Infrastructures for Next Generation Ultrabroadband and Mobile Networks

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Università La Sapienza, Venerdì 23 novembre 2018

Outline

- Introduction to 5G: Fiber to support 5G
- Short overview on Fiber systems and networks
- Optical Fiber Access (PON)
- 5G Overview
- Fiber optics for 5G (New Access Network, costs!)
- Slicing: Software Defining Network (SDN)& Network Function Virtualization (NFV)
- Slicing-SDN FUB model: Carrier Ethernet approach
- Experimental tests.
- Next steps: Information Centric Networks
- Conclusions

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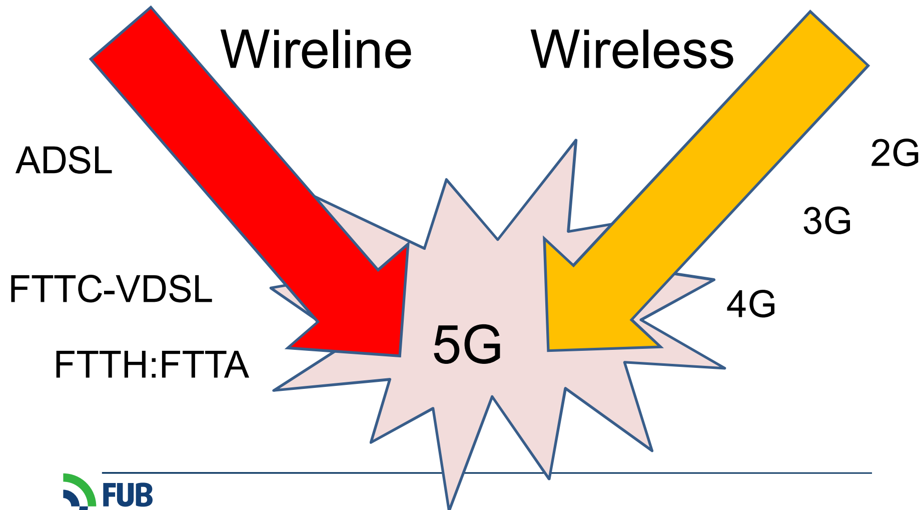
User Infrastructure Network Trend



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Fiber to the x (FTTx), x: Curb, Home, Antenna

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Network Segments

- Core: Wide Geographical networks
- Metro: ring+WDM
- Access: up to the Home (xDSL, Fiber,…)
- Domestic: Wi-Fi, Plastic Optical Fiber, UDP,…
- RAN: Radio Access Networks
- XHAUL: From Antenna to the core

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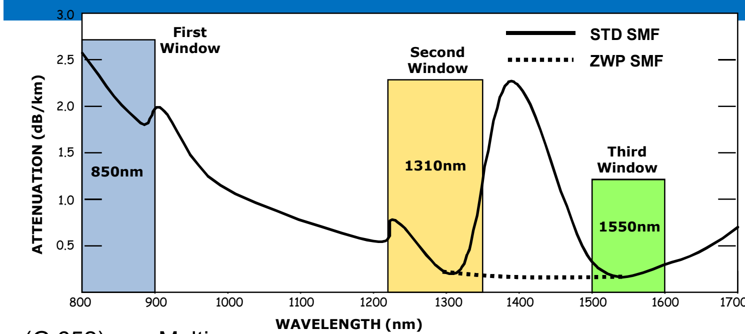
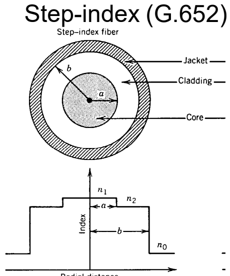
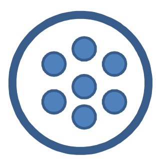
Short Optical Fiber Overview

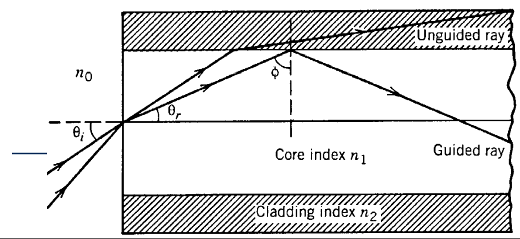


Step-index (G.652)

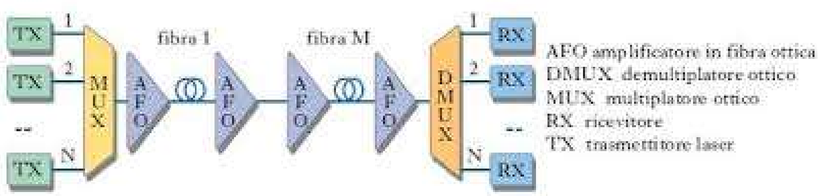


Multicore





Optical Transmission Systems



- IM-DD (intensity Modulation Direct Detection)
- Coherent Systems (field detection)
- Multilevel System
- Wavelength Division Multiplexing (WDM)
- Orthogonal Frequency Division Multiplexing

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Link Capacity

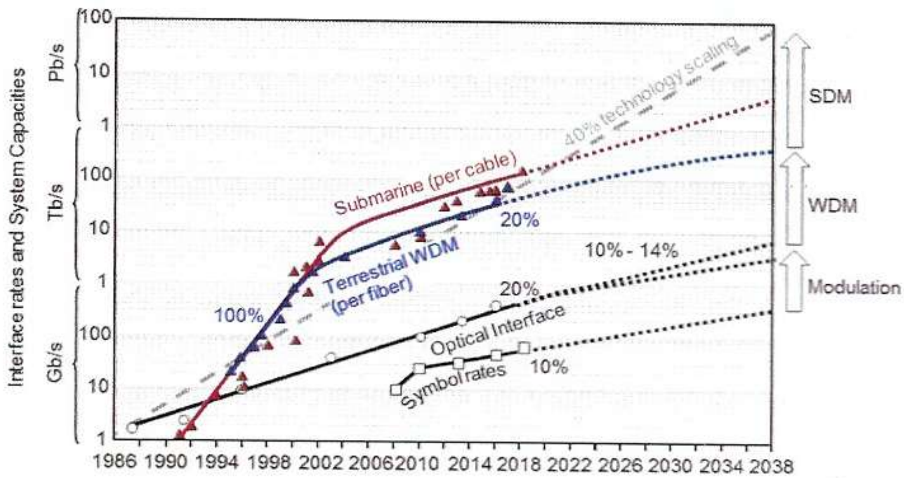


Fig. 1. Evolution of commercial optical transmission systems over the past 30 years and extrapolations for the coming 20 years (after [1]).

Examples of Optical Transmission Systems

Table 1. The previous 20 years and an extrapolation into the next 20 years of fiber optic systems. (*Record numbers in independent experiments; +Submarine cable capacities, counting both directions)

		1997		2017		2037
		Products	Research	Products	Research*	Products
Interface rate R_{Ch}		2.5 – 10 Gb/s	20 Gb/s 40 Gb/s pol mux	100 – 400 Gb/s	1.3 Tb/s [12]	2 – 6 Tb/s
Wavelengths		16	25 – 55	96 – 192	several hundred	16 – 66
Single mode	C_{Sys}	40 Gb/s	1 Tb/s	10 – 76 Tb/s	115 Tb/s [15]	32 – 400 Tb/s
	C_{Sys} x L	14.4 Tb/s.km	150 Tb/s.km	up to 240 Pb/s.km	881 Pb/s.km [18]	500 Pb/s.km
	SE	0.0125 b/s/Hz	0.27 – 0.4 b/s/Hz	2 – 8 b/s/Hz (flex.)	17.3 b/s/Hz [17]	7 – 20
Cable+ /SDM	C_{Sys}	20 Gb/s	-	288 Tb/s	10 Pb/s [16]	5 – 100 Pb/s
	C_{Sys} x L	118 Tb/s.km	-	3,686 Pb/s.km	1,508 Pb/s.km [19]	30,000 Pb/s.km
Router blade		2 x 2.5 Gb/s	-	6 x 400 Gb/s	-	128 x 6 Tb/s
Router capacity		24 x 2.5 Gb/s	-	120 x 400 Gb/s	-	5,120 x 6 Tb/s

Research vs Products

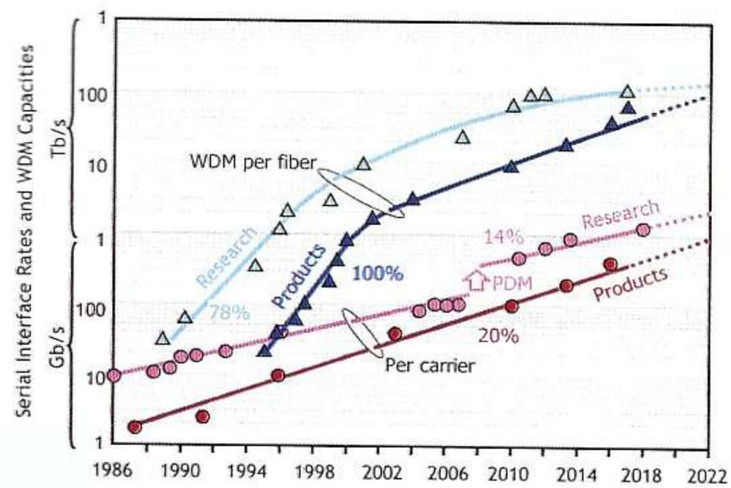
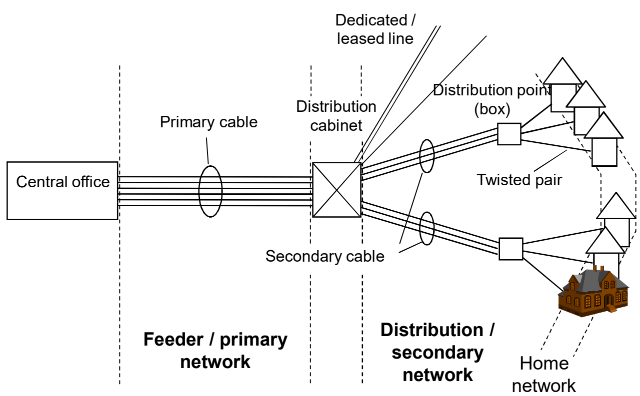


Fig. 2. Comparison of products and research records in terms of per-carrier interface rates and WDM capacities. The discontinuity in single carrier interface records around 2007 is due to the introduction of coherent detection using polarization division multiplexing (PDM). (Figure after [27].)

Access Network Evolution



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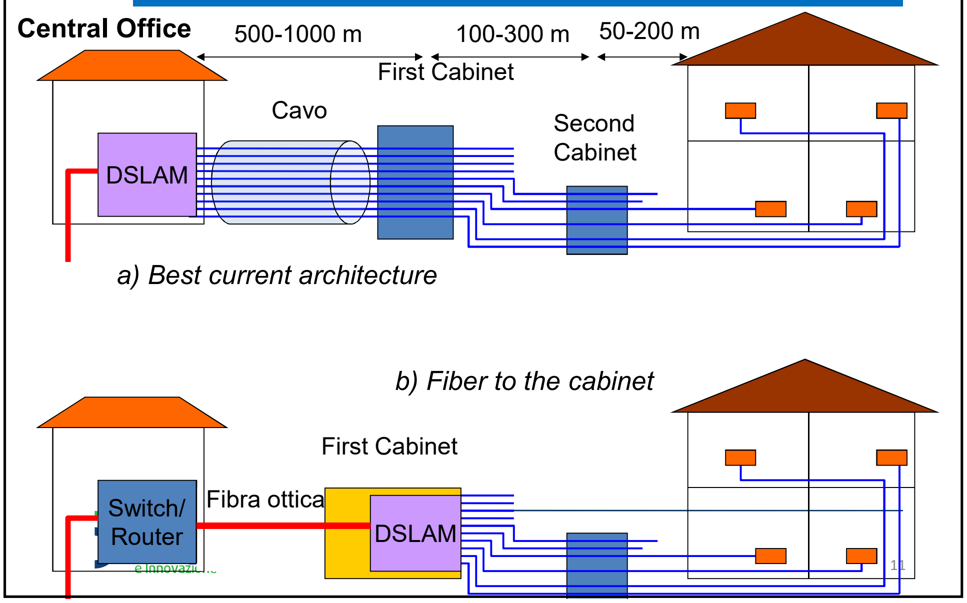
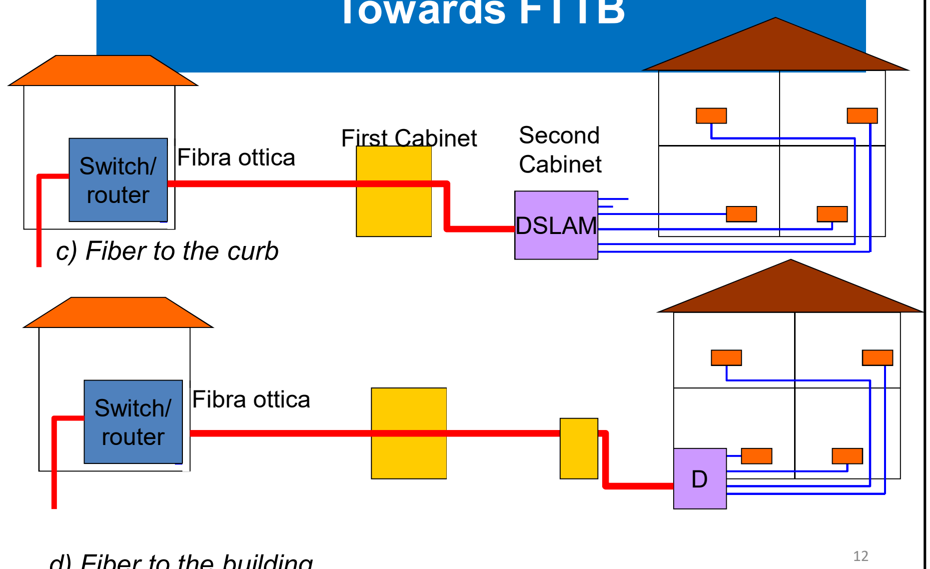
Access network



Towards FTTB



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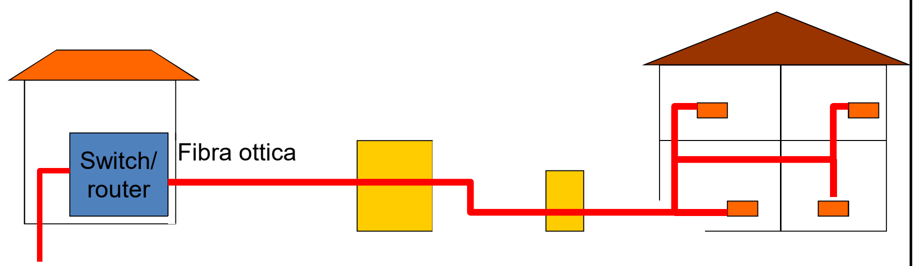
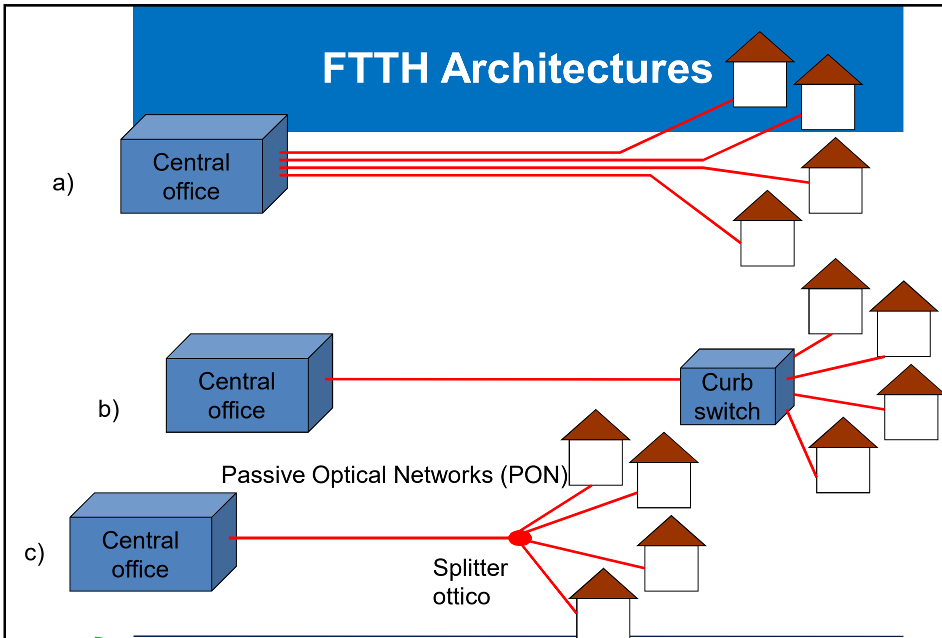
FTTH



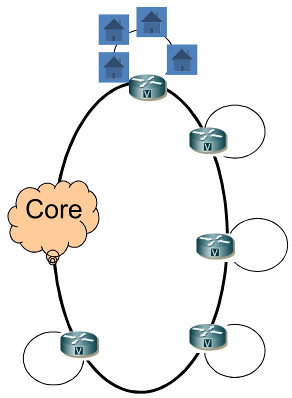
e) Fiber to the home

FTTH Architectures



GbE based: i.e. FASTWEB in 2000

Daisy chain architecture



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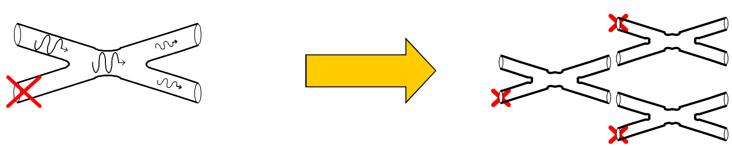
Passive Splitters

- 1x2 Splitter
- 1xN Splitter



- The basic element consists of two fibers fused together
- Every time the signal is split two ways, the signal is reduced by *10log(0.5)=3dB*
  - Loss ~*3dB* x *log*$_2$*(#ONUs)*

	Conventional	Low-loss
Splitter 1x2	3.7dB	3.4dB

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PON Scheme

- The optical line terminal (OLT) broadcasts data downstream on 1,510 nm and the ONTs burst data back upstream on 1,310 nm in their assigned time slots.

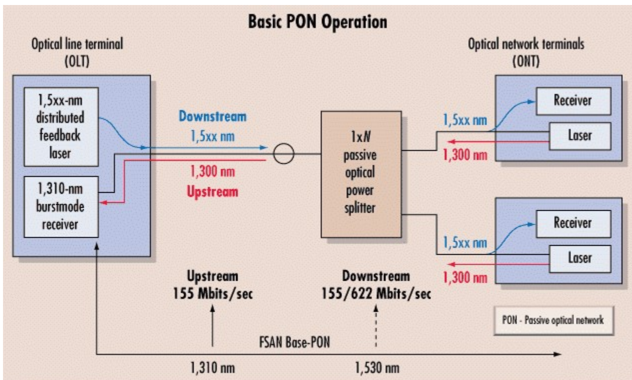


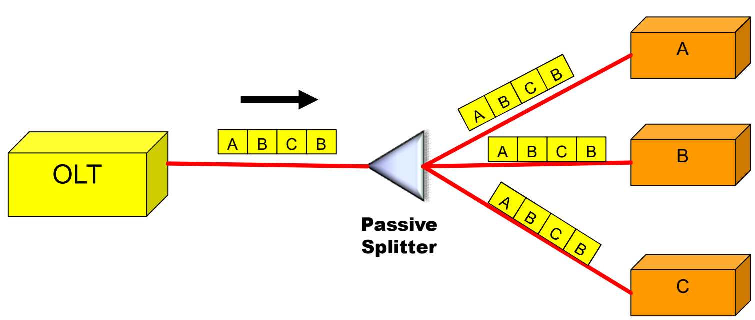
Figure 1. A basic passive-optical-network operation enables service to as many as 32 optical-network terminals (ONTs). Each ONT, in turn, can be connected to multiple subscribers, making fiber more affordable for access networks.

Ethernet PON (EPON)

GPON (based on synchronous SDH frame)

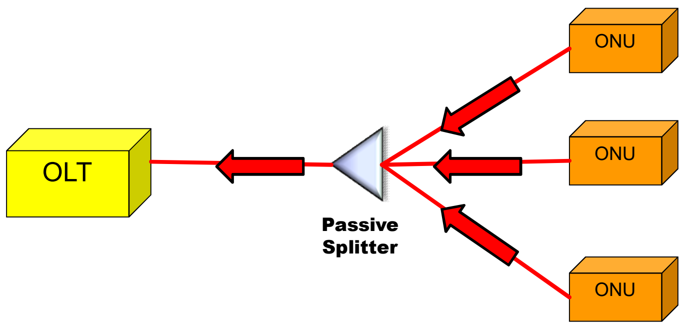
Downstream Traffic Scheduling

- OLT schedules traffic inside timeslots
  - -Time Division Multiplexing (TDM) scheme
- Time slots can vary from ~µs to ~ms



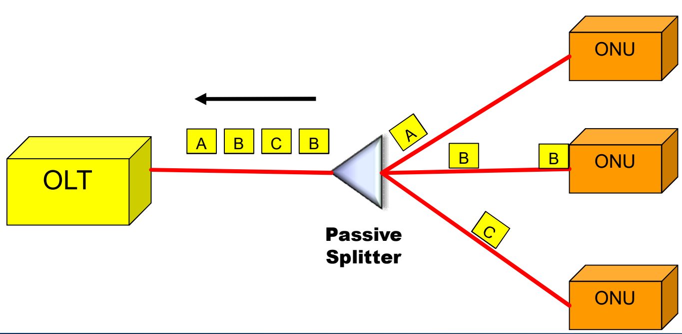
Upstream Traffic (1)

- All ONUs share the same upstream channel
  - ONUs cannot exchange data directly
  - Collisions may occur at the splitter/combiner



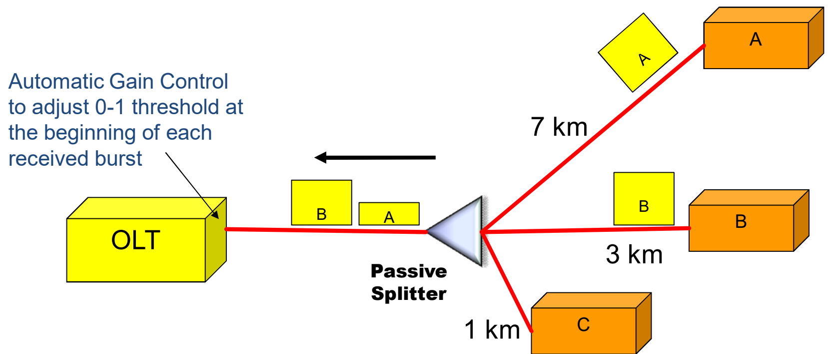
Upstream Traffic Scheduling (2)

- In general, PON standards propose Time Division Multiplexing Access (TDMA) schemes
  - Upstream time slicing and assignment



Upstream Frame Reception

- The OLT receives frames with different powers
  - Much difficult to recover synchronism (clock and data recovery)
  - Burst Mode Receiver (complex) @ OLT
    - Sets 0-1 threshold on a burst basis



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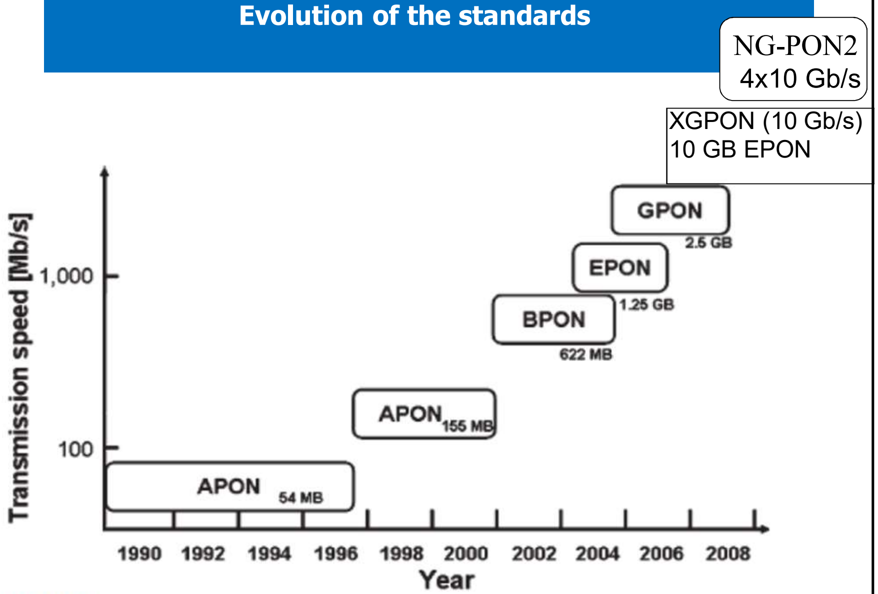
Evolution of the standards



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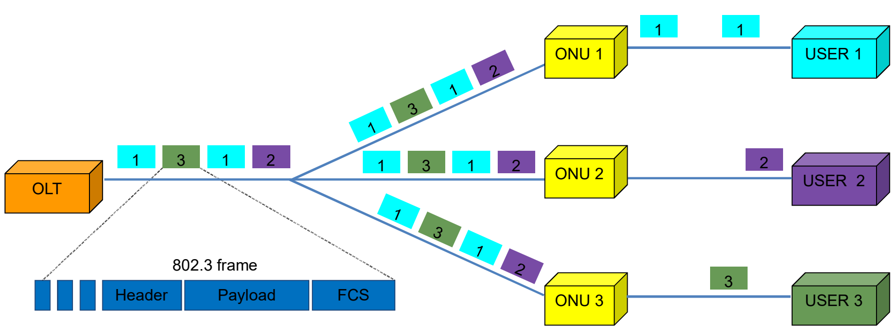
Ethernet PONs (EPONs)

- All packets carried in EPON are encapsulated in Ethernet frames
  - Support for variable size packets
- Similar wavelength plan to BPON
- Maximum bit rate is 1Gbps MAC-MAC (1.25 Gbps at the physical layer with 8b/10b line coding)
- Minimum number of splits is 16
- Maximum reach is
  - 10 km (FP-LD @ ONUs, limited by dispersion in downstrea for G.652)
  - 20 km (DFB-LD @ ONUs)
- Different configurations are allowed

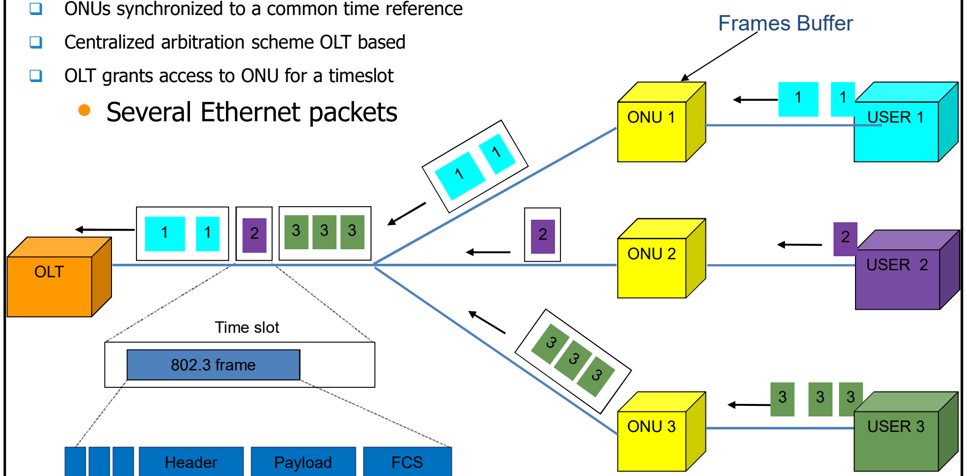
EPON Downstream Traffic

- Similar to a shared medium network
- Packets are broadcasted by the OLT and selected by their destination ONU



EPON Upstream Traffic

- ONUs synchronized to a common time reference
- Centralized arbitration scheme OLT based
- OLT grants access to ONU for a timeslot
  - Several Ethernet packets



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GPON Main characteristics (G.984.1 Service Requirements)

Item	Target	
Bit rates	1.25Gbit/s symmetric or higher (2.4 Gbit/s). Asymmetric with 155/622Mb/s upstream	
Physical reach	Max. 20 km or max. 10 km	
Logical reach	Max. 60 km	
Branches	Max. 64 in physical layer	
Wavelength allocation	Downstream: 1480 – 1500nm Upstream: 1260 – 1360nm	Downstream video wavelength (1550 – 1560nm) may be overlaid

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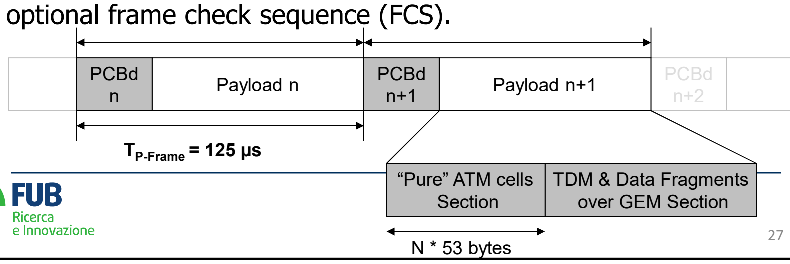
GPON Encapsulation Mode (GEM)

- GEM provides a *Generic Frame* where to carry both TDM and packet traffic over fixed data-rate channels
  - Similar Generic Framing Procedure (GFP) used in SDH/SONET
- A *Generic Frame* consists of:
  - a core header
  - a payload header
  - an optional extension header
  - a payload
  - an optional frame check sequence (FCS).



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Technical Standards Comparison

Technology	Standard	Downstream/ Upstream Bandwidth	# ONT served	Lambda	Framing/ Protocol	Distance
APON/BPON (ATM PON/ Broadband PON)	ITU-T G.983.x	155, 622 or 1244 Mbit/s down 155 or 622 Mbit/s up	Limited by power budget and ONU addressing limits: 16 to 32 splitter	1490 nm Down 1310 nm Up (1550 nm Down for RF video)	ATM	20 km
GPON (Gigabit PON)	ITU-T G.984	1.2 or 2.4 Gbit/s down 155, 622, 1.2 or 2.4 Gbit/s up	Up to 64(physical) Up to 128 (logical)	1490 nm Down 1310 nm Up (1550 nm Down for RF video)	GEM: G-PON Encapsulation Method (supports Ethernet), ATM	10/20 km (up to 60 km)
EPON (Ethernet PON)*	IEEE 802.3ah	Symmetric 1.25 Gbit/s	Up to 16	1550 nm Down 1310 nm Up	Ethernet	10/20 km
10GEPON (10 Gigabit Ethernet PON)	IEEE 802.3av (Working Task Force)	10 Gbit/s down 1 Gbit/s up (symmetric 10 Gbit/s in the future?)	32 (maybe more?)	1480-1500 nm Down ? 1260-1360 nm Up ? 1550-1560 Video overlay ?	Ethernet	20 km

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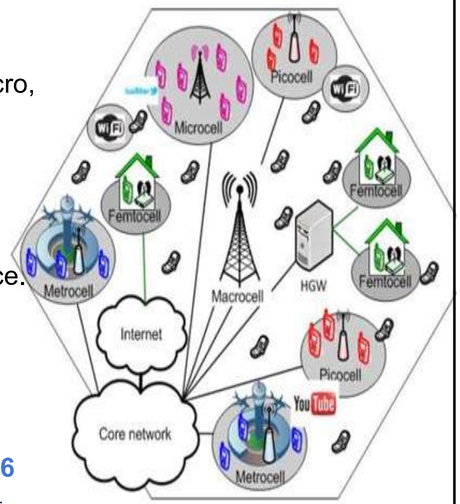
5G Main Characteristics

- From 2G to 4G: Capacity increasing
- HetNet: macrocellS AND small cells (micro, pico, femto, relay).
  - **Network Densification**
  - More capacity, less latency
- Coverage
  - According to required SNR for service.
  - QoS/QoE.
- **Coexistence**.
- **Handover**
- **New band frequency: 700 MHz (deep indoor), 3.6 GHz (BB enhancement), 26 GHZ**



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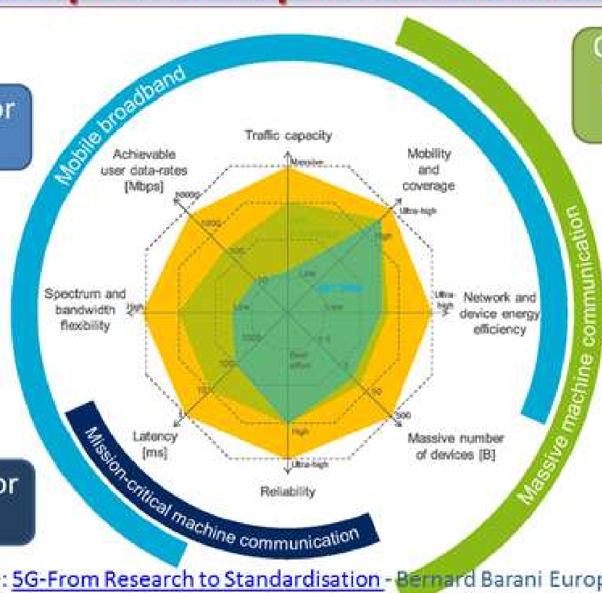
5G: Multiple inter-operable standards?

Optimize for data rate

Optimize for connection numbers



Optimize for delay

Image Source: 5G-From Research to Standardisation - Bernard Barani European Commission, Globecom2014

Non-confidential – Public © eXplanoTech Ltd. eXplanoTech

5G Services

- Enhanced Mobile Broadband (eMBB):
  - High capacity
  - Higher radio bandwidth
- Massive machine type communications (mMTC):
  - Machine to Machine (M2M) (not IP necessary)
  - Internet of things (IoT)
  - High density devices
- Ultra-reliable and low latency communications (URLLC):
  - Tactile, driving,….

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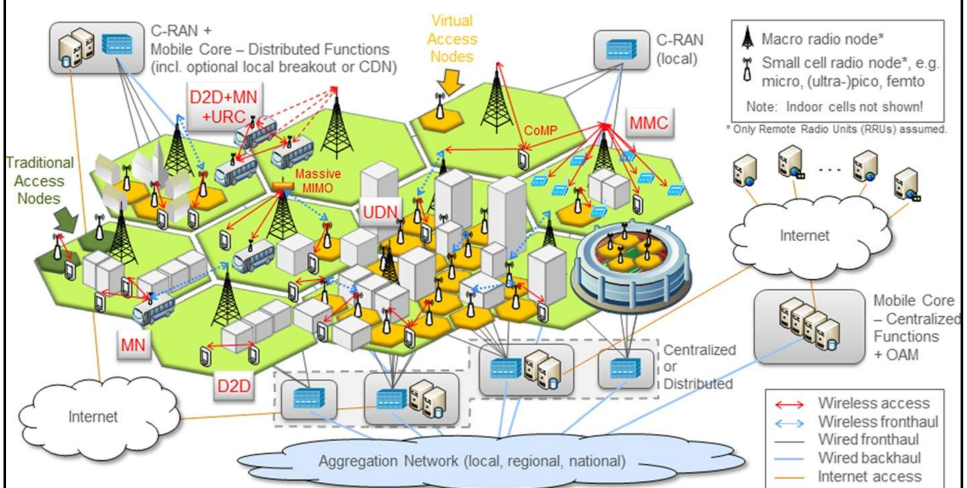
Rete 5G (HetNet)



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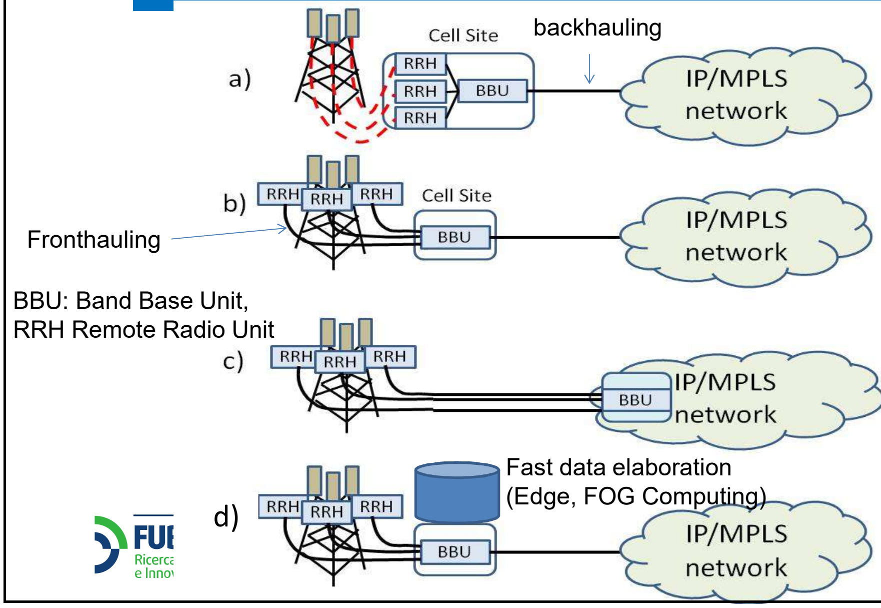
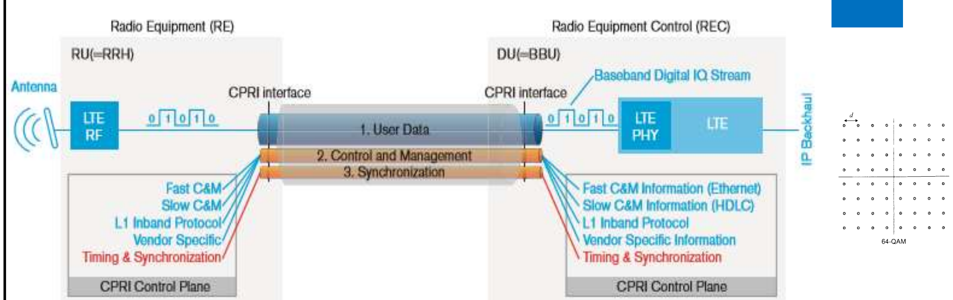
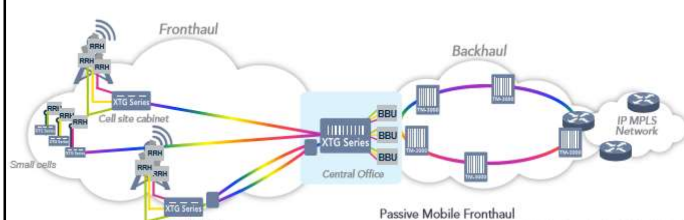
Centralized/Cloud Radio Access Network evolution



Fronthauling (Digital Radio Over Fiber)





Passive Mobile Fronthaul
Fig 9: The Infinera Mobile Fronthaul Solution Featuring the XTG Series-based Passive WDM Option Enabling Low – or Even No – Power Consumption.

From RF Multilevel to optical digital.

Bandwidth explosion (x14!)

Analogic Radio Over Fiber: Direct RF to Optical Conversion

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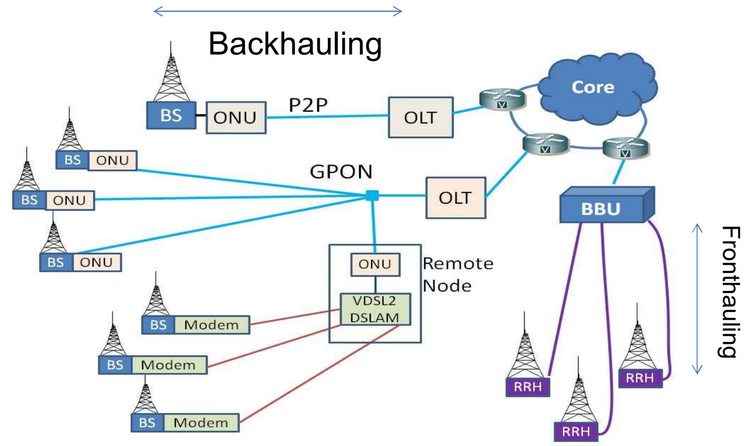
Next GenerationAccess Network for 5G



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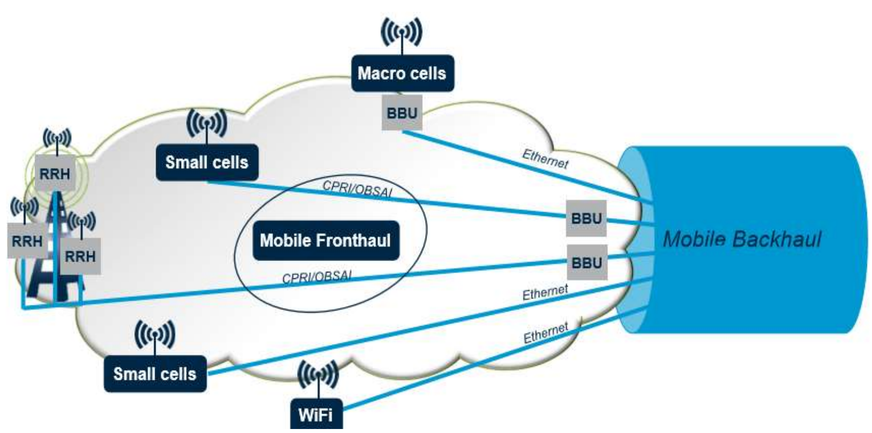
Backhaul vs Fronthaul



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Example of eBBM

- Model for RAN taken from EARTH FP7 Project, Ideal Manhattan-like grid, ..
- Cellular layout (Grazioso et al Fotonica 2018)
  - an umbrella macrocell with omni antenna located at the centre of the area and 30 m high
  - a variable number of identical microcellular base stations 10 m high
- Overall throughput computed as:

$$T_{syst} = W\,N_{site}\,N_{sect}\,S_{eff}$$

- Where W is the allocated bandwidth in MHz (20 MHz) , N_{site} is the total number of BS/RRH sites, N_{sect} is the number of sectors per cell site and S_{eff} is the spectral efficiency in b/s/Hz/sector.
  - S_{eff} =3.8 and 4.2 for macrocells (1.8 GHz) and microcells (3.5 GHz) respectively.
  - Modules of 228 Mb/s for macro and 84 Mb/s for microcell.
  - 1 Macrocell+23 microcell

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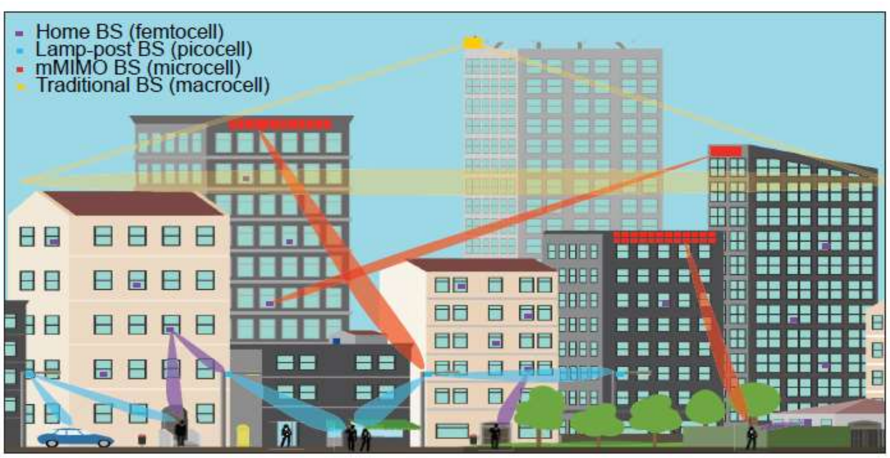
26-28 GHz new radio: Radio beams



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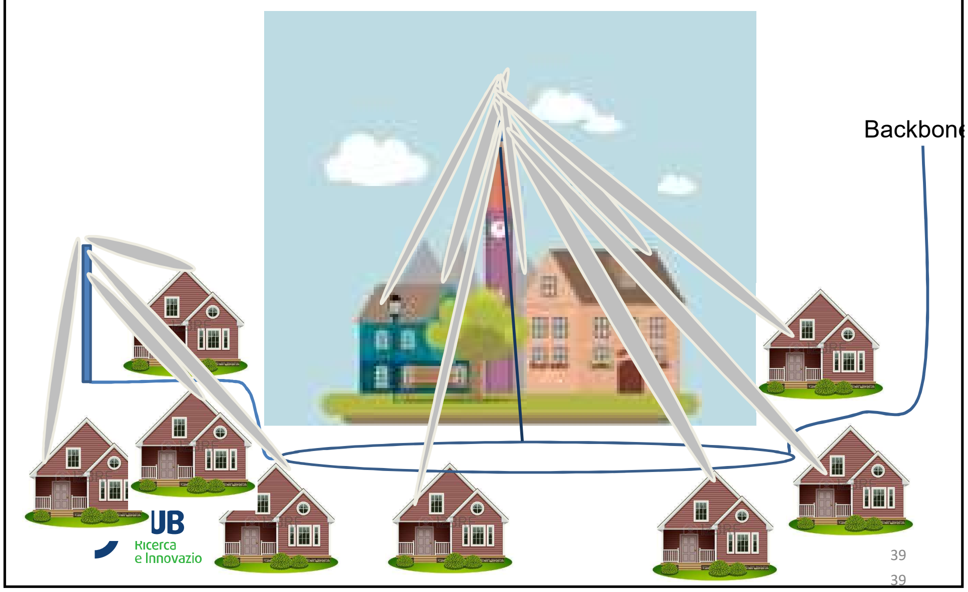
26-28 GHz for rural Areas



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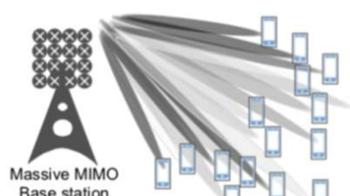
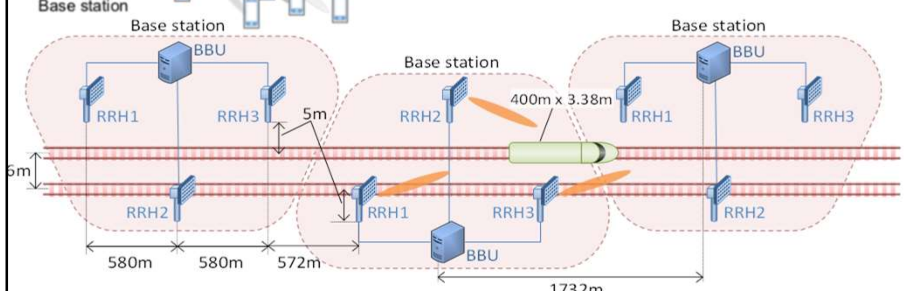
26-28 GHz other examples



- Verizon
- Open Fiber
- Transportation



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IoT Contest

- Smart grid, tactile, robotic, Automotive, domotic,…
- Massive data
- Different solutions:
  - Based on 2G, 3G, 4G (LTE-Machine Type Communication, MTC)
  - Proprietary solutions: i.e. *LPWA (Low Power Wide Area) Networks (*LoRa, SigFox, e WMBus*)*
- Different approach for storage and elaborations
- Security
- Distributed management
- Distributed legend: Blockchain

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IoT automatic transportation

- Smart road
- Automatic drive
  - Radar, lidar, video
  - Fast elaboration
  - Close repository
- EDGE Computing
- FOG Computing (more performance in terms of computing by means of suitable devices)

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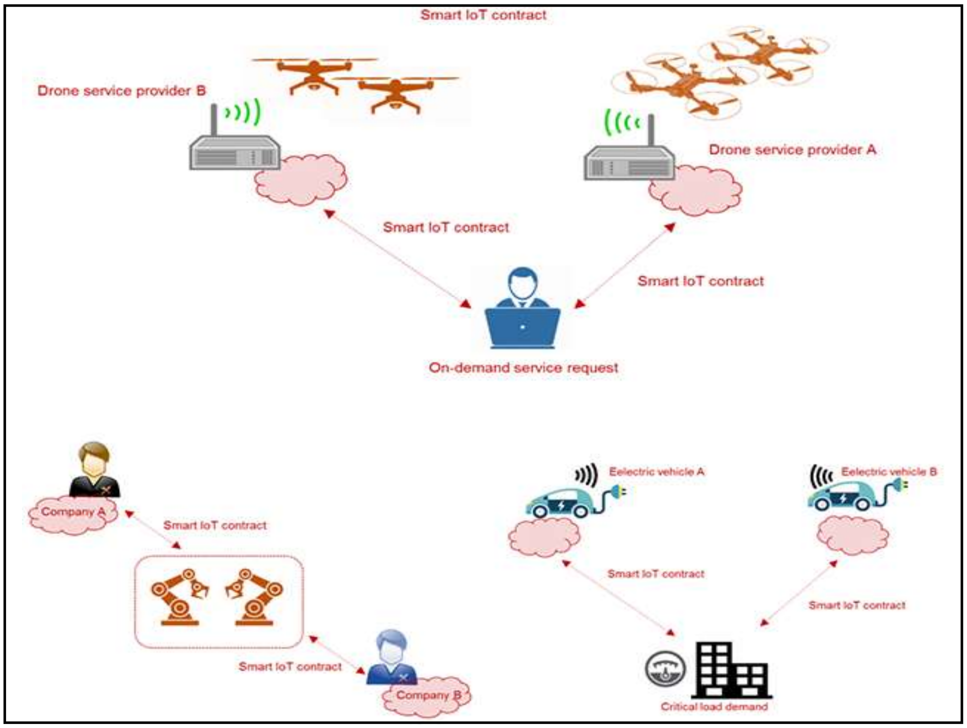

Access Infrastructure costs

4 different areas for building density and Real Estate Units (unità immobiliari, U.I). Supposing a mix of different trenchs and existing infrastructures. MISE model (28 M U.I.)

AA High Building density (Buildings/kmq>100) and High HU for building (HU/builging>4.5)
AB High Building density (Buildings/kmq>100) and low HU for building (HU/builging<4.5)
BA Low Building density (Buildings/kmq<100) and High HU for building (HU/builging>4.5)
BB High Building density (Buildings/kmq<100) and High HU for building (HU/builging<4.5)

Costi medi primaria per U.I. (euro)
AA=120;
AB=170;
BA=200;
BB=300

Costi medi secondaria per U.I (euro)
BB=1492;
BA=658;
AB=457;
AA=332;

Cost for verticals(FTTH) 250 euro for all

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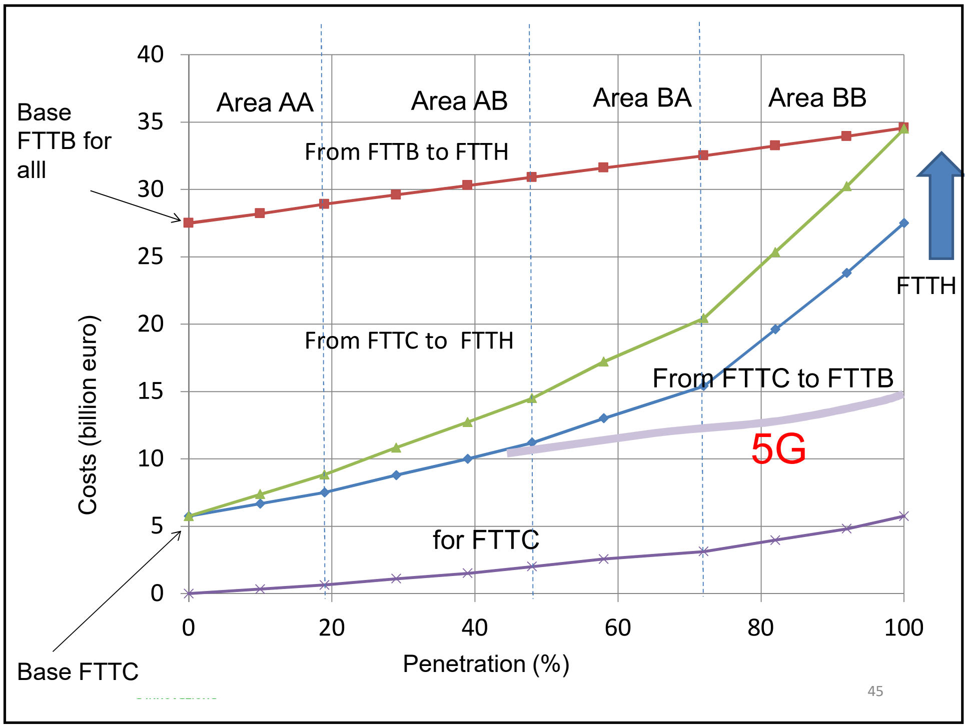
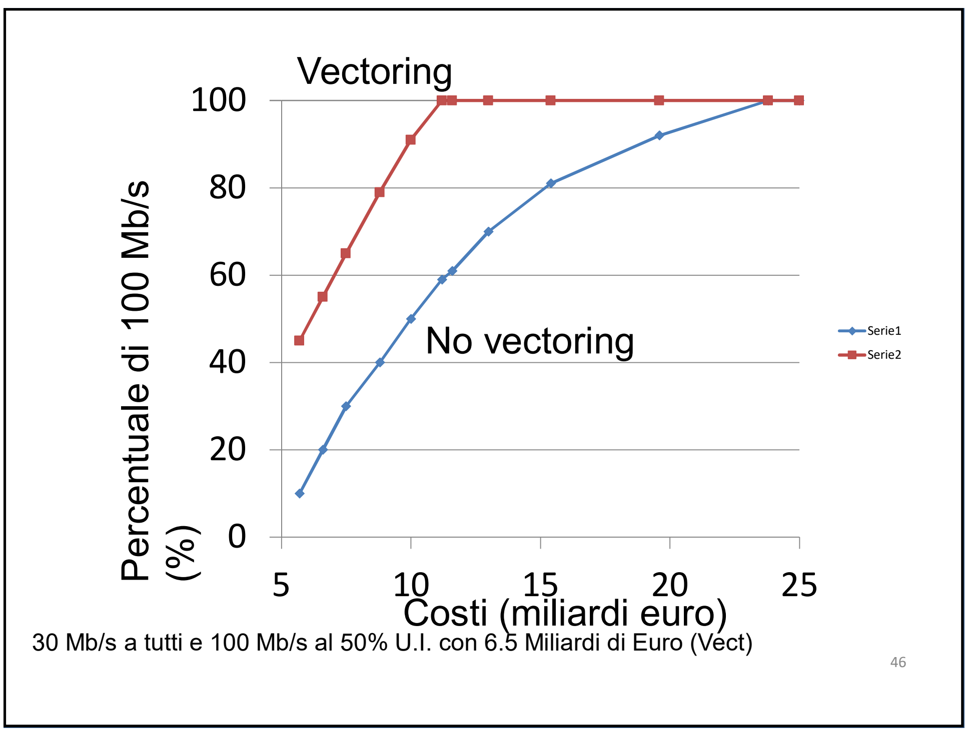

Area AA
Area AB
Area BA
Area BB
Base FTTB for alll
From FTTB to FTTH
FTTH
From FTTC to FTTH
From FTTC to FTTB
5G
for FTTC
Base FTTC
Costs (billion euro)
Penetration (%)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
45


Vectoring
No vectoring
Percentuale di 100 Mb/s (%)
Costi (miliardi euro)
0
20
40
60
80
100
5
10
15
20
25
Serie1
Serie2
30 Mb/s a tutti e 100 Mb/s al 50% U.I. con 6.5 Miliardi di Euro (Vect)
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Slicing (1)

- The whole access-metro-core network establishes multiple networks
  - optimized to each different service and key capability.
- This is the Slice.
- Each one is comprised of a set of network functions that are selected for a specific service
- In details the operator's physical network is sliced into multiple virtual and end-to-end (E2E) networks and each slice is logically isolated.

A. Valenti et al"Experimental Investigation of Quality of Service in an IP All-Optical Network Adopting Wavelength Conversion" IEEE/OSA J. of Optical Communications and Networking, Vol. 1, Issue 2, pp. A170-A179, July 2009

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Slicing (2): 3GPPP approach

- 3GPP: Network Slicing Istances: Preparation, Commissioning, Operation, Decommissioning;
- Depending on the service type (eMBB, URLLC, mIoT), different service types may include different service requirements information for network slicing, for example: Area traffic capacity requirement, Charging requirement, Coverage area requirement, Degree of isolation requirement, End-to-end latency requirement, Mobility requirement, Overall user density requirement, Priority requirement, Service availability requirement, Service reliability requirement, UE speed requirement
- Operator management system (OMS) to OMS interface for multi-operator NSI creation

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Our Slicing approach

- Logical Subnet implementation based on Carrier Ethernet approach;
- Exploitation of Fiber Access Networks (GPON vs NGPON2)
- QoS monitoring: **mPlane** measurement plane
- Experimental tests on a Geographical Area Network Test bed;
- Emulation of LTE and WiMax (NS3)
- Simple SDN management approach
- Reliability and latency

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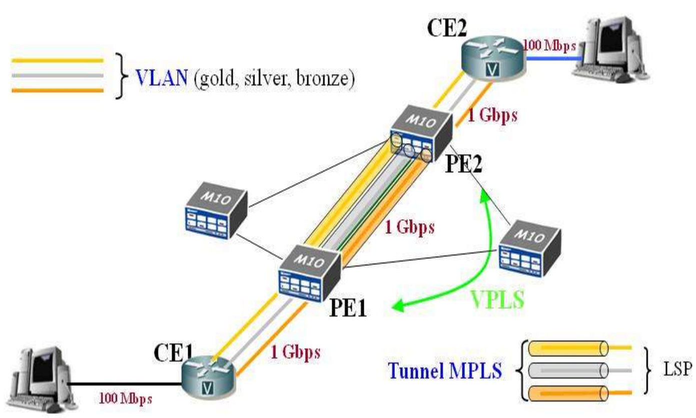
Slicing: Encapsulation from VLAN to Virtual Private LAN Service (VPLS)



Provider Backbone Bridging Traffic Engineering (PPB-TE) is a Carrier Ethernet approach

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Software Defined Networks

- SDN adopts a separation of the *control* and *data plane;*
- it uses a central entity (*Controller*, *Orchestrator)*.
- OpenFlow is the most well known protocol that rules the communication between Controller and switches.
- Other protocols for SDWR: Route flow, Flow N and Flow Visor;
- Based on Network Function Virtualization (NFV) the Routing function are managed by the Controller

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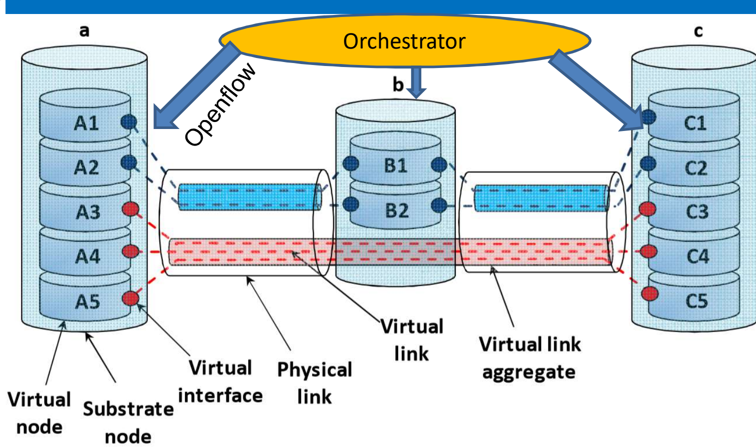
SDN

Centralized SDN



All the Layer OSI routing funcions can be managed by the Orchestrator; We only consider L1-2-3, since they allow to adopt current devices: Simple Network Management Protocol (SNMP) adopted [Tego E.,et, J. of Elect. and Comp. Engin., March 2014]

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Centralized vs distributed SDN

- Centralized SDN Problems:
  - *Scalability (Wide Geographical Area Networks);*
  - *Reliability and Security*
  - *Multioperator Environment: who wins?*
- Distribuited Controller [J. Xie et al , "Control plane of.." Comput. Commun. V. 67, pp-1-10, 2015].
- To meet the requirement of centralized view of the network controllers such as Onix, Hyperflow, ONOS, OpenDayLights share infromation among each other. [H. Tahaei et al, IEEE Access, v. 6, 2018]
- Controllers have to synchronize their state with each other.
- Synchronization causes network overhead. Control in data plane

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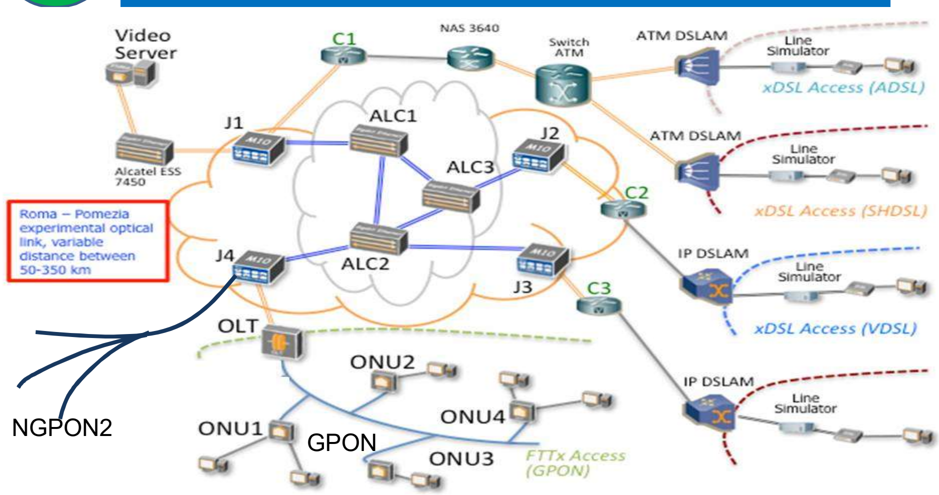
5G

LAB ISCOM



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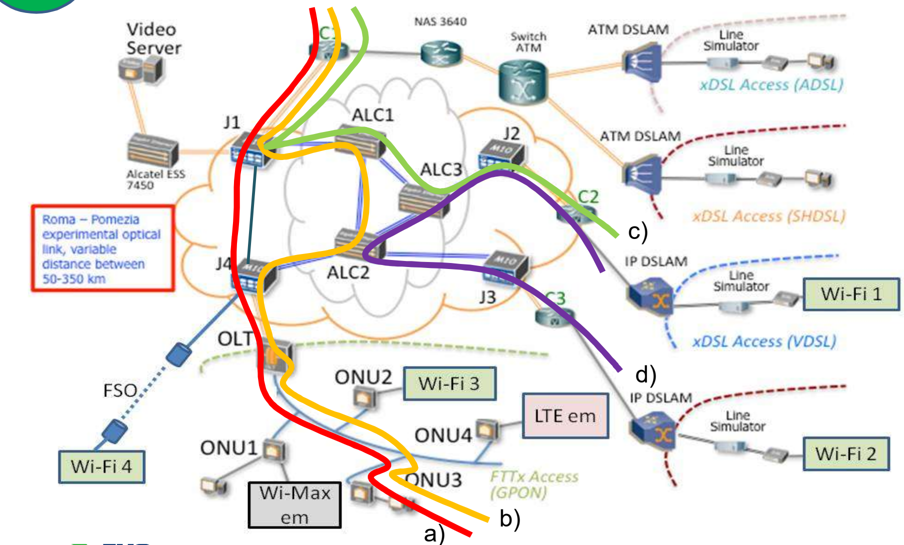
5G

Slicing: LAB ISCOM



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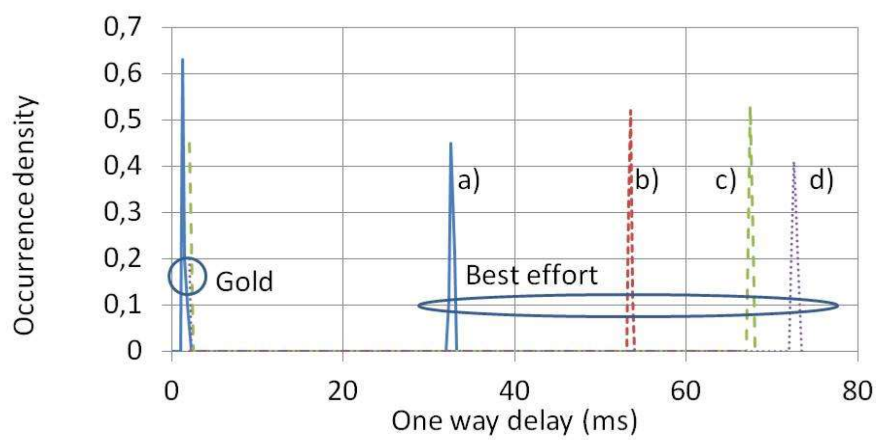
Latency with slicing

Matera F., et al. "**Optical Network Slicing Approaches with Carrier Ethernet test**" IEEE Fotonica 2017



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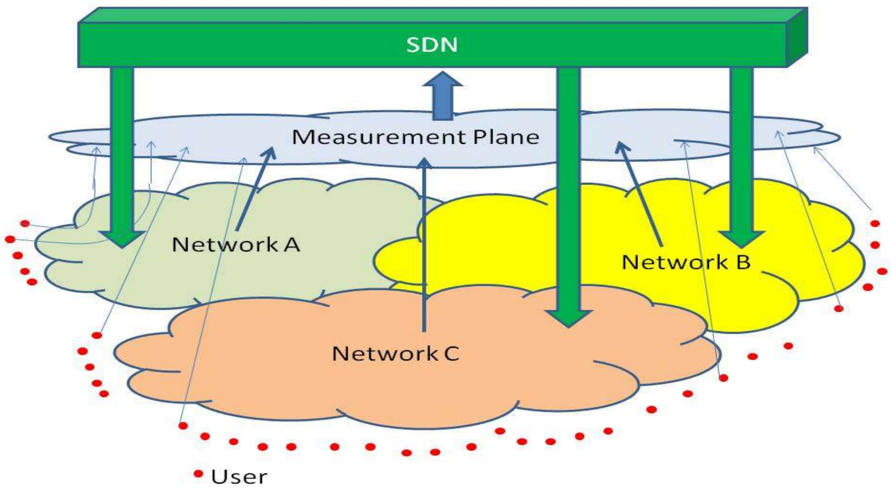
With NG-PON2 Latency<0.2 ms! S. Pompei et al submitted to IEEE Fotonica 2018

FUB: SDN+Measurement plane



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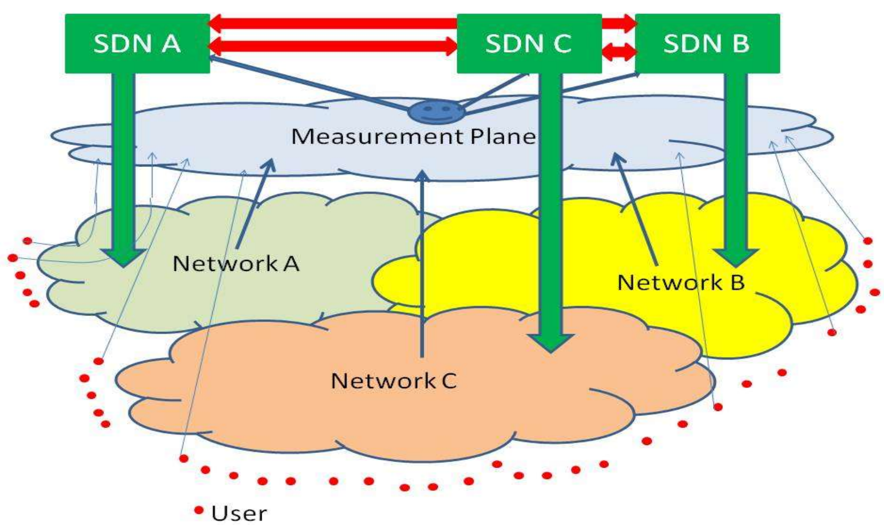
SDN Distributed Controller



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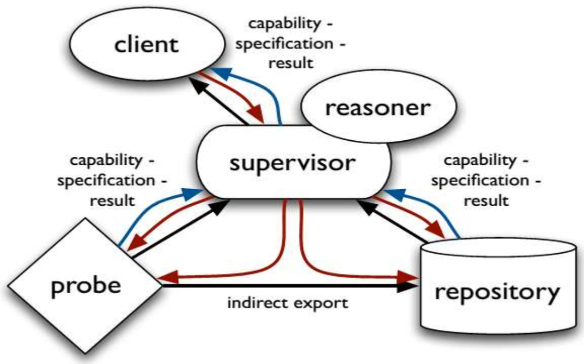
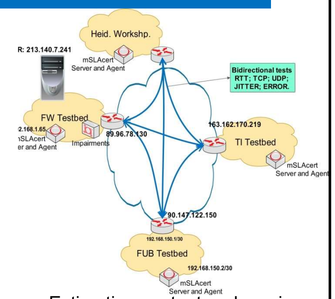
SDN

mPlane architecture (EU FP7)





•Estimating content and service popularity,
•Anomaly detection and root cause analysis,
• Passive content promotion and curation,
•Multimedia content delivery,
•QoE for web browsing,
•Mobile network performance,
•SLA verification and certification

Active Probe: QoS (throughput, jitter, packet loss, traceroot, ping
Passive probe: traffic monitoring

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E. Tego, et al "[Unveiling network and service performance degradation in the wild with mplane]" IEEE Communication Magazine, March 2016, pp. 71-76

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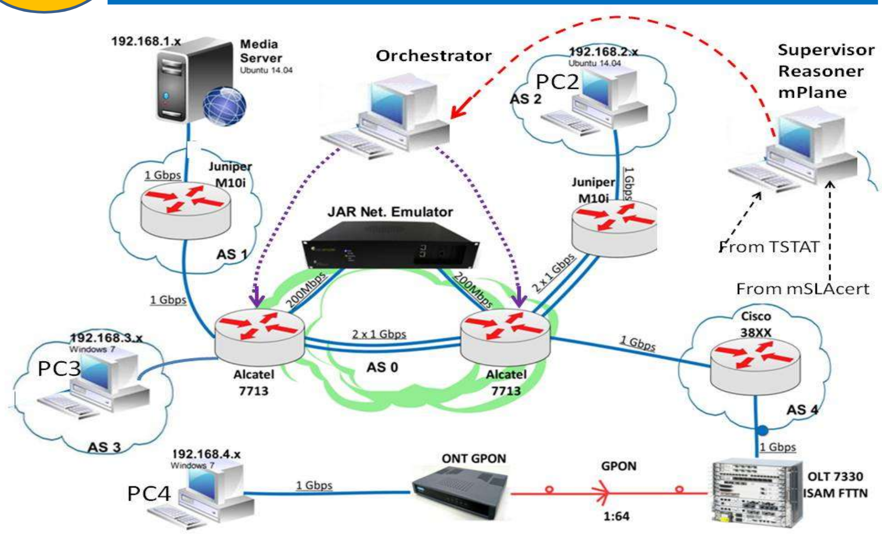
SDN

SDN-mPlane test (1)



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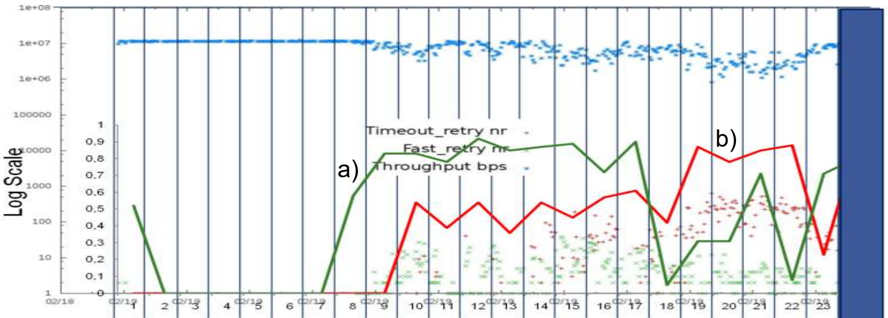
SDN

SDN-mPlane test (2)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Thrghpt C Rtr Tmout	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.50 43	-0.39 69	-0.54 14	-0.36 95	-0.54 39	-0.45 85	-0.57 22	-0.61 40	-0.42 69	-0.87 14	-0.78 99	-0.85 86	-0.88 38	-0.23 04
Thrghpt C Rtr Fst rtr	-0.52 03	NaN	NaN	NaN	NaN	NaN	NaN	-0.58 55	-0.83 37	-0.83 11	-0.78 79	-0.92 92	-0.85 06	-0.87 93	-0.89 22	-0.72 07	-0.90 50	-0.50 36	-0.31 07	-0.31 14	-0.71 77	-0.08 40	-0.71 73
Thrghpt C Time	-0.19 10	0.162 4	0.093 2	0.069 2	0.036 1	0.028 6	0.386 5	-0.52 65	-0.92 78	-0.94 29	-0.81 05	-0.91 73	-0.93 08	-0.87 37	-0.83 46	-0.84 81	-0.94 14	-0.39 85	-0.92 81	-0.86 88	-0.93 53	-0.93 83	-0.71 58

correlations between Throughput and Fast_retry (a) and between Throughput and Timeout_retry(b)

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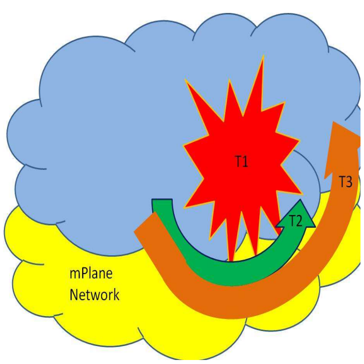
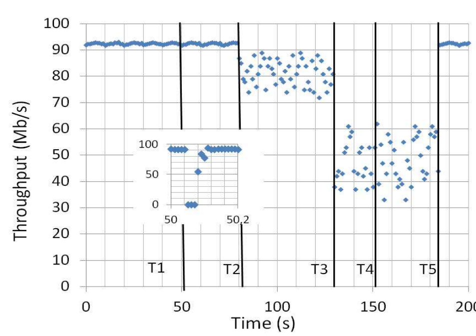
A. Valenti et al "Quality of Service monitoring adopting correlation among active and passive measurements" Networks 2016, Montreal September 2016.

Slicing reliability: disaster recovery





E. Tego et al "A Measurement Plane for Optical Networks to Manage Emergency Events" Fiber and Integrated Optics, Taylor & Francis, published online December 13 2017, pp. 227-241.

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Slicing case: Next Generation Emergency Networks

- migration of current emergency systems based on legacy telecommunication technology. Cooperation within IP?
- Current emergency systems must be upgraded to operate in a full IP world
- Procedures to assign reliable and secure paths and must monitor networks in order to avoid congestions and other impairments. See *slicing* before
- Unique platform to manage all the emergency calls: NG112 (EENA)
- Information from social networks. i.e. prog. EMYNOS

(www.emynos.eu)

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ICN

Information Centric Networks

- Current *host-centric* (Server-client) Internet architecture is becoming inadequate for the modern services
- Semantic networks: routing according *content*,
- Information Centric Networks (Content Centric Networks):
  - Content-Client: research according to *name*
  - IP revolution: *Broadcast searching for a "name" to all the nodes closest to client*
  - *Router containing "name" send all its content to the client*

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ICN

ICN strategies

- Cost analisys:
  - Cost advantages with respect standard IP and CDN A. Araldo, M. Mangili, F. Martignon, D. Rossi, "Cost-aware cashing: optimizing cache povisioning and object placement in ICN", Globecom 2014, December 8-14 2014Austin USA
  - More efficiency in Wavelength Routing and Assignment (RWA) *M. F.Al-Naday, N. Thomos, M. J. Reed, "Information-Centric Multilayer Networking: Improving Performance Through an ICN/WDM Architecture" IEEE/ACM Transaction on Networking, vol. 25, n. 1, Feb. 2017*
- Power consumption:
  - Servers+routers= CCN better than standard IP U. Lee, I. Rimac, V. Hilt, “Greening the Internet with Content-Centric Networking” Proceedings of the 1st International Conference on Energy-Efficient Computing and Networking, Passau, Germany — April 13 - 15, 2010
- Slicing operating in a ICN Contest:

https://www.cisco.com/c/dam/m/en_us/service-provider/ciscoknowledgenetwork/files/601_06_29-16-ICN_29Jun2016_CKN_Final.pdf

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Conclusions

- Towards Mobile Next Generation Networks
- Towards FTTH and Fiber to the Antenna
- Role of Radio Access with 5G
- IoT transforms Architectures (FOG, EDGE) and data management (blockchain)
- Dynamic management with SDN&NFV

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