Power and Cost Modeling for 5G Transport Networks

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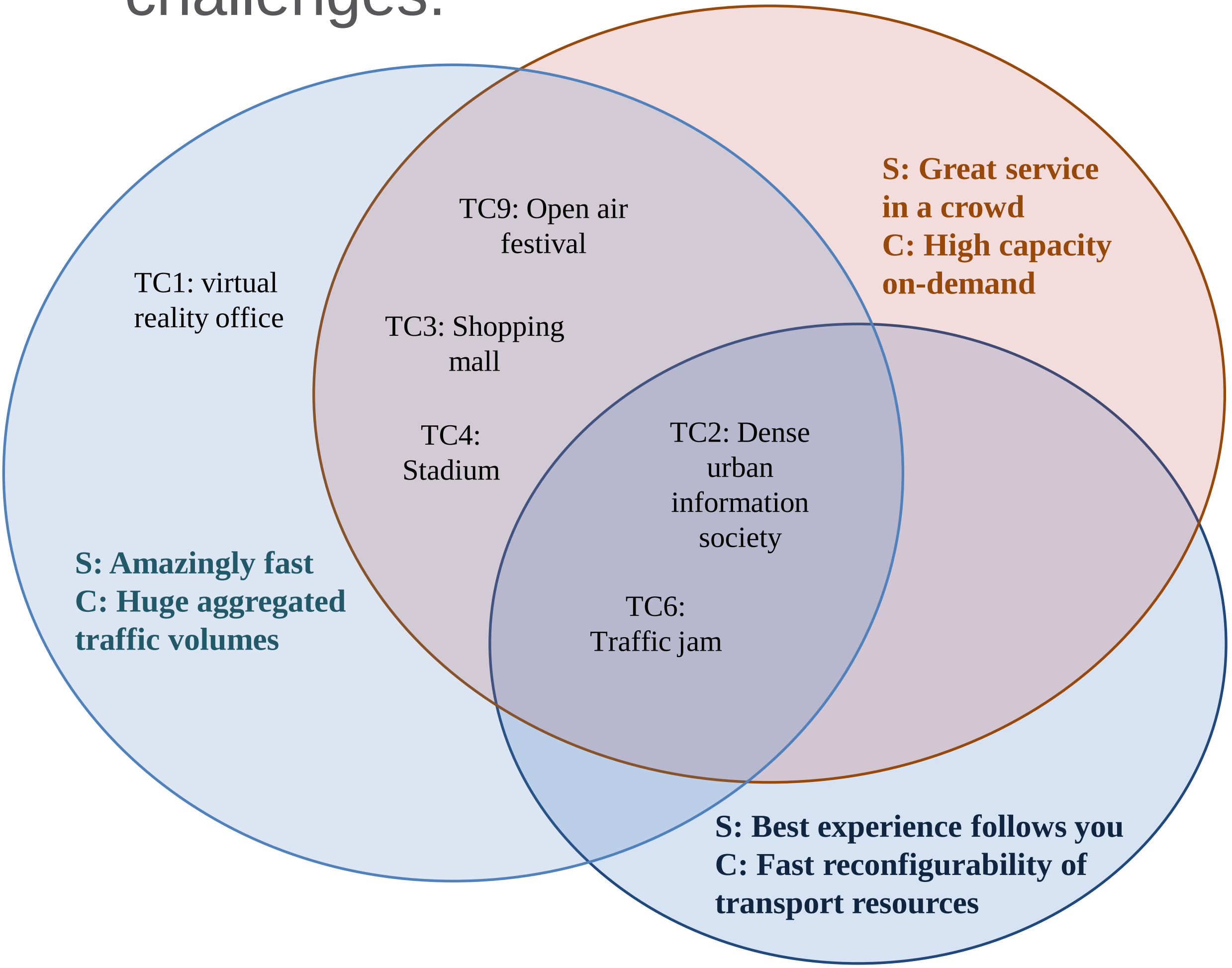
Outline

- 5G Networks → 5G transport challenges
- NFV effective in flexible transport resource provisioning
- Architectural options enabling NFV: power vs. cost analysis
- Conclusions

5G transport challenges

- The 5G challenges → transport challenges:



TC9: Open air festival

TC1: virtual reality office

TC3: Shopping mall

TC4: Stadium

TC2: Dense urban information society

TC6: Traffic jam

S: Great service in a crowd
C: High capacity on-demand

S: Amazingly fast
C: Huge aggregated traffic volumes

S: Best experience follows you
C: Fast reconfigurability of transport resources

- **Very high data rate** → huge aggregated traffic volumes
- **Very dense crowds of users** → provide high capacity on-demand
- **Best experience follows you** → fast reconfigurability of transport resources

- **Latency**: new applications with extreme delay requirements, e.g., ITS, mission critical M2M, and their requirements on transport to be investigated
- The **massive number of connected devices** not a major issue: the traffic from a large number of machines over a geographical area will be aggregated

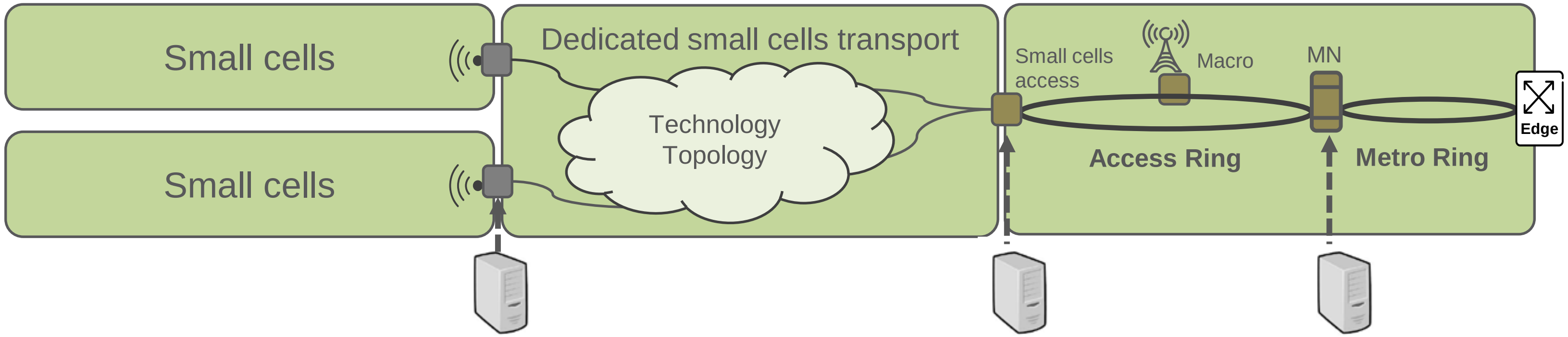
M. Fiorani, P. Monti, B. Skubic, J. Mårtensson, L. Valcarenghi, P. Castoldi, L. Wosinska, "Challenges for 5G Transport Networks", *in Proc. of IEEE ANTS,* 2014.

How to tackle transport challenges?

- Two main directions for provisioning high capacity on-demand and in a flexible way
- **Overprovisioning**: high capacity on-demand with (possibly) fast resource reconfiguration is satisfied thanks to the ubiquitous availability of ultra-high capacity transport
  - Pros: relatively low complexity at the control plane
  - Cons: potentially high cost because of inefficient use of network resources
- **“Intelligence”** in the transport infrastructure
  - **Dynamic resource sharing:** re-configurable systems for dynamically sharing limited transport resources
  - **Network functions virtualization (NFV)**: dynamically push network functions to different locations, e.g., closer to the users so that a portion of the traffic requests can be served locally

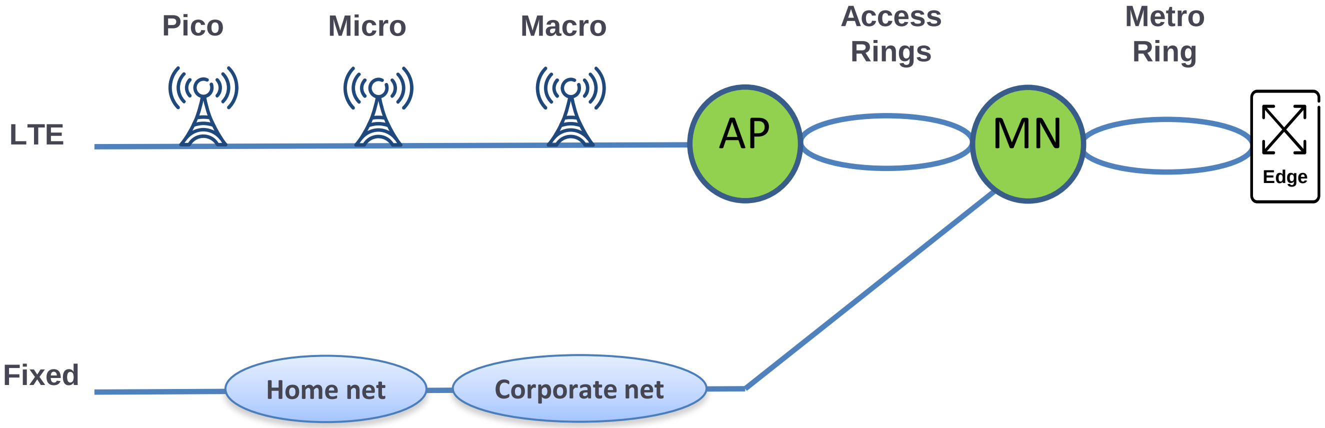
Network function virtualization

- The type of resources that can be dynamically virtualized depends on:
  - Service type required by the user
  - Business model (agreement between wireless and transport providers)
- Example of resources that can be virtualized:
  - Wireless network functions: BB processing, evolved packet core (EPC)
  - Transport network functions: packet aggregation
  - Cloud resources: cache/storage
- Servers/micro-DC needs to be available in different network locations



Data plane options for NFV

- “Metro simplification” is a power/cost efficient architecture allowing for the reduction of the number of local exchanges (i.e., simplification)
- Comprises two type of rings
    - Optical access ring: collects the traffic from mobile network via an access point (AP)
    - Optical metro ring: connected to the access ring via a metro node (MN) aggregates and transmits traffic (possibly including the fixed one) toward the service edge



B. Skubic, I. Pappa , “Energy consumption analysis of converged networks: Node consolidation vs. metro simplification”, *in Proc. of OFC/NFOEC*, 2013

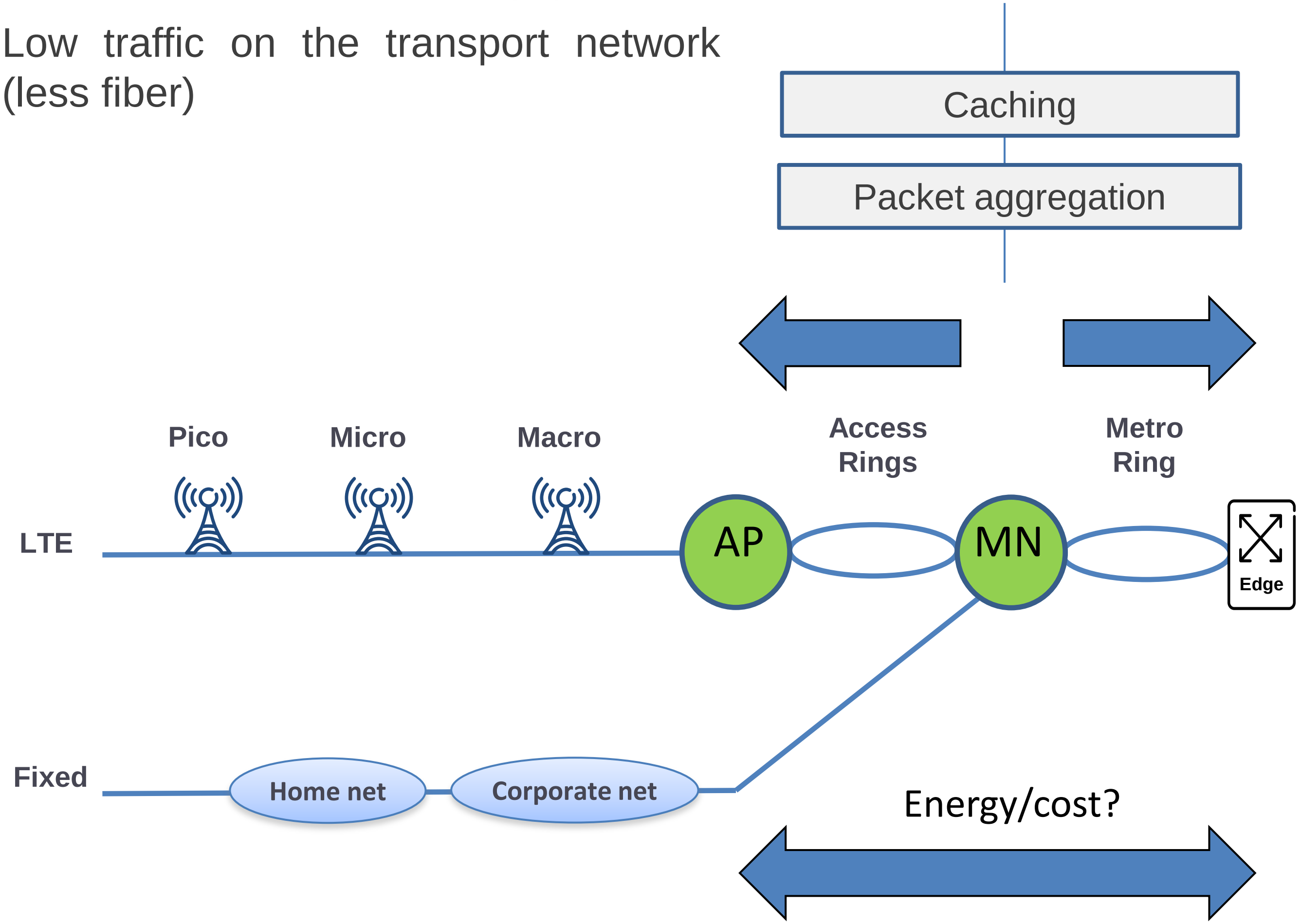
Impact of functionality placement

Moving functions toward the users:

- ■ Large amount of network equipment
- ✓ Low traffic on the transport network (less fiber)

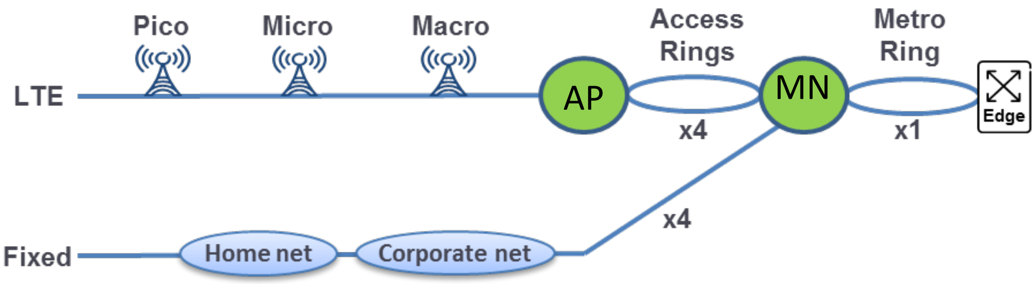
Moving functions toward the core:

- ✓ Small amount of network equipment
- ■ High traffic on the transport network (more fiber)

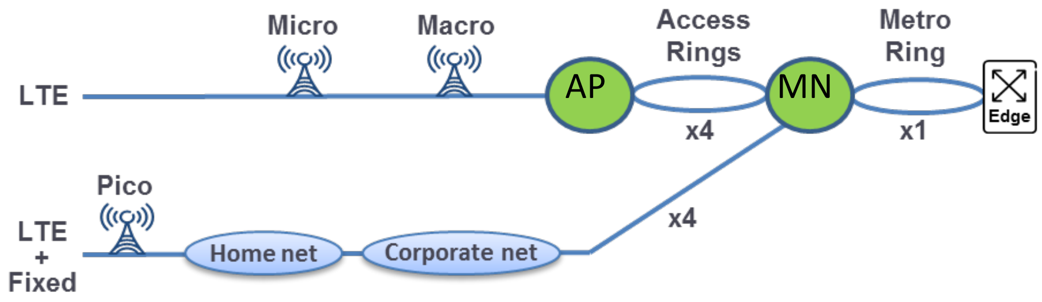


Data plane architectural options

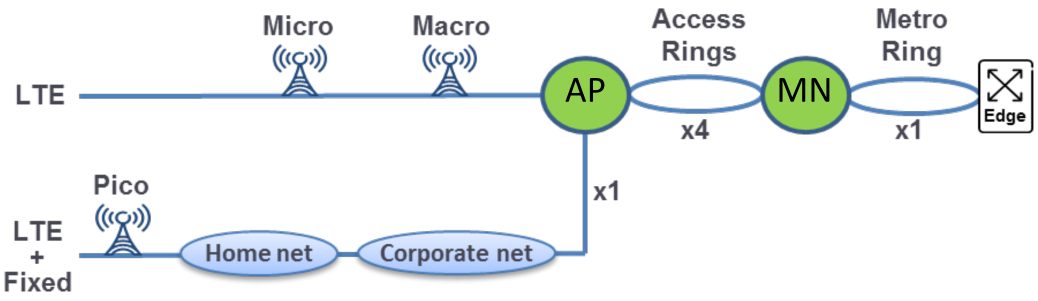
Case I



Deployment A



Deployment B



Deployment C

Case I = optical switching at MN / no caching

Case II = optical switching at MN / caching at AP

Case III = electronic switching at MN / no caching

Case IV = electronic switching at MN / caching at MN

Case V = electronic switching at MN (hybrid 10G/100G) / no caching

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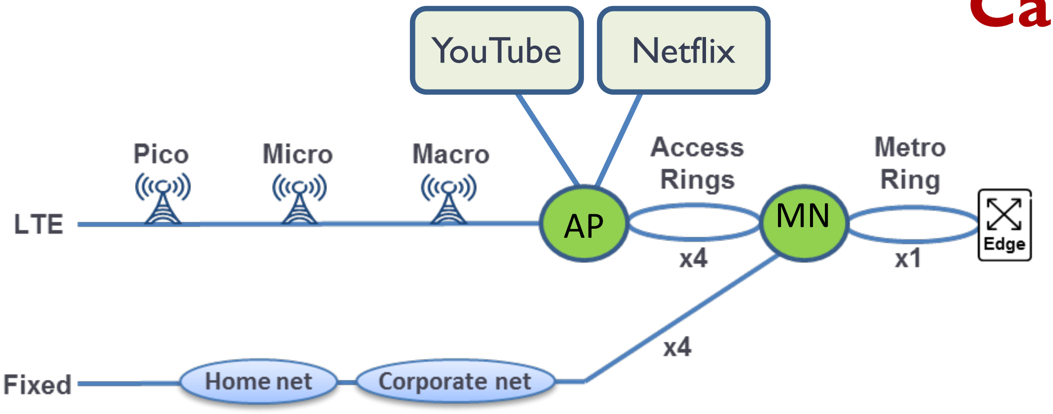
Data plane architectural options

Case II



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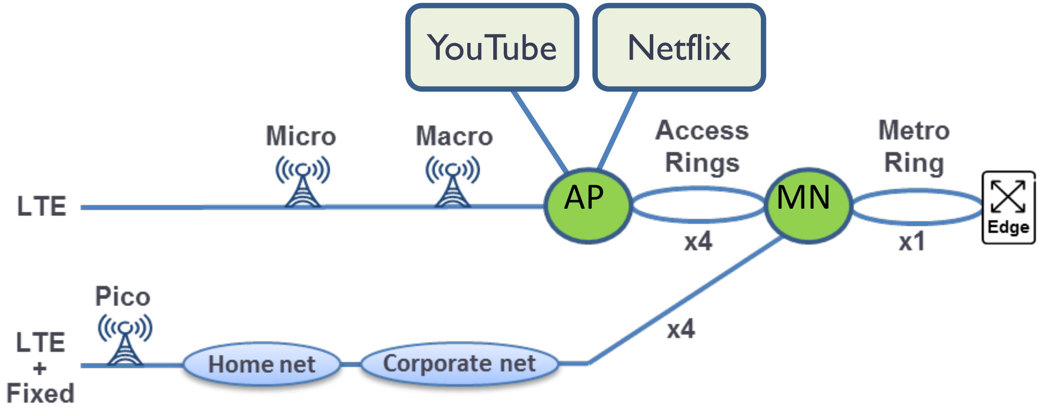

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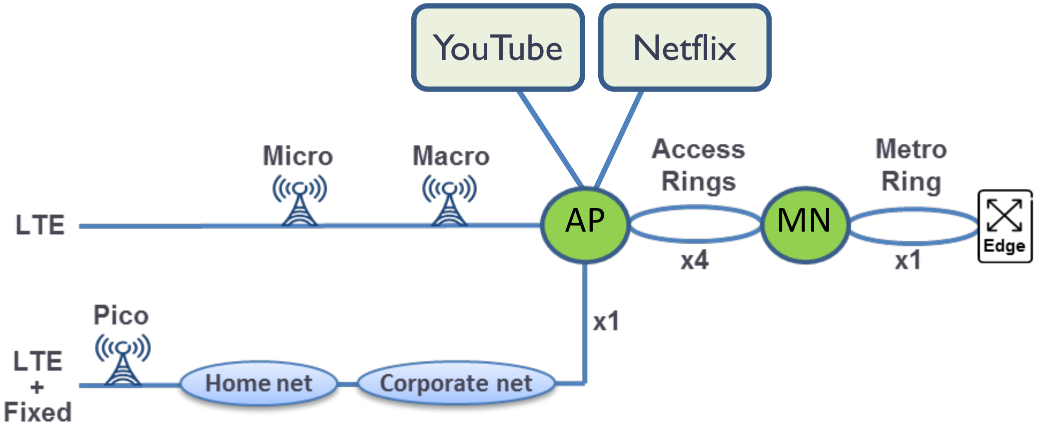

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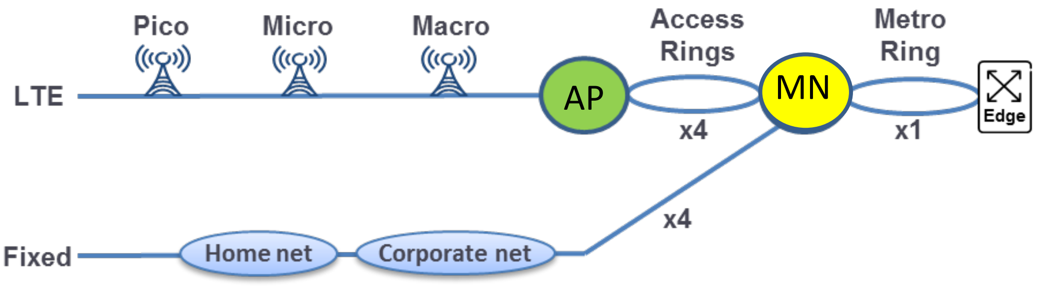
Data plane architectural options

Case III



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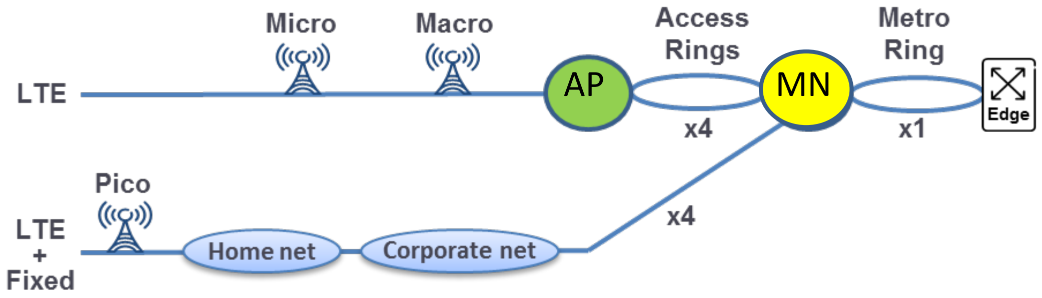

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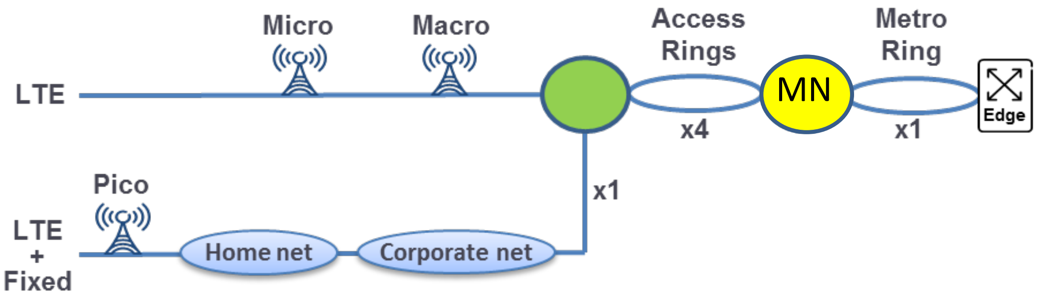

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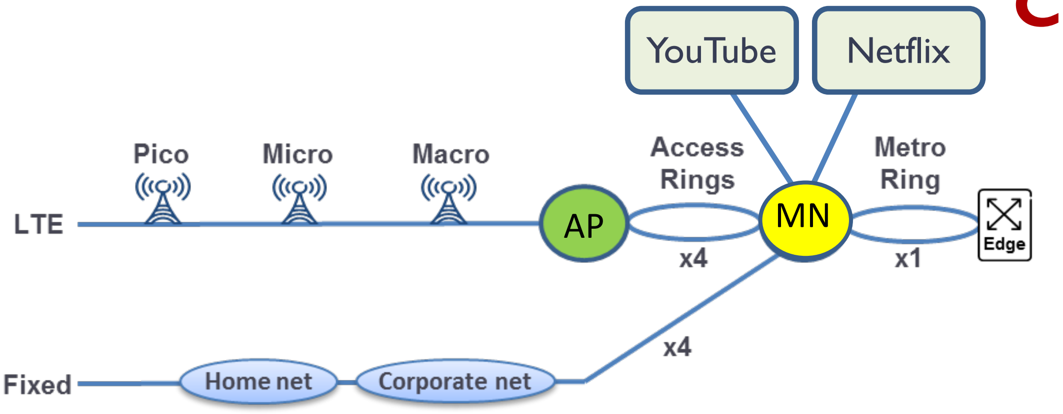
Data plane architectural options

Case IV



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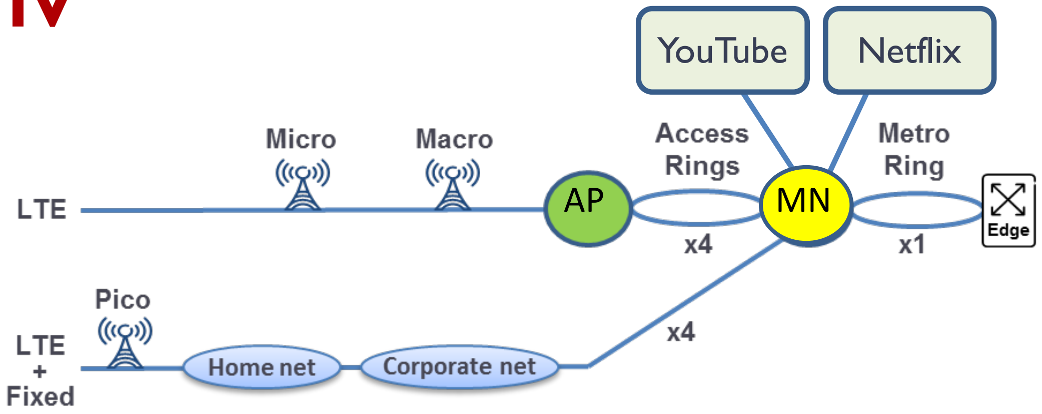
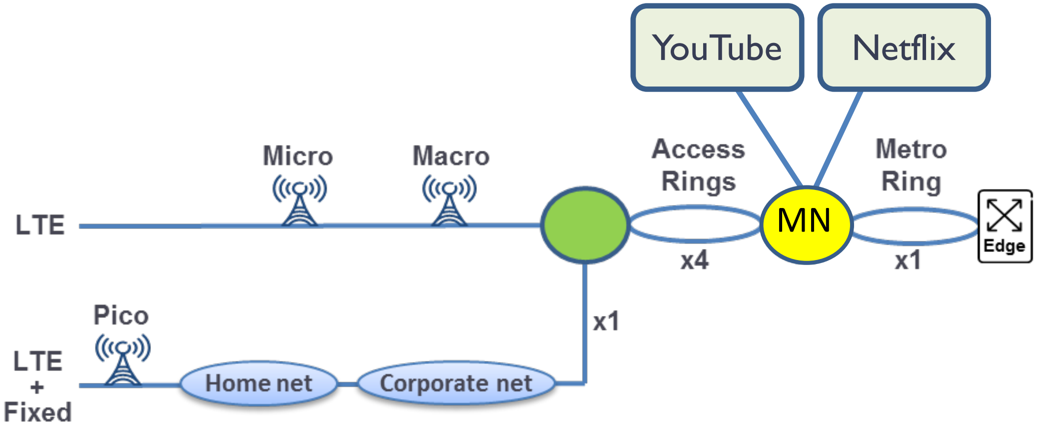


Deployment B



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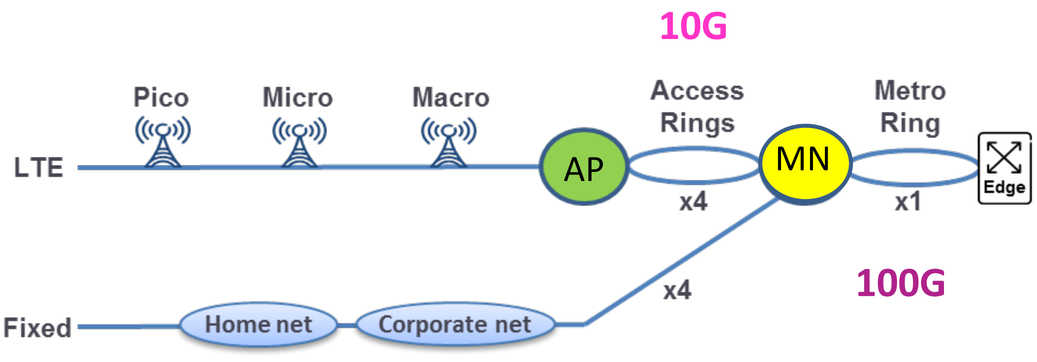
Data plane architectural options

Case V



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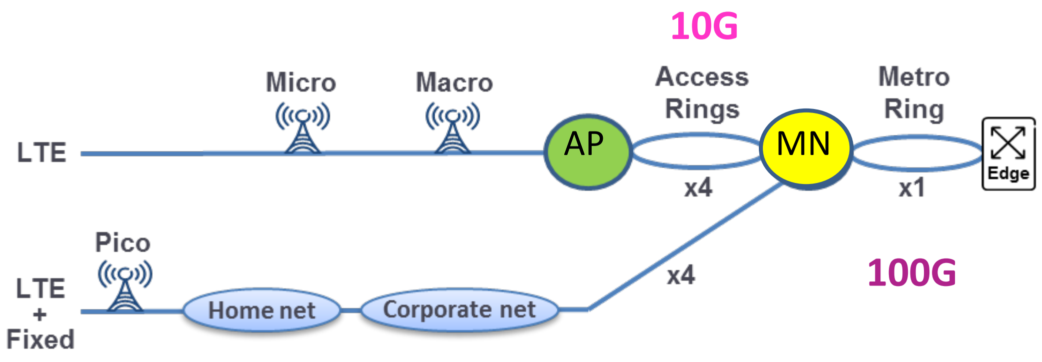
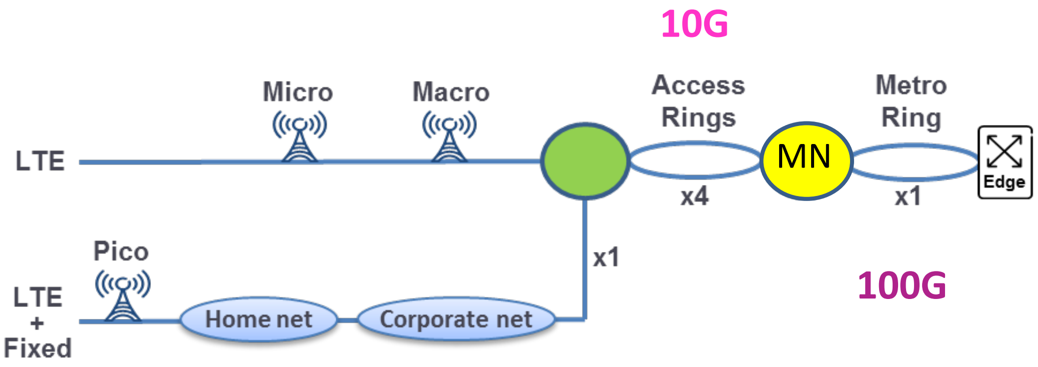


Deployment B



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Data plane architectural options

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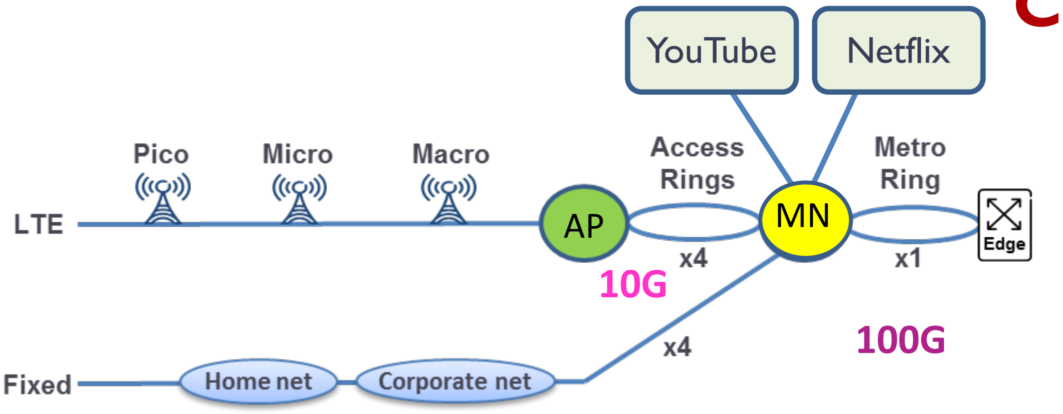

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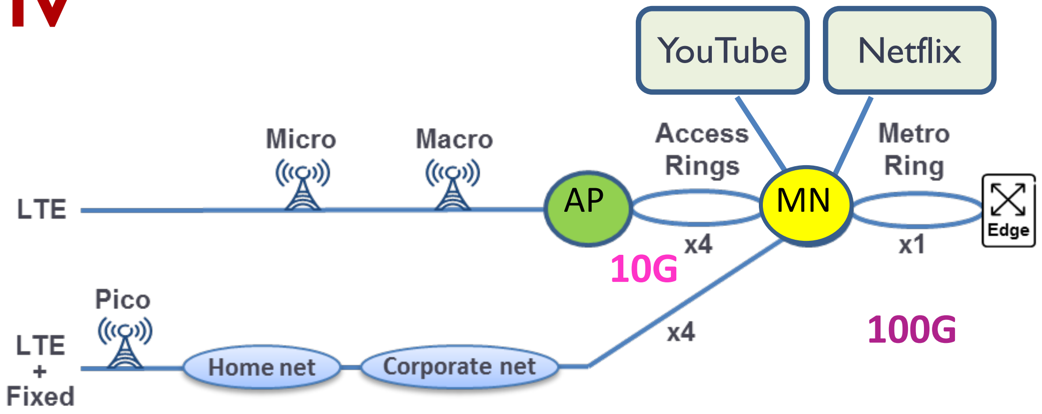

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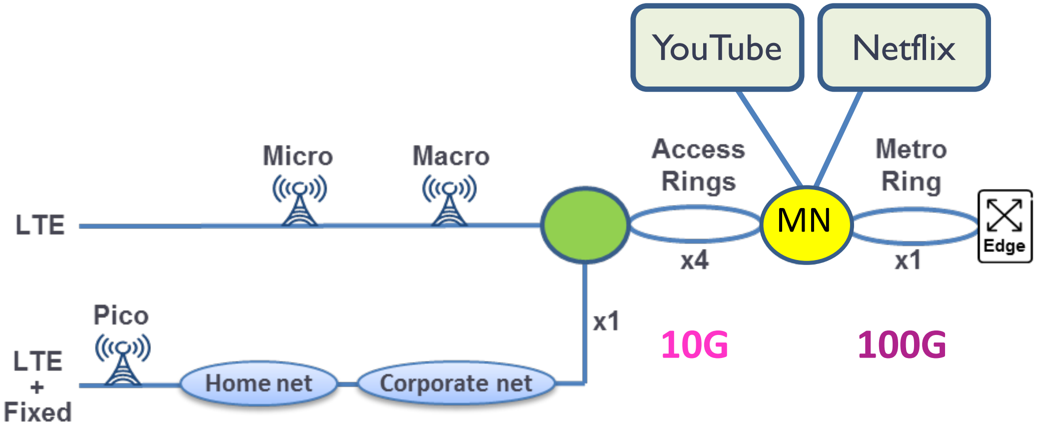

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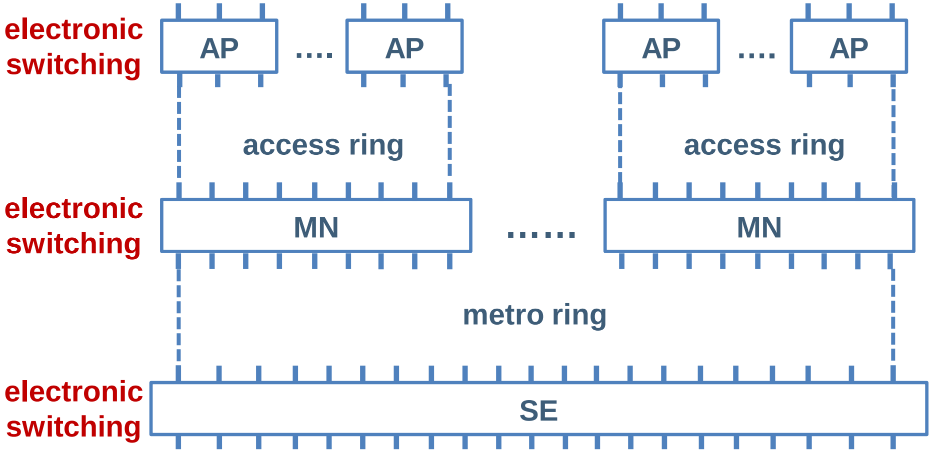
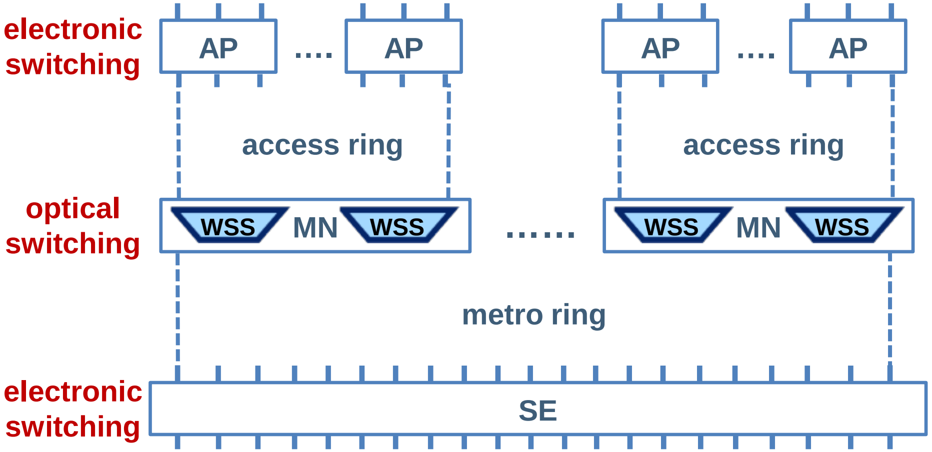
Power consumption model

- Assumption: power consumption increases linearly with the number of ports at AP, MN and SE



Model for packet-centric networks



Model for DWDM-centric networks

$$
\begin{aligned}
P_{total} = {} & \left(N_{in,\,AP}\;P_{AP} + N_{out,\,AP}\;P_{AP}\right) \times \text{number of APs} + \\
& \left(N_{in,\,MN}\;P_{MN} + N_{out,\,MN}\;P_{MN}\right) \times \text{number of MNs} + \\
& \left(N_{in,\,SE}\;P_{SE} + N_{out,\,SE}\;P_{SE}\right) \times \text{number of SEs}
\end{aligned}
$$

$$
\begin{aligned}
P_{total} = {} & \left(N_{in,\,AP}\;P_{AP} + N_{out,\,AP}\;P_{AP}\right) \times \text{number of APs} + \\
& \left(N_{WSS,\,access}\,P_{WSS}\,n_{access} + N_{WSS,\,metro}\,P_{WSS}\,n_{metro}\right) + \\
& \left(N_{in,\,SE}\;P_{SE} + N_{out,\,SE}\;P_{SE}\right) \times \text{number of SEs}
\end{aligned}
$$

where

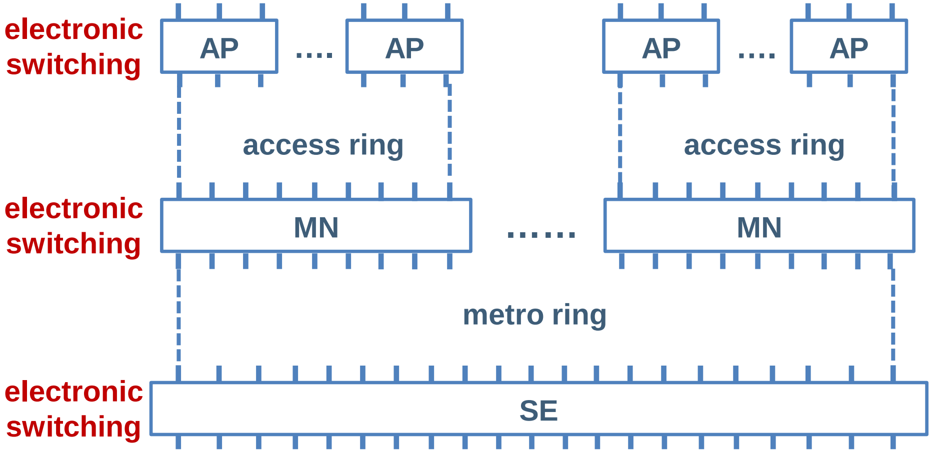
$N_{in,\,AP}$ = number of input ports per AP
$N_{out,\,AP}$ = number of output ports per AP
P_{AP} = power consumption per port of AP

and so on…

n_{access} = number of access rings
$N_{WSS,\,access}$ = number of WSS per access ring
P_{WSS} = power consumption of WSS

Cost model

- Assumption: cost increases linearly with the number of ports at AP, MN and SE



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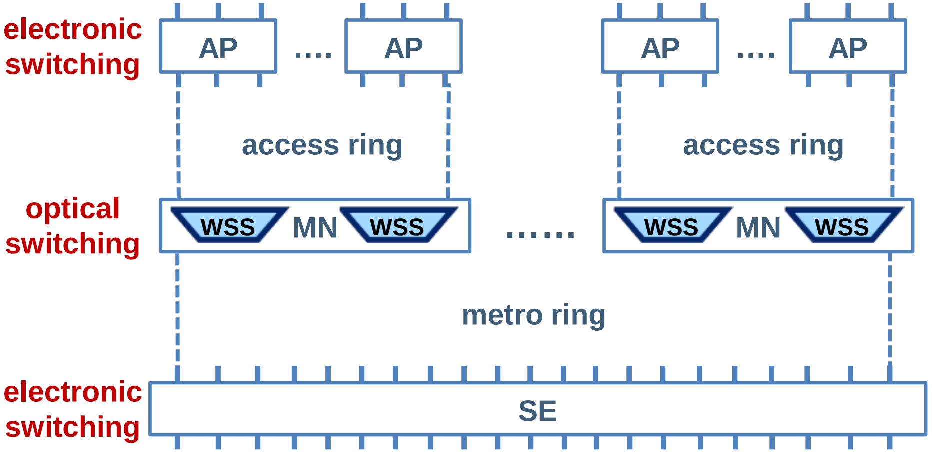

Model for DWDM-centric networks

$$\begin{aligned} C_{total} = {} & \left(N_{in,\,AP}\ C_{AP} + N_{out,\,AP}\ C_{AP}\right) \times \text{number of APs} + \\ & \left(N_{in,\,MN}\ C_{MN} + N_{out,\,MN}\ C_{MN}\right) \times \text{number of MNs} + \\ & \left(N_{in,\,SE}\ C_{SE} + N_{out,\,SE}\ C_{SE}\right) \times \text{number of SEs} \end{aligned}$$

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C_{AP} = cost per port of AP

and so on…

n_{access} = number of access rings
$N_{WSS,\,access}$ = number of WSS per access ring
C_{WSS} = cost of WSS

Geo-type: very dense urban area

Scenario:

1. CO service area: 2 km^2
2. Macro: 60 (30 per km^2)
3. Micro: 600
4. Pico (indoor): 6000
5. Buildings (in 2 km^2 area): 400
6. Businesses: 10 per building
7. Homes: 50 per building
8. People: 200k
9. People (office): 160k
10. People (res): 40k

Service Requirements :

1. Macro: 228 Mb/s
2. Micro: 90 Mb/s
3. Pico (indoor): 132 Mb/s
4. Residential user: 16 Mb/s
5. Business user: 202 Mb/s

	Number per AP	Rate/each [Gbps]	Traffic [Gbps] per AP	Total Traffic [Gbps] for 60 APs
LTE				
Macro	1	0.228	0.228	13.7
Micro	10	0.090	0.9	54
Pico	100	0.132	13.2	792
Fixed				
Residential	333	0.016	5.33	320
Business	67	0.202	13.47	808

** Note that only LTE backhaul (no CPRI) is assumed.

Typical power and cost values

- Typical power and cost values

		Power Consumption [Watt]		Cost [CU] [3] in Year 2014	Cost [CU] [3] in Year 2018
electronic switching	Ethernet 10 Gbps port	38	[1]	1.56	0.89
	Ethernet 100 Gbps port	205	[1]	28.89	10
optical switching	WSS 10 Gbps / 100 Gbps	20	[2]	5.56	3.89

- Caching
  - Sandvine 1H-2014 Global Internet Traffic Report

Fixed YouTube	12,28%
Mobile YouTube	17,26%
Fixed Netflix	31,09%
Mobile Netflix	4,55%

$$P_{cache} = (N_{cache,MN} P_{MN} + P_c)\, n_{MN}$$

$$C_{cache} = (N_{cache,MN} C_{MN} + C_c)\, n_{MN}$$

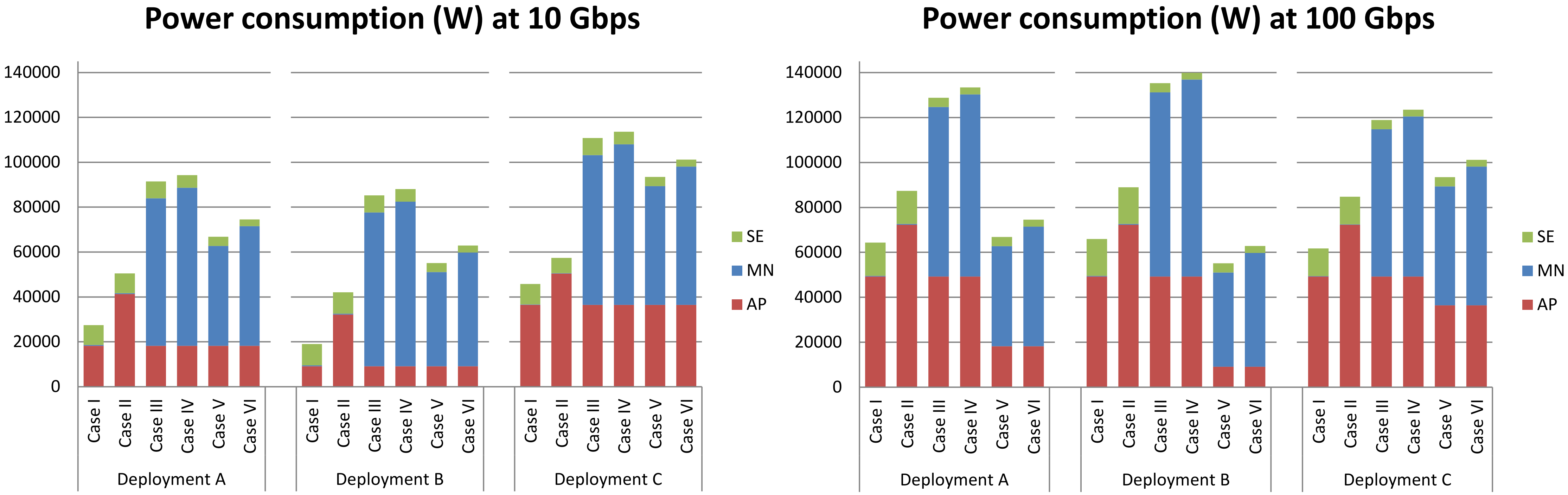
  - Offloading factors: YouTube 24%, Netflix 77,7%

[1] Van Heddeghem, Ward, Filip Idzikowski, Willem Vereecken, Didier Colle, Mario Pickavet, and Piet Demeester. 2012. “Power Consumption Modeling in Optical Multilayer Networks” *Photonic Network Communications* 24 (2): 86–102

[2] http://www.finisar.com/sites/default/files/pdf/DWP100_Wavelength_Selective_Switch_Product_Brief_9_2011_V6.pdf

[3] 1 CU = market price of 10 Gbps transponder during the year 2014

Power consumption evaluation



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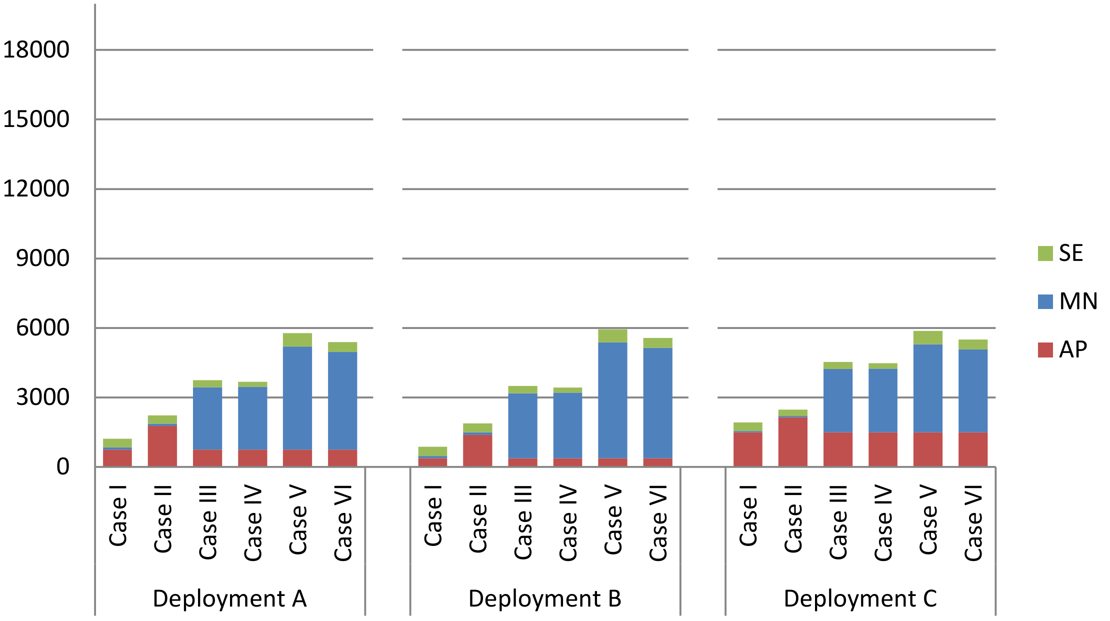
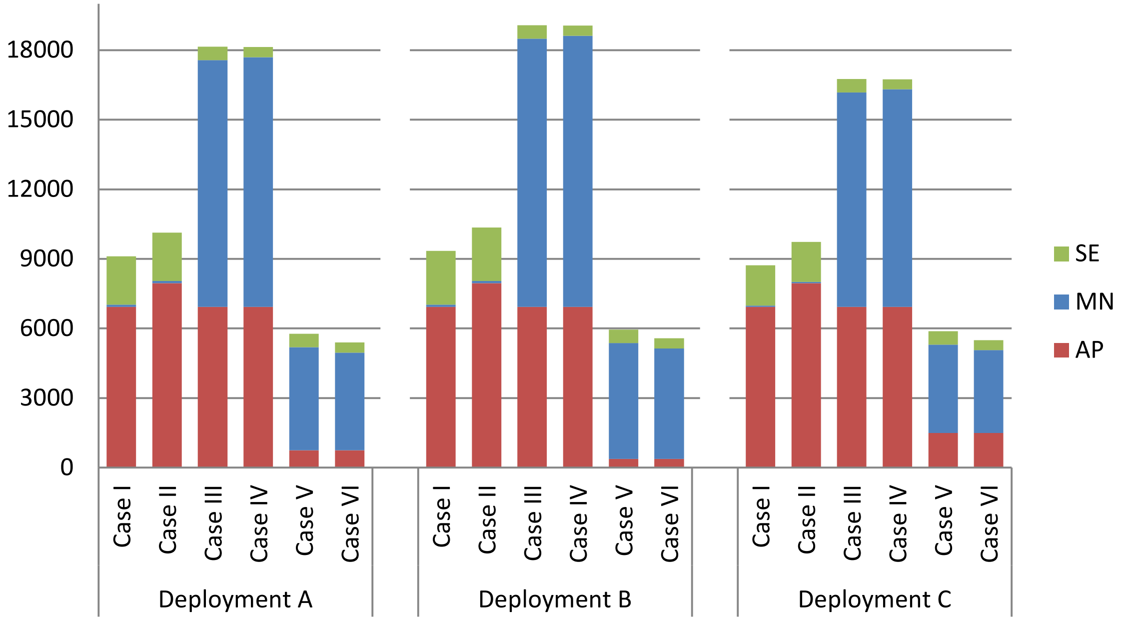
WSS 10 Gbps / 100 Gbps	20	5.56	3.89

Cost evaluation: the 2014 case



2014: Total Cost (CU) at 10 Gbps



2014: Total Cost (CU) at 100 Gbps

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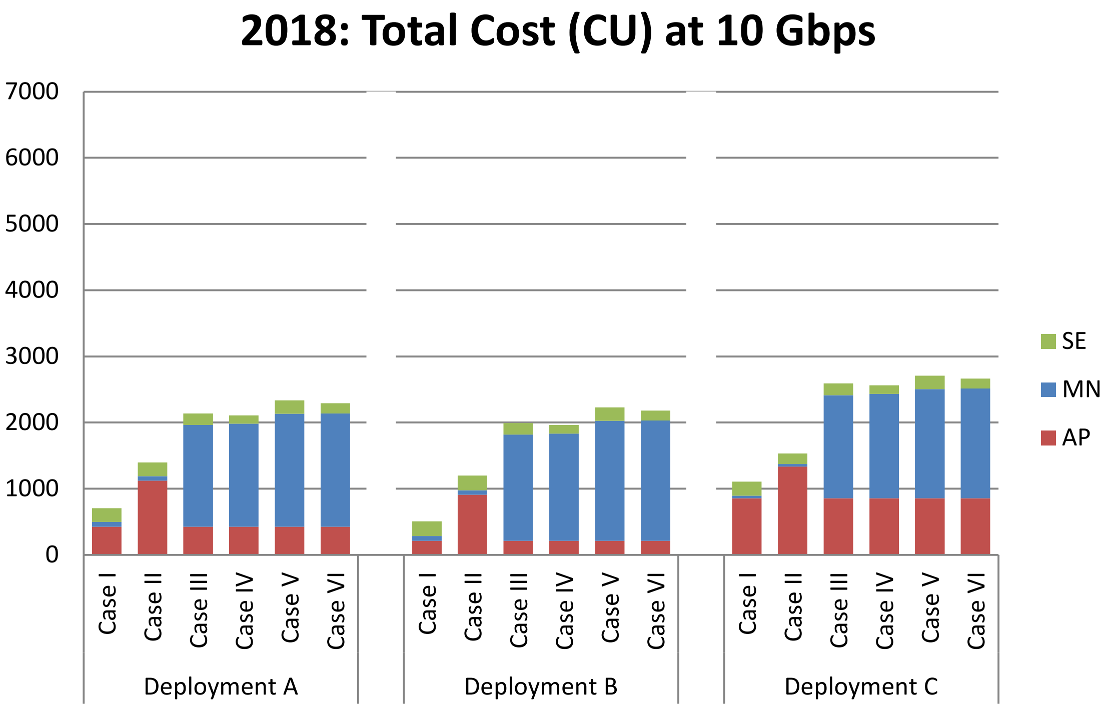
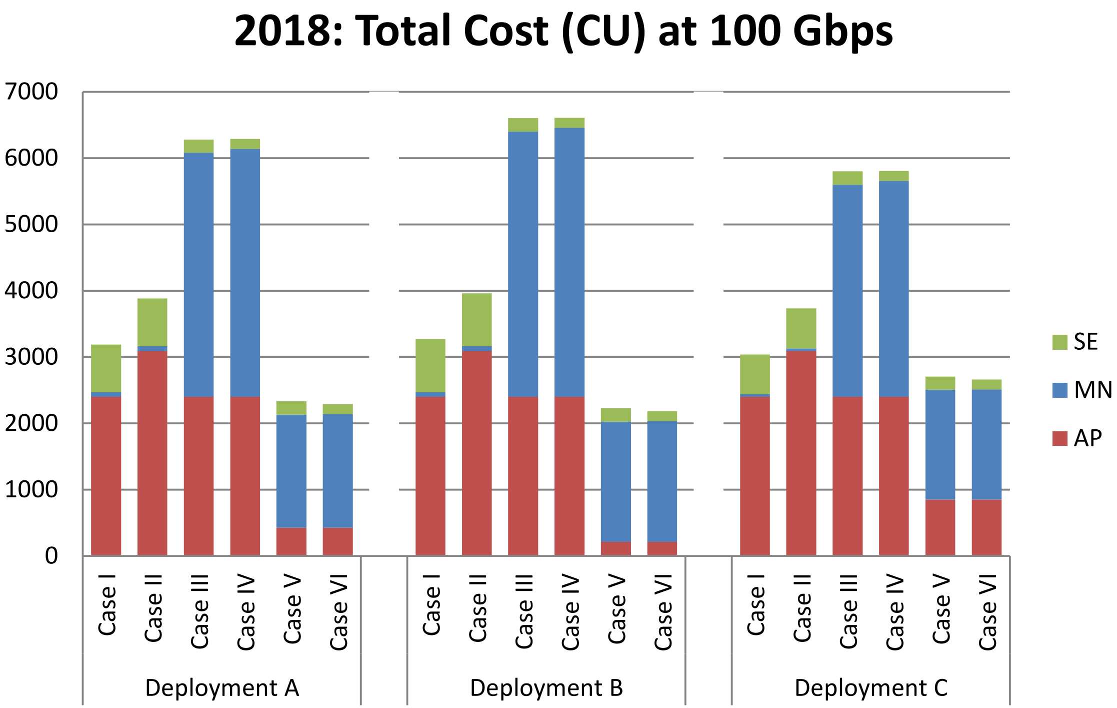
Cost evaluation: the 2018 case


2018: Total Cost (CU) at 10 Gbps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Conclusions

- Discussed the challenges a transport network has to face in order to accommodate future 5G services
- Analyzed cost and power performance of a number of data plane architectures that can enable NFV
- Introducing NFV has an impact in terms of cost and power consumption
- Hybrid 10G/100G with electronic aggregation might be a good compromise
- Interesting to investigate the pros/cons when balanced with the benefits in the wireless access segment, e.g., cost and energy benefits brought by FH

References

- M. Fiorani, B. Skubic, J. Mårtensson, L. Valcarenghi, P. Castoldi, L. Wosinska, P. Monti, "On the Design of 5G Transport Networks," Springer Photonic Network Communications (PNET) Journal, Vol. 30, No. 3, pp. 403-415, December, 2015
- M. Fiorani, P. Monti, B. Skubic, J. Mårtensson, L. Valcarenghi, P. Castoldi, L. Wosinska, "Challenges for 5G Transport Networks," in Proc. of IEEE International Symposium on Advanced Networks and Telecommunication Systems (ANTS), New Delhi, India, December 14-17, 2014
- B. Skubic, I. Pappa , "Energy consumption analysis of converged networks: Node consolidation vs. metro simplification", in Proc. of OFC/NFOEC, 2013
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