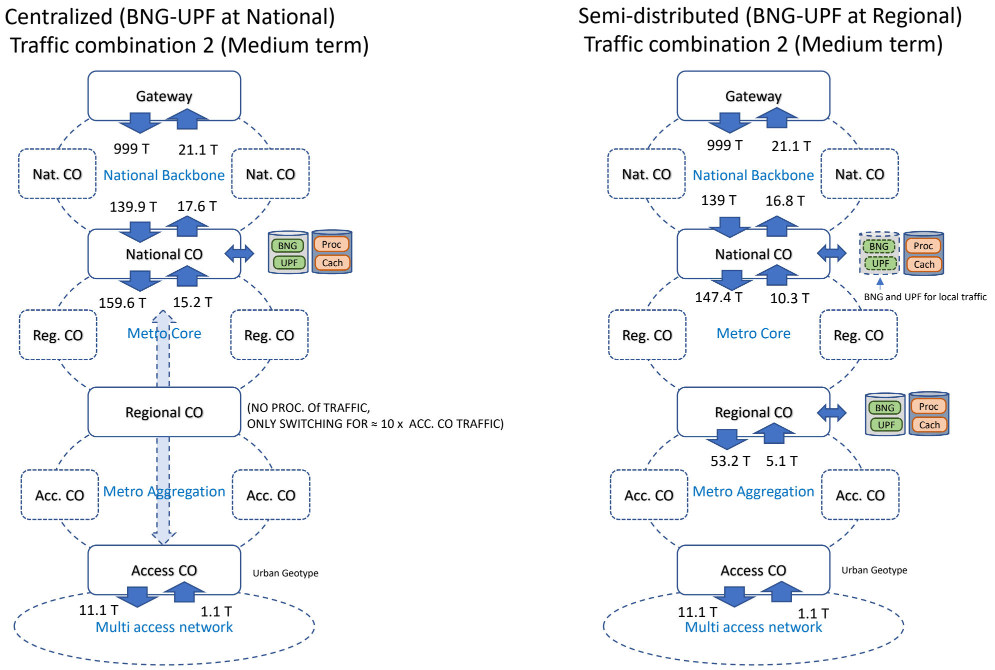

Fig. 7.3. Traffic exchanged at different network-segments for traffic combination 2 (Medium term) and for the two architecture options centralized and semi-distributed.

For a semi-distributed scenario, the values of traffic switched and processed by National nodes are slightly lower while Regional Nodes should be able to switch and process few tens of Tb/s in combination 1, hundred Tb/s for combination 2 to a few hundreds of Tb/s for combination 3.

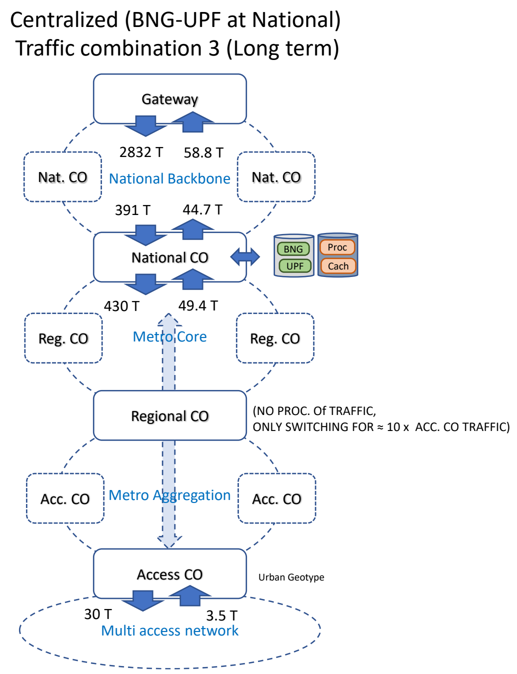

Fig. 7.4. Traffic exchanged at different network-segments for traffic combination 3 (Long term) and for the two architecture options centralized and semi-distributed.

8 PERFORMANCE KPIS

The Performance KPIs that 5G-PPP are working on are collected in the group's KPI cartography:

1. User Data Rate
2. Peak Data Rate
3. Capacity
4. Latency
5. Device Density
6. Mobility
7. Reliability
8. Availability
9. Position Accuracy (Location)
10. Service Deployment Time
11. Energy Efficiency
12. Network Management (CAPEX/OPEX)

There are different problems with this list:

- There is no definition of each KPI, so each EU Project may have a different understanding
- 5G-PPP takes a mobile network centric view so some KPIs are not applicable to fibre networks
- Some KPIs refer to mobile devices or air interface without being explicit about it

The consequence is that when collating all KPIs from different projects, their comparison is made very difficult.

8.1 FIXED TRANSPORT NETWORK SPECIFIC KPIS

B5G-OPEN proposal took a document that was being prepared in the 5G-PPP Steering Board during 2019 on specific KPIs for transport networks (Table 8-1) and used it to derive the project KPIs presented in the project proposal.

Table 8-1. Transport Network Specific KPIs (source: 5G-PPP SB in 2019)

	Target KPI	Current (2020)	Short-term Evo (~2025)	Mid-term Evo (~2028)	Long-term Evo (~2030)
Metro/ Core	Spectrum[1]	5 THz	15 THz	30 THz	50 THz
	Port speed[2]	400 Gb/s	1.6 Tb/s	3.2 Tb/s	6.4 Tb/s
	Bandwidth[3]	< 75 GHz	< 150 GHz	< 300 GHz	< 600 GHz
	Line capacity[4]	25 Tb/s	200 Tb/s	600 Tb/s	1.5 Pb/s
	Node capacity[5]	150 Tb/s	1.2 Pb/s	3.6 Pb/s	9 Pb/s
Access	PON speeds	10 Gb/s	50 Gb/s	100 Gb/s	> 200 Gb/s
	User data rate[6] (consumer)	100 Mb/s	~ 1 Gb/s	> 2.5 Gb/s	> 5 Gb/s
	User data rate[6] (business)	1 Gb/s	~ 10 Gb/s	> 25 Gb/s	> 50 Gb/s
	Latency[7]	< 1 ms	< 100 µs	< 10 µs	< 1 µs
Other	Power consumption[8]	100% (base)	40 %	30 %	20 %
	Service provisioning	Hour	Min	Second	Sub-second
	Network operations	Reactive	Intent-based, proactive	Self-diagnosing	Self-optimizing

1. 25% CAGR, in line with conservative traffic predictions
2. Extrapolation of Ethernet roadmap
3. Using 400G DP-16QAM as baseline
4. 50% CAGR, in line with internet content provider traffic predictions. Assumes exploitation of frequency and space domain
5. Based on degree 4 node with 50% local add/drop
6. 50% CAGR based on Nielsen's law
7. Excluding propagation delay
8. 15% reduction per Gb/s p.a., extrapolated from past transponder data

8.2 B5G-OPEN KPIs

B5G-OPEN KPIs were identified from the objectives as set out in the proposal, which were derived from Table 8-1. The objectives and related KPIs are shown next:

Objective 1: *Design a cost-effective, energy-efficient, programmable, and disaggregated end-to-end optical network and which removes terminations between network domains, thus drastically reducing electronic hops, to provide an optical network continuum between access, metro, and core segments*

- KPI: none associated

Objective 2: *Design and validation of an innovative optical transport infrastructure supporting MB connectivity and transparent network continuum from User Equipment to DC*

- KPI 2.1: Reduction of total power consumption from 30% to 50% with respect to SoA architectures (e.g. H2020 METRO-HAUL results) and legacy solutions
- KPI 2.2: CAPEX reduction above 50% in the end-to-end "domain-less" architecture relative to fixed-domain metro-access/regional/core segments
- KPI 2.3: Increase of 10× in-service bandwidth w.r.t. currently deployed C-band transport solutions

Objective 3: *Design of novel optical network devices for switching, amplification and transmission to enable B5G-OPEN solutions and demonstration*

- KPI 3.1: MB Optical Switching Matrix with bandwidth covering S, C, L and O-band, supporting multiband operation on 50-100 GHz-grid, reducing the overall switching time to < 1 ms, enabling multiband reconfiguration with added flexibility (dynamicity) in order to improve effective and agile usage of the traffic pipes. The modularity of the architecture will help to scale the node capacity to 3 Pb/s in a pay as it grows approach. Moreover, photonic integrated technology improves the power consumption by a factor of >4 ×.
- KPI 3.2: MB filter-less add-drop stage with bandwidth covering at least S, C, L and O-band, supporting flex-grid multiband operation based on passive components and thus negligible power consumption.
- KPI 3.3: MB amplification with cumulative gain bandwidth of at least three times the bandwidth of SoA EDFAs, gain flatness sufficient to allow four transmission spans without gain equalization, and gain control response time in the millisecond range.
- KPI 3.4: MB transceivers: Increase the capacity of SoA transceivers up to 2× - 4× by exploiting multiple transmission bands while enabling appropriate slice/band selection according to the network path. Pluggable solutions fully integrated within the white box enabling the removal of stand-alone network elements (e.g. xPonders, OLTs, etc.).

Objective 4: *Design and validation of next-generation optical access & X-Haul for B5G applications enabling massive cost-efficient 5G and Li-Fi small cell deployment*

- KPI 4.1: 50% CAPEX reduction in the X-Haul infrastructure compared to NG-PON2, by leveraging on open disaggregated solutions over MB, pluggable technology, and avoiding stand-alone OLT/SBT
- KPI 4.2: 100x offered capacity increase of fixed-line systems compared to NG-PON2 by leveraging on standardized cost-effective 100GHz channel spacing technology and pay-as-you-grow strategy for MB
- KPI 4.3: 50% energy reduction in small cell deployments as of today, by leveraging on power efficient Li-Fi small-cells and AI-based throughput optimization algorithms
- KPI 4.4: LiFi handover: QoS-guaranteed handover with minimum throughput higher than 50% of the capacity by predicting the mobility and anticipating flow rerouting and parallel delivery to adjacent APs. In case of blockage of the line-of-sight link, the auto-reconnection time < 2× blockage period.

Objective 5: *Development of an end-to-end monitoring platform covering the optical MB transmission, switching and the packet layer*

- KPI 5.1: 10× more physical monitored data than what is today available in the field
- KPI 5.2: 20% OpEx reduction (in combination with O8 and ZTN) by minimizing the power consumption impact of this massive new monitoring platform
- KPI 5.3: Accurate measurements over different bands, e.g. < 1.5 dB uncertainty of OSNR measurements

Objective 6: *Design, implementation, and validation of an operating system for the novel network elements*

- KPI 6.1: Flow adaptation/control/monitoring capabilities in the microseconds time scale, enabled by AI prediction and wire-speed P4 operations with no SDN Controller intervention
- KPI 6.2: Service Provisioning. Multi-vendor operations through fully specified models and APIs, enabling seamless support of optical adaptation functionalities within the packet-optical white box
- KPI 6.3: 50% CAPEX reduction by avoiding node solutions entirely designed for the optical market while leveraging and enhancing white box designed for the much wider computing market

Objective 7: *Design, implementation and validation of the service orchestration and infrastructure control system*

- KPI 7.1: High level service provisioning (e.g. interconnected cloud native functions and containers) relying on low level service setup performed in the sub-second time scale (data connectivity services, leveraging on the MB fully integrated packet-optical infrastructure and supported predictive capabilities)
- KPI 7.2: Reduction on the average setup time of connectivity service by 30% compared to serialized provisioning, exploiting approaches relying on parallelism and concurrency
- KPI 7.3: 10× number of controlled devices, based on advanced SDN deployments with microservice-based lightweight virtualization and hierarchical arrangements and device / node abstraction

- KPI 7.4: 10× rate of end-to-end provisioning supported services (e.g. number of requests per hour) leveraging on telemetry-empowered SDN Controller communication across multiple domains of visibility and cluster-based deployments for load sharing between controllers

Objective 8: *Build a framework for an AI-assisted autonomous and dynamic network supporting real-time operations and ZTN*

- KPI 8.1: Speed of decision-making in the sub-second scale by placing the intelligence near the devices, applying advanced AI/ML techniques, accurate model training based on simulation tools, and knowledge sharing among controllers
- KPI 8.2: Reduce overheads/overprovision by >20%, by proactively adapting the capacity to the demand
- KPI 8.3: Reduce OpEx by >20%, by increasing autonomous operations and reducing manual intervention
- KPI 8.4: Improve and guarantee service and network availability (> 6x9s availability will be reached by combining MB and PtMP with anticipated degradation detection and proactive decision making).

Objective 9: *Influence major vendors and service providers to adopt B5G-OPEN principles*

- KPI: none associated.

8.3 Definition of Performance KPIs & Cartography

Although Table 8-1 lists a number of performance KPIs specific to fixed transport networks, they still lack clarity. Table 8-2 defines the KPIs in a more specific way.

Table 8-2. Definition of Transport Network Specific KPIs

	Target KPI	Definition
Metro/ Core	Spectrum	Fibre Spectrum (1260nm – 1625nm); C = ~4 THz; C+L = ~11 THz; S+C+L = ~21 THz; O+E+S+C+L = ~53 THz; Fibre spectrum bands where optical channels can be allocated anywhere in the network optical layer
	Port speed	Port line rate per optical carrier in a transmission system (min. 20 km)
	Bandwidth	Optical channel baud rate in a transmission system (min. 20 km)
	Line capacity	Total fibre transmission capacity in a transmission system (min. 20 km)
	Node capacity	Total maximum throughput of a network node including the Add/Drop traffic
Access	PON speeds	Aggregated capacity in a system over a P2MP ODN (e.g. TDM-PON)
	User data rate (consumer)	Residential service peak rate
	User data rate (business)	Business service peak rate
	Latency	Half the Round-Trip Delay between the Access Point and the VM where the service application is hosted excluding fibre propagation time
Other	Power consumption	Relative power consumption reduction in optical transponders per Gb/s with respect to optical systems in 2020
	Service provisioning	Total time to set up application service between UE and VM where the application is hosted
	Network operations	Operation model to maximise the utilisation of installed capacity in the network and minimise operational expenditure

We can now connect the project KPIs as defined within the objectives with the fixed transport network KPIs (Table 8-2) and the current 5G-PPP KPI cartography to which the B5G-OPEN specific KPIs will contribute (Table 8-3).

Table 8-3. B5G-OPEN KPIs Cartography

Target KPI	**Relation with Table 8-1**	**Relation with 5G-PPP KPI Cartography**	**B5G-OPEN Objectives (Table 8-1 & Long-Term Objectives Associated KPI)**	**KPI#**
Service Bandwidth	Port speed, User data rate	User & Peak data rate	10x wrt C-band only	2.3
MB Optical Components	Spectrum, Node capacity	Capacity	Switching Matrix, Add/Drop, Amplifier, Transceiver with own KPIs	3.1, 3.2, 3.3, 3.4
Capacity	Spectrum, Line capacity	Capacity	100x wrt NG-PON2	4.2
Power consumption reduction	Power consumption	Energy Efficiency	30% to 50%	2.1, 4.3, 5.2, 5.3
Autonomous operation	Network operation, Service provisioning	Network mgmt., Service deployment time & Availability	Microsecond timescale	6.1, 8.3
Service provisioning	Service provisioning	Service deployment time	Multi-technology & multi-vendor	6.2, 7.1, 7.2
Network Operations	Network operations	Network management & Availability	10x monitored data, accuracy (uncertainty <1.5dB)	5.1, 5.2, 5.3, 8.1
Service availability	Network operations	Availability	> 6x9s	8.4
CAPEX reduction	None	Network management	50%	2.2, 4.1, 6.3, 8.2
LiFi Mobility	None	Mobility	Hand-over throughput >50%	4.4
Control capacity	None	Network mgmt.	10x	7.3, 7.4

Table 8-4 shows summarises the 5G-PPP KPIs where B5G-OPEN contributes to.

Table 8-4. B5G-OPEN contribution to 5G-PPP performance KPIs

5G-PPP Performance KPI		**B5G-OPEN KPIs**
1	User data rate	2.3
2	Peak data rate	2.3, 3.1, 3.2, 3.3, 3.4
3	Capacity	3.1, 3.2, 3.3, 3.4, 4.2
4	Latency	
5	Device density	
6	Mobility	4.4
7	Reliability	
8	Availability	6.1, 8.3, 8.4
9	Position accuracy (location)	
10	Service deployment time	6.1, 6.2, 7.1, 7.2, 8.3
11	Energy efficiency	2.1, 4.3, 5.2, 5.3
12	Network mgmt. (CapEx/OpEx)	2.2, 4.1, 5.1, 5.2, 5.3, 6.1, 6.3, 7.3, 7.4, 8.1, 8.2, 8.3

9 CONCLUSIONS

This deliverable reports on the activities of WP2 during the first year of the project. The work was split into two parts with the objectives being:

- Defining use cases, service requirements and the network architecture in a generic way and more specific cases that will be used as guidelines to the project.
- Providing reference network topologies and architecture to be used in the project for experiments and performance evaluation.

These objectives have been fully achieved as WP2 have clarified the B5G-OPEN network. Here we defined several of the concepts as they were part of the project proposal, and a clear framework upon which we can base and steer future activities of the remaining technical work-packages.

The high-level view of the network architecture was the first definition that proved to be useful for various activities, which have been carried out later within WP2, WP3 and WP4. Since B5G-OPEN deals with different technologies, network segments and domains, it was of high importance to understand where the different technologies and topologies fit. Another relevant outcome of this definition has been the convergence in the use of network terminology. A significant effort was needed to study how the different networks of the three involved operators could be mapped onto this high-level view.

The definition of the key features of the B5G-OPEN network – in a clear and distinctive way – is also an important outcome that helps the project to focus on the important anticipated results, which were in the project proposal, but were not properly identified and highlighted. These are important definitions that will be used as guidelines and main goals to demonstrate in WP5.

WP2 looked at existing work in other key projects and public documents, from which some future type of services have been identified. This search also brought up performance KPIs, which can be used to measure and validate the B5G-OPEN network concepts. In addition, WP2 has analysed two specific service use cases with the intention to show off some of the project key features and giver further guidelines to some of the activities where necessary. One is a network service use case illustrating the Integrated Access feature, specifically how using LiFi along other access systems. The second one develops a volumetric video service in a Digital Twin use case, which can potentially require an extremely high network capacity connectivity. These two specific use cases were defined and later used to help generating traffic matrices that will be used in WP3 & 4 to dimension the B5G-OPEN network.

WP2 have presented a layered architecture where IP/MPLS termination and processing is performed at relevant central offices. Such architecture has been remarkably enhanced thanks to the introduction of the multi-band technology. Two network architectures have been specifically proposed and preliminary investigated, based on either vertical or horizontal organization of resources. The former vertical approach appears, at this stage, as the most relevant one since it includes features that might be anyway required also for the alternative horizontal approach. This includes the need for new models and procedures for standardized multi-domain impairment-aware path computation, provisioning, and recovery, also encompassing packet-optical white boxes. This input has fed WP3 and WP4 which are providing specific solutions to address this challenging aspect.

Access is traditionally a network segment that for various reasons is difficult to handle together with the other network segments in terms of connectivity, which is only made more complex in the context of the B5G-OPEN key features, especially the optical continuum. Therefore, WP2 carried out an analysis of existing access technologies looking at how they could link with the other network segments allowing for the application of the main concepts (i.e. key features), which resulted in the definition of the access plus metro/aggregation architectures in the short, medium and long term. The short- and medium-term architectures look more feasible because access systems need to be terminated at a fixed locations due to the tight control of some physical layer parameters. Still, a concession was made for the long-term architecture in case access systems developments allows the dynamic optical bypass of the access node termination. The conclusions drawn from this analysis will be important for some of the work in WP3 & 4.

This report shows the initial ideas for the control plane based on the B5G-OPEN concept and architectural & service definitions. This study is brief and mainly states the starting point to define the functional architecture repeatedly pointing and the main body of work that is being carried out inWP4. The two most important points for the control plane are a) an architecture that performs service and network operations E2E from the Access Point to the Cloud node, which might include monitoring and AI/ML, and b) it is based on IBN and zero-touch networking paradigms, with autonomous operation built using closed-control loops at various levels, from device to network. The control plane is empowered by a distributed AI/ML-based engine, which performs data collection and intelligent aggregation, analysis, and autonomous operation acting on the network components, which enables coordinated decision-making across domains.

The largest task in WP2 has been the definition of the reference network topology and traffic characterisation. Mainly based on the TIM's network for the parameters' values, and after consolidating with the other two operators' networks, the reference network topology has been defined so that it can be used in WP5 for the validation studies. A traffic characterization methodology was also defined that can be used for different activities such as planning, dimensioning, and techno-economic studies in WP5. The methodology was oriented to provide flow-based metrics in network scenarios fitting with the B5G-OPEN high-level architecture ("Edge" and "Cloud" segments). The ambition of the methodology was to provide a procedure to generate traffic scenarios combining mass market services with other innovative services foreseen in the B5G-OPEN scope.

By using the traffic characterization methodology, a preliminary traffic analysis on a realistic operator network example has been carried out. In particular, total traffic volumes conveyed by different CO types under different adoption scenarios for both mass market and B5G-OPEN services are evaluated. In particular, from short to long-term scenarios, a CAGR of 30% is assumed for mass market services, as well as an increasing penetration for B5G-OPEN services is considered. The main conclusions that can be extracted from that preliminary study are:

1) Total volumes from several tens to hundreds of Tb/s are expected to be conveyed at National CO level (metro-core and national network segments) for medium-term scenarios. Similar volumes are foreseen at Regional CO level (metro-aggregation segment) for long-term scenarios. To support such traffic needs, optical capacity at several network segments needs to be dramatically increased in the coming years. In this regard, MB becomes a potential technology to invest in order to achieve such extremely high-capacity optical networks.

2) The combination of different scenarios (centralized, semi-distributed, distributed) for different services opens the opportunity to optimize capacity resources utilization, e.g. fostering centralized approaches for those services with no stringent latency requirements. In this sense, MB can facilitate that differentiation e.g. by assigning different bands to different configurations and services.
3) The complex mix of services that networks might require to transport in medium and long-term scenarios can generate extremely large variations of traffic along day. Recall that unprecedented average/peak ratios are expected for B5G-OPEN use cases. This poses challenges to network planning and dynamic operation, including autonomous network operation. Note that inaccurate decision making can have a critical impact in terms of traffic losses (if capacity is under-dimensioned) or large costs (if capacity is over-dimensioned).

The final activity reported in this deliverable tries to clarify the performance KPIs of the project and investigate how it relates to the KPI's cartography of the 5G-PPP, which is expected to help in the advancements of its activities and interpreting the results of the B5G-OPEN project in front of the rest of projects.

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< End of the deliverable report >