Telecom Argentina

Transport Network Evolution For Future Services

A Technical Paper prepared for SCTE•ISBE by

Javier Ger
Cloud Infrastructure Strategy Manager
Telecom Argentina
Aguero 2392 - C1425EHZ , CABA - Argentina
+541155304531
jger@teco.com.ar

Esteban Poggio
Cloud Infrastructure Strategy Architect
Telecom Argentina
Aguero 2392 - C1425EHZ , CABA - Argentina
+541155304756
epoggio@teco.com.ar

Miguel Masache Ojeda
Cloud Infrastructure Strategy Architect
Telecom ArgentinaTelecom Argentina
Aguero 2392 - C1425EHZ , CABA - Argentina
+541140015669
mmojeda@teco.com.ar

Furquan Ansari
Partner
Bell Labs Consulting
600 Mountain Avenue, Murray Hill, NJ 07974
+1-732-768-5876
furquan.ansari@bell-labs-consulting.com

Ben Tang
Principal Consultant
Bell Labs Consulting
4573 Kentucky Drive, Plano, TX 75024
+1-469-910-3698
ben.tang@bell-labs-consulting.com

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Abstract

CSPs[1] all over the world are evolving their networks to be future-ready as the march towards 5G[2] continues. The new Telecom Argentina, formed through the merger of a cable and a telco companies, is not only undertaking the complex merger and consolidation of the two disparate and diverse networks, but at the same time also transforming to a unified and converged next-generation architecture that can support all future needs.

This paper addresses the transformation of the IP[3] and optical Core/Backbone architecture and technology, considering not only an optimized and flexible topology from a TCO[4] and current/future services point of view, but also features and functionalities this network has to support to meet the afore-mentioned objectives for the next 5 years and beyond. It addresses some of the key challenges, drivers, and specific characteristics such as fiber plant locations, diversity and resiliency requirements, traffic patterns, and densities, etc. that must be taken into consideration to develop a candidate set of network topologies for the given geography and demography. Both qualitative and quantitative criteria are then applied to select the right future architecture. It also provides rules that can be applied to determine optimal conditions to adapt this architecture to future demands with minimal impact, i.e. to create a dynamically adaptive network that can support any future, on-demand services.

The work will further elaborate on some of the salient points of this new architecture - including traffic and capacity optimization, content distribution strategies, network function distribution, DC[5]/edge cloud distribution, IGP[6] strategies,optical features, etc. to ensure an economically and operationally efficient backbone. It will discuss the incorporation and use cases of new technologies such as SR[7], SDN[8], NFV[9], etc. as key enablers to truly achieve this target flexible network able to support next-generation services.

Content

1. Overview Of Telecom Argentina

The new Telecom Argentina is the result of the merger between two companies, Cablevision Argentina, which was a cable company, and Telecom Argentina itself, a traditional telco and one of the most important telecommunications companies in the country.

The new company has approximately 30 million customers in Argentina, distributed as follows.

- 18.6 million mobile subscribers
- 4.1 million fixed broadband subscribers
- 3.5 million TV subscribers

[1] Communications Service Providers.
[2] 5th Generation Networks.
[3] Internet Protocol.
[4] Total Cost of Owership.
[5] Datacenter.
[6] Interior Gateway Protocol.
[7] Segment Routing.
[8] Software Defined Networks.
[9] Network Functions Virtualization.

- 3.6 million fixed telephone lines

These numbers clearly demonstrate the importance and leadership position of new Telecom Argentina and sets itself as the most important company to offer 4Play[10] services (see Figure 1)

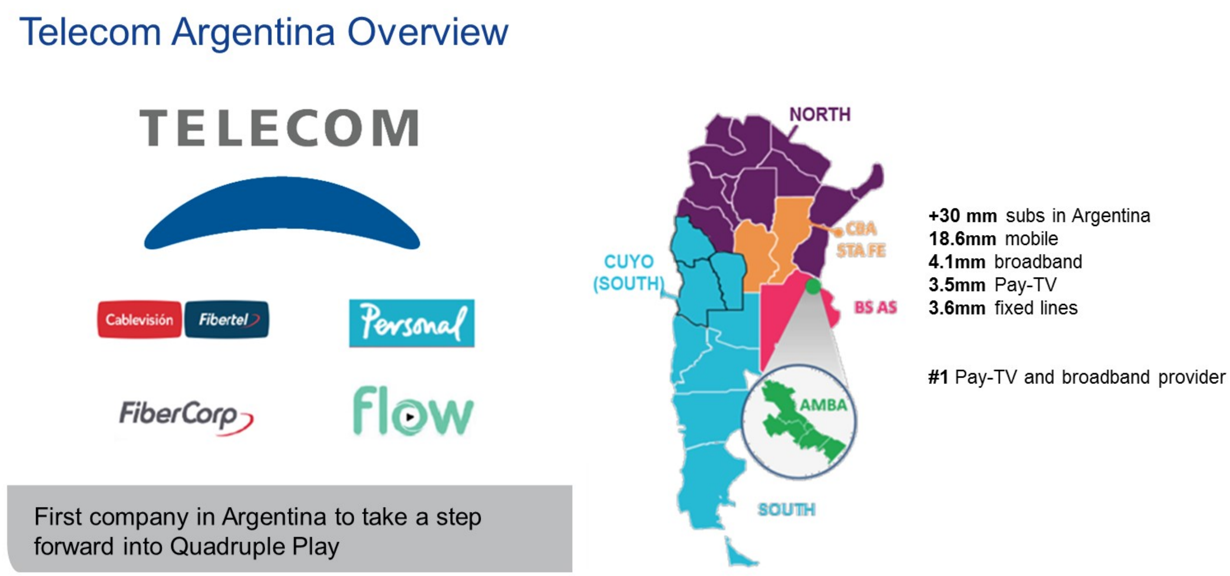

Figure 1 - Presentation of the new Telecom Argentina.

2. Strategic Objectives And Drivers

2.1. Strategic Objectives

As part of the merger process, the new Telecom Argentina defined strategic objectives at both business and technical levels across the combined company, including for the Core/Backbone network. The strategic technical objectives were defined to meet the strategic business objectives, in such a way that they were coherent with and complimentary to each other.

The goal of the merger is to make (and retain) the new Telecom Argentina as the leading CSP in Argentina. To achieve this, the following strategic business objectives are defined:

- Market Leadership: Maintain the leadership in the fixed broadband service, increase the market share of the mobile service and corporate services with diversified solutions.
- User Experience: Enhance this aspect to increase the ARPU[11], to evolve the FLOW[12] offer, leveraging the granularity of fixed and mobile access to offer bundled service packages.
- Enhance Synergies: Optimize investments (avoiding overlaps) through integration of the Core/Backbone networks. The execution of the integration could last a period of approximately 3 years.

[10] 4Play - Quad Play Products - Offers products that package Internet, Video, Mobility and Fixed Telephony.
[11] Average Revenue Per User.
[12] Telecom Argentina IPTV Services and Video On-Demand.

These strategic business objectives are translated into strategic technical objectives for the Core/Backbone network in the form of a consolidated, evolved, future-proof Core/Backbone network that has a flexible and scalable architecture that allows for growth of current services, deployment of futures services and has ability to adopt new technologies on the 5G path. It should also be simple to plan and operate, distributing content and traffic efficiently to improve the user experience and optimize the deployment of infrastructure, capacity and resources.

2.2. Drivers For Network Architecture Change

In order to meet the key business objectives defined in the previous section, the need arose to develop a single, consolidated Core/Backbone network for the merged company that would be sufficiently different from either of the existing former company networks (known as PMO[13]). The consolidation was meant to retain and leverage the strengths of each of the former networks. The high-level strategic objectives were further evolved into the following requirements for the Core/Backbone network:

- Minimize the TCO: In order to maintain the market leadership position, it is imperative that the network is run as cost efficiently as possible. Network TCO is a major challenge mainly due to the aggressive traffic CAGR[14] values that are being observed and the demand that the future new services could generate.
- Improve Time to Market (TTM[15]): Create a flexible and highly adaptable network architecture that will increase revenues by accelerating the service creation and instantiation with just-in-time delivery.
- Minimize latency: Based on service specific requirements, especially those driven by 5G (for example, IoT[16]).
- Assure resilience: Support fault conditions minimizing possible impact on services and customers.

In order to cover these requirements, e.g. to adapt services and product offers dynamically (a classic example is being able to generate bandwidth on demand), the flexibility, agility and simplicity of the future architecture are fundamental properties that should be taken into account.. The aforementioned architecture must adapt to the traffic matrix and its possible changes in a scalable manner. It should allow for designing optimal routing, fiber layout, connection schemes, operations and multilayer redundancies with coordinated work between the IP and optical layers. It should avoid lock-in by suppliers/vendors and improve innovation cycles of architectural components.

3. Backbone Network Challenges & Architecture Evolution

As mentioned, the architecture design of the new Telecom Argentina network should not only consider unifying the networks of both former companies but also evolve them by taking into account the combined traffic growth and profiles. This new architecture will be called the FMO[17].

On one hand, from the point of view of the IP layer there are a series of challenges to consider, including resolving possible overlap of IP addressing (mainly private) when unifying the IGP, consolidating into a

[13] Present Mode of Opeation.
[14] Compound Annual Growth Rate.
[15] Time to Market.
[16] Internet of Things.
[17] Future Mode of Operation.

single ASN[18], connections to Internet providers and route reflectors, unifying QoS[19], provisioning and monitoring systems, etc.

On the other hand, from the optical layer point of view, there are different challenges to consider, such as diversity of optical platforms, partitioniong of the optical network into vendor-specific networks, type and quality of the optical fiber deployed by the two companies (G.653, G.655 and G.652), etc. It is therefore necessary to analyze (not in this first stage but at a future point) the optical domains individually to allow for their optimization and also identify a strategy for the deployed optical fiber that will solve possible limitations of bandwidth, either due to the conditions inherent to certain types of fiber or to the distances of the links based on the transmission rates required.

3.1. Target Topology Selection

This section describes the procedure for selecting the FMO. As a starting point, the existing topologies of each former company prior to the merger should be considered (see Figure 2).

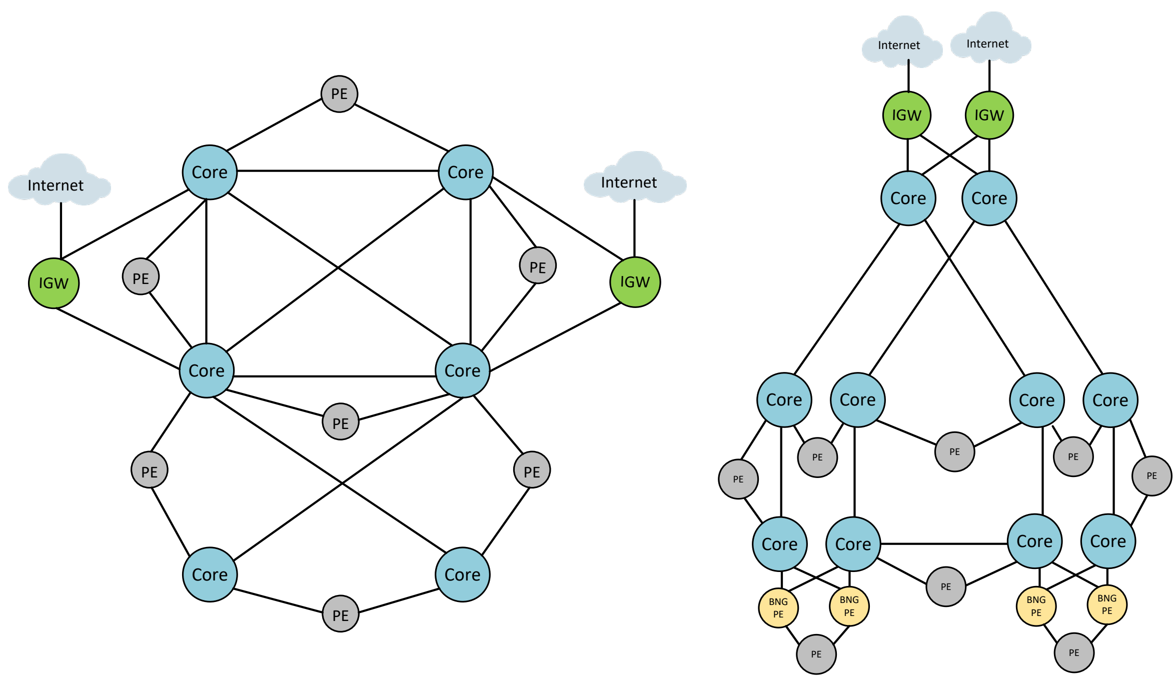

Figure 2 - Former companies existing topologies.

As part of the process, different topologies for the FMO selection were evaluated. Various candidate topologies were proposed, taking into account the subscriber base, traffic profiles and future traffic growth. From them, 7 candidates were selected (see Figure 3)

Figure 3These candidate topologies, called FMO1 to FMO7, covered all the alternatives proposed by the working group for further analysis. These topologies represent different configurations of polygons with diverse geographic locations of different devices and numbers of Inner-core and Outer-core, to star

[18] Autonomous System Number.
[19] Quality of Service.

topologies, ring and combinations thereof. It also includes potential optimization using optical bypass, where possible.

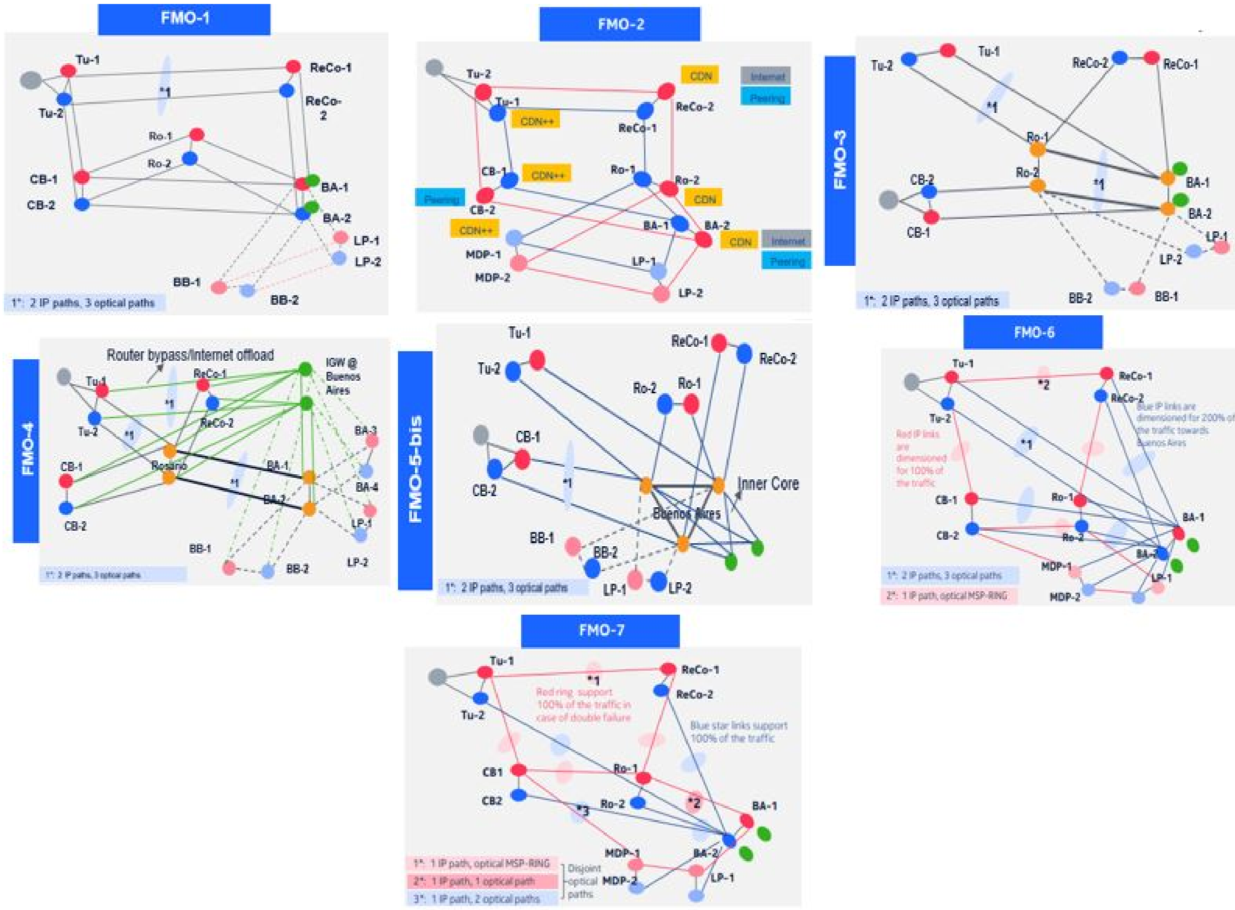

Figure 3 - Candidate topologies.

These candidate FMOs were analyzed and scored based on various evaluation criteria, each with a specific metric and weight.

- Cost Efficiency
- E2E[20] Latency
- Resiliency
- Architecture Flexibility
- Operational Simplicity
- Simplicity of Migration
- Future Evolution Capacity
- Security

A qualitative analysis was accomplished based on the proposed weighting of all criteria for all the candidate FMOs. This qualitative analysis resulted in two finalist FMO architectures (at this point, in

[20] End-To-End.

addition to the topologies, different options of functionalities, technologies, etc. were also considered and analyzed). This procedure is outlined in Figure 4.

Finally, for the two final candidate FMO architectures, a detailed quantitative analysis was performed that included traffic routing and failure simulations using network modeling tools and took into account other technical aspects, including flexibility and change impacts, etc. The quantitative anlysis resulted in a 5-year TCO calculation for both candidate FMO architectures. Based on these results, the definitive one was selected. The selected architecture is the one identified as FMO5.

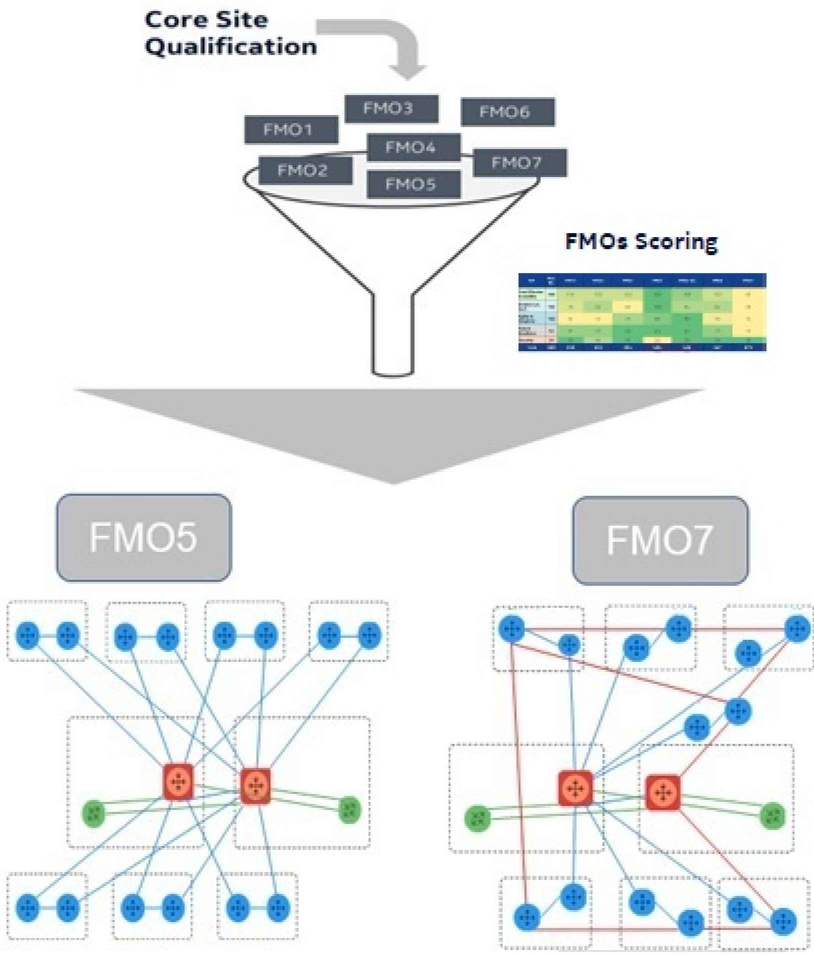

Figure 4 - FMO selection process.

3.2. IP Network

As a result of the process described in section 3.1, the target architecture for the FMO, in the IP layer, is shown in Figure 5.

This architecture defines a star configuration where there are two main nodes called Inner Cores (as star centers) deployed in the AMBA[21] region that connect the co-located Internet nodes (IGW[22]).

In Argentina, connections to Internet providers are only available in AMBA. This leads to the conclusion that any content that can not be served from within our network will arrive to AMBA (that is, there is a star-oriented traffic matrix with traffic flows emanating/terminating from center of star located in AMBA). This traffic distribution characteristic and profile was critical in developing the appropriate topology.

On the other hand, there are "n" pairs of nodes called Outer Cores connected to each other and both connected in a dual-home configuration (figure of a "U") to the Inner Cores. These Outer Cores aggregate the Edge PE[23] nodes from the different defined regions.

According to the previously described traffic patterns and the demographic and economic particularities of Argentina, the need for 2 pairs of Outer Cores in the AMBA region is justified by volume/capacity (traffic, number of connected PEs, customers, products and services, etc.), where one of these pairs is in the same physical site of the Inner Cores.

In the current architecture, there are PE nodes that connect to the national (linked to Inner Cores) and regional DC (linked to the Outer Cores), PEs that aggregate connections from final clients, as well as self-owned and/or third-party CDNs, etc. In the future, an Edge DC level hierarchy with multiple sub-levels will be added and the PE nodes and their associated infraestrucuture (i.e. NFVI) will be sized based on the needs of the areas and customers they serve, volume of traffic, services and products, etc.

[21] AMBA (Buenos Aires Metropolitan Area) is the common urban area determined by the Autonomous City of Buenos Aires and other 40 municipalities of the Province of Buenos Aires. According to the 2010 census, this area has 14,800,000 inhabitants, representing 37% of Argentina total, approximately 45% of the country's total GDP and more than 40% of our network traffic.
[22] Internet Gateway.
[23] Provider Edge Router (Label Edge Router).

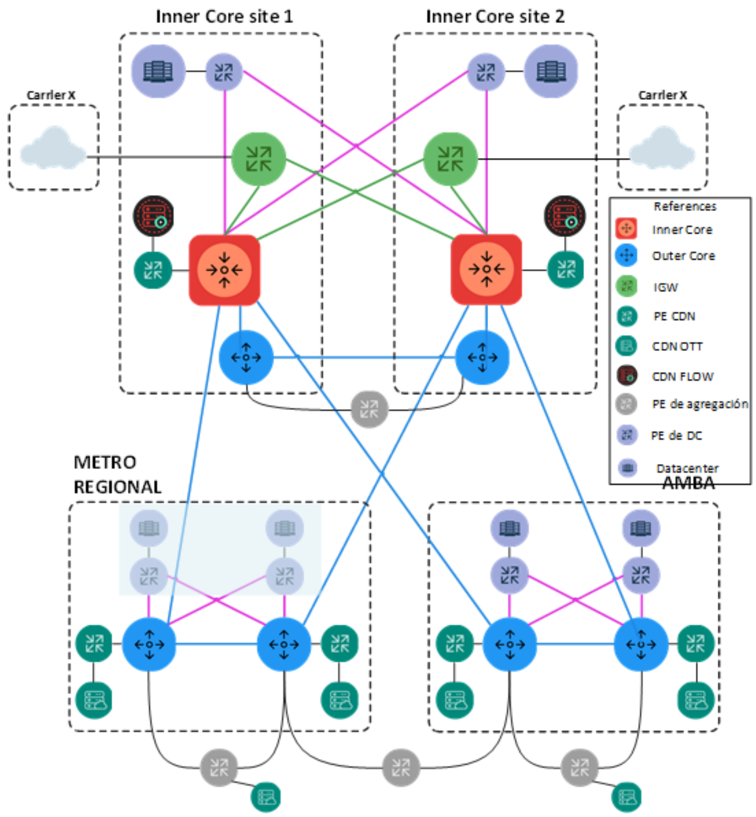

Figure 5 – FMO IP Topology.

Transitioning the Core/Backbone to a full IPv6 network was evaluated. However, given the complexity, cost and technical maturity involved, it was considered best to offer IPv6 services from the edge.

The new Core/Backbone will continue to be based on MPLS[24] and IP4 and it is defined that the Inner and Outer Core nodes should only have P-node[25] functionality within the MPLS domain. This approach could eventually reduce hardware costs because it reduces the functionalities required in these devices.

IPv6 services will be provided through the 6PE and 6vPE functionality.

Complementing the previous figure and as a synthesis of what is being developed, Figure 6 shows the new architecture divided by functional layers (figure on the left) and is shown together with the initial geographic distribution (on the right) of Inner Core and Outer Core nodes.

With a view to the future, rules for opening/adding Outer Core sites are defined according to strategic business and technical parameters, such as: number of subscribers, traffic (% increase or threshold-based), number of PE Edge nodes aggregated, latency due to distances, etc.

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24 Multi-Protocol Label Switching.
25 Provider Router (Label Switching Router).

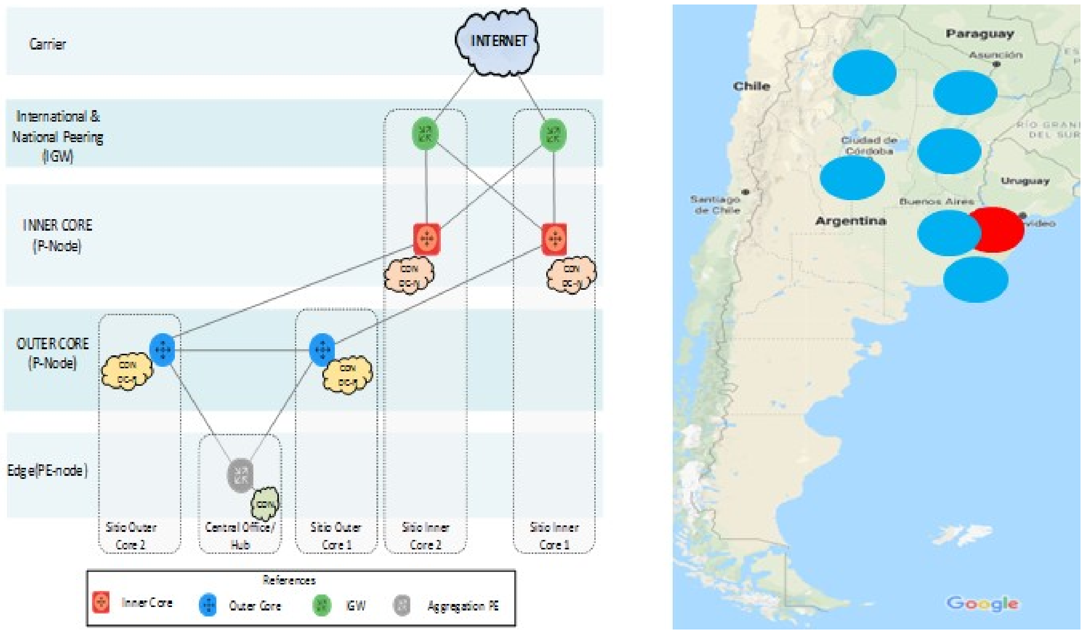

Figure 6 - New topology by layers and main nodes geographical locations.

Given that both former networks were running OSPF protocol, a link state IGP, it was determined to be operationally simpler to unify the IGPs with a single OSPF to begin with. However, in the longer term, a decision has been made to transition from OSPF to IS-IS as the IGP protocol of choice due to a number of reasons – including a future migration to full IPv6.

The definitions for the BGP[26] control plane will follow the usual practices for CSP networks. That is, a full-mesh iBGP[27] of the PE nodes must be achieved through RR[28] dedicated to each particular AFI[29]. The FRT[30] should only be present in the IGW nodes. The PE Edge, DC Gateway and CDN Gateway nodes should include in their routing table only the default route and the networks marked as internal routes for both IPv4 and IPv6 (criteria on which the forwarding plane is based). Thus, starting the MPLS forwarding in PE edge nodes, DC Gateway and CDN Gateway for all services, the Inner and Outer Core nodes must limit their functionalities to switch labels within the MPLS domain.

Although the current RR architecture does not present scalability limits, as the number of RR clients can increase considerably due to the PE nodes number growth in the new network, a flat centralized distribution differentiated by services is defined, connecting the RR in the Inner Core layer. In this way, each RR associated with a service will have its own scalability. Regarding the performance of BGP, this process could be optimized due to the lower number of clients to update.

The IGP (IS-IS in the future, OSPF currently) contains in its topological database only the infrastructure prefixes.

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[26] Border Gateway Protocol.
[27] Internal Border Gateway Protocol.
[28] Route Reflectors.
[29] Address Family Identifier.
[30] Full Routing Table – Complete Internet Routing Table.

Currently, the MPLS control plane of both companies is based on LDP[31]. It is proposed to maintain this protocol while the unification process lasts. Then, once the integration of the networks and the new architecture is achieved, it is necessary to evolve towards a control plane based on SPRING[32] (also known as Segment Routing) in order to provide value-added services such as Traffic Engineering.

3.3. Optical Network

In the design of the optical network lies the key to the resilience expected for the FMO. It is defined that the optical link between Inner and Outer Core nodes must use an optical DWDM[33] network based on ROADM[34] CD (Colorless-Directionless) nodes, upgrade to FlexiGrid, a control plane that allows the restoration of links and connecting through three, disjoint optical paths.

The new Telecom Argentina has an important fiber optic plant at the country level comprised by the combination of the fiber assets of both former companies. Due to the geographic distribution of the main nodes, in the future, the definition of the optical domains and the vendors co-existence will be reviewed. These definitions and the vendors strategy are subjects of future analyses[35]. Other options such as open platforms will also be part of these future analyses.

It is also necessary to consider that the access/entrance of the three fiber connections to the different sites and / or buildings must be done through at least two disjunct routes. However, it would be desirable for resiliency purposes that three routes be available. Additionally, the fiber to be used must be one dedicated to core services exclusively. Access or clients fiber must not be used to connect to the core in order to avoid unwanted interventions that can generate an impact on it (for example, connecting new clients).

With focus on operational simplicity, the deployment and use of alien lambdas between optical networks of different suppliers is discouraged in this first stage (again, the analysis of open platforms will be done in the near future).

Otherwise, there are some options to overcome the limitations associated with G.653 fiber, such as higher transmission capacity on the channel (100G to 200G, etc.), increase in the amount of lambdas supported by single fiber or replacement by G.652 fiber (incurring in additional costs for fiber deployment). Each of these options has an associated cost and technical implications that should be considered to choose the most appropriate option.

In the case of the rest of the fibers, the capacity upgrade of the lambdas is also considered based on the traffic evolution and considering the TCO to define appropriate capacity.

As an example, Figure 7 shows a normalized cost analysis for the main option of increasing transmission capacity on G.653 fiber. This figure also evaluate different distances that correspond to some of the links currently most compromised in terms of capacity.

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[31] Label Distribution Protocol.
[32] Source Packet Routing In NetworkinG.
[33] Dense Wavelength Division Multiplexing.
[34] Reconfigurable Optical Add-Drop Multiplexer.
[35] The current situation is clearly conditioned by the migration scenarios of the current architectures to the FMO in order to achieve the reduction of the proposed TCO as soon as possible.

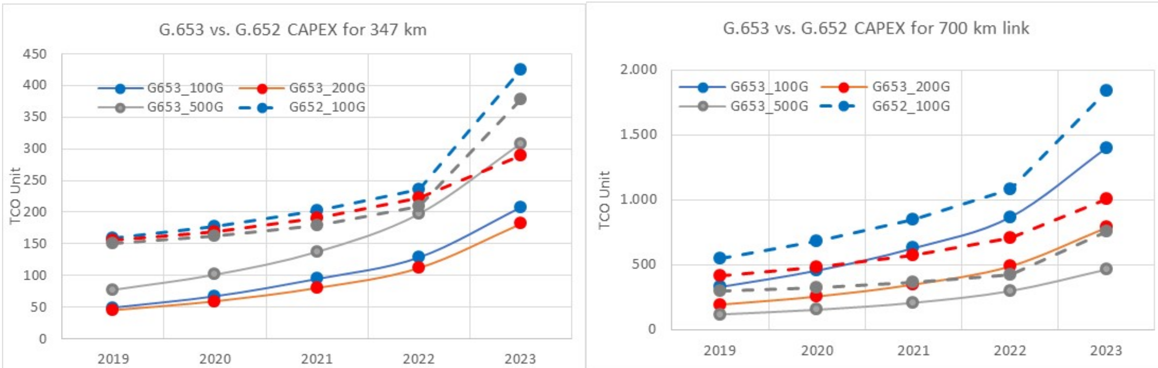

Figure 7 - Options to solve G.653 fiber capacity limitations.

There will be three disjoint optical paths between Inner and Outer core nodes that were previously mentioned. This requirement is justified by analyzing the current failure rates of the various components, mainly fibers and considering independent failure probabilities. This determines failure cases to tolerate, based on the desired availability.

In the target FMO, it is necessary to be able to support two simultaneous failure scenarios, considering the joint behavior of the IP and optical layers. These failure scenarios are the following (see Figure 8):

- Outer core site (or Inner Core) failure, simultaneously with a fiber cut
- Double fiber cutting in the Inner and Outer core links

When the first fiber cut of the optical link between Inner core 1 and Outer core 1 occurs, the optical control plane starts the process of restoring the link through the alternative optical node (optical switch). Temporarily, during the restoration (several seconds), there will be a re-convergence in the IGP (with the BFD[36] assistance to accelerate the process) and 100% of the traffic will be transported through the Inner-core 2 and Outer-core 2 links. Once the path is restored, the traffic between the IP nodes is rebalanced back and 50% is established for each link.

As the picture on the left side of Figure 8 shows, if the fiber cut described previously is added with an Inner or Outer core node going down (be it at the DWDM or IP level), the network will continue to be available. This is because there will still be an optical link between Inner-core 1 and Outer-core 1, through the alternative optical node (optical switch), with the IP interface running 100% of the traffic (again relying on BFD to accelerate re-convergence and minimizing the impact on packet loss).

Finally, the failure case of simultaneous fiber cuts is shown in the picture on the right side of Figure 8. In this case, a second concurrent fiber cut is added, where the link between Inner-core 1 and Outer-core 1 going by the alternative optical node (optical switch), also becomes unavailable. In this condition, the IGP re-converges and 100% of the traffic will begin flowing between Inner-core 2 and Outer-core 2 (once again with the BFD help to speed-up the re-convergence). Once the traffic is established in this way, the optical link between Inner-core 1 and Outer-core 1 must not be restored, that is, there only has to be one restoration of each link. Traffic should be maintained between Inner-core 2 and Outer-core 2 in this contingency situation.

[36] Bidirectional Forwarding Detection.

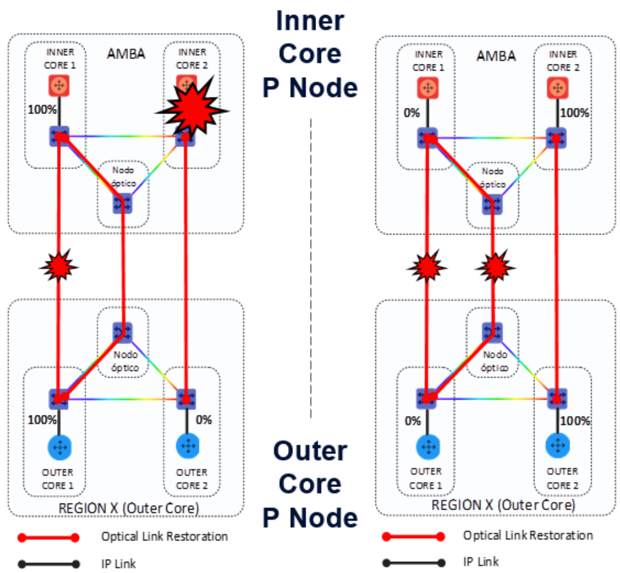

Figure 8 – Failures supported considering optical and IP layers behavior.

3.4. CDN Strategy

One of the fundamental premises of the new architecture is the distribution of content, services and functionalities, whenever possible, in such a way that allows minimizing the deployment of infrastructure and transport capacity and to improving QoE[37] (as a consequence of latency and RTT[38] optimization). This distribution scheme serves the needs of future services on the path to 5G. Considering the above, one of the cases to be considered is an optimal distribution of CDN, mainly due to the volume represented by OTT[39] services over the total traffic of our network (see Figure 9).

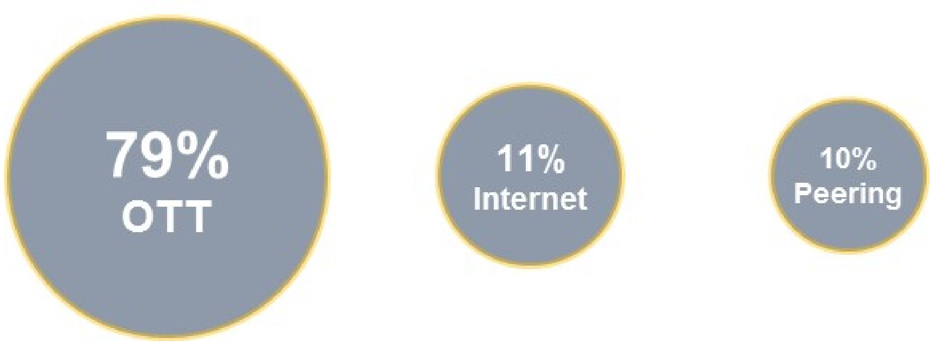

Figure 9 - Traffic distribution in the Telecom Argentina Network.

To accomplish this, two CDN cache hierarchies are proposed, one at the Outer core level and next, even closer to the susbcribers, at the Edge site level. These categories of the CDN are based on measured

[37] Quality of Experience.
[38] Round Trip Time.
[39] Over The Top.

traffic patterns previously mentioned and shown in Figure 9 (at peak time, 79% of the traffic currently corresponds to OTT traffic and the remaining 21% is divided into Internet and Peering).

The traffic thresholds for the decentralization of the CDNs towards the Edge sites can be variable according to the CSP and there is also a dependence on the OTT. These PE Edge node level caches are from multiple content providers, therefore, the links between core and Edge nodes must be sized to support the OTT server failure with the highest traffic volume. In order to maintain consistency in the savings related to the sizing of the links, the redundancy of these CDNs should be within the same region and located on the corresponding Outer Cores to avoid over-dimensioning of long haul links.

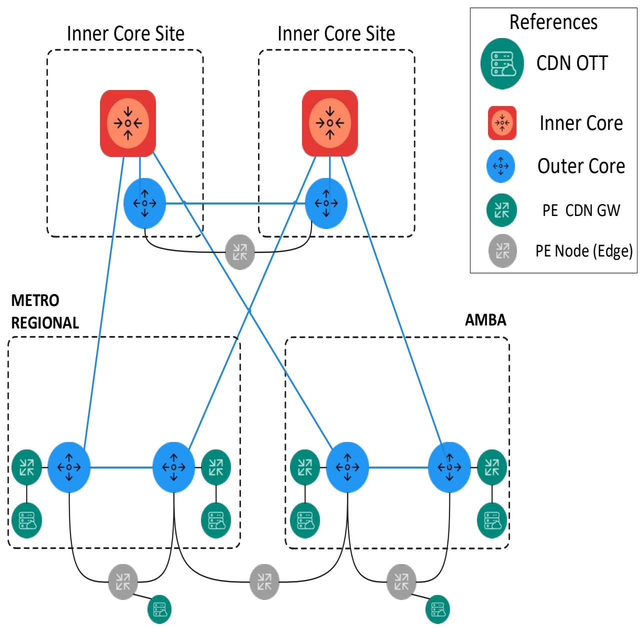

Figure 10 - CDN strategy for content distribution.

Figure 10 shows a CDN distribution scheme, where all the Outer core sites will host CDNs and connect to the Outer-core routers through dedicated PE CDN gateways. To further help with content distribution and network efficiency, CDNs will be placed at select Edge PE site locations as well. Not all Edge PE node sites justify having a CDN – criteria for selecting an Edge PE site to host CDN is based on traffic volumes. Two Edge sites (grey colored PE nodes) corresponding to different regions with their respective CDNs are shown as a reference in the figure. This PE node not only connects customers and access technologies, but also acts as an aggregator of the CDN, without a need for an additional PE CDN gateway as an aggregator, as was the case in the afore-mentioned Outer-core sites.

3.5. End-To-End Architecture (2023+)

Considering the integration of both former companies and based on the evolution of the current services and the new services that will emerge on the path to 5G, a unified and distributed architecture of a telco cloud is defined. This architecture is related to the DC hierarchies that are mentioned in the previous sections and in the disaggregation of services and components, including aspects as hardware, software, CUPS[40], segmentation of the network, etc. This is shown in Figure 11. In this architecture, only three-level DC hierarchy is shown: two National DCs (co-located to Inner cores), dozens of Regional DCs (colocated to Outer cores) and hundreds of DC Edge (on PE Edge nodes). However, the hierarchy may vary and the edge DC may have different levels according to the volume of customers, traffic, demand for services, infrastructure to support these demands and so on. The common aspect is that in all of them we will have a general purpose generic infrastructure that will allow us to deploy services in a unified manner regardless of their location[41].

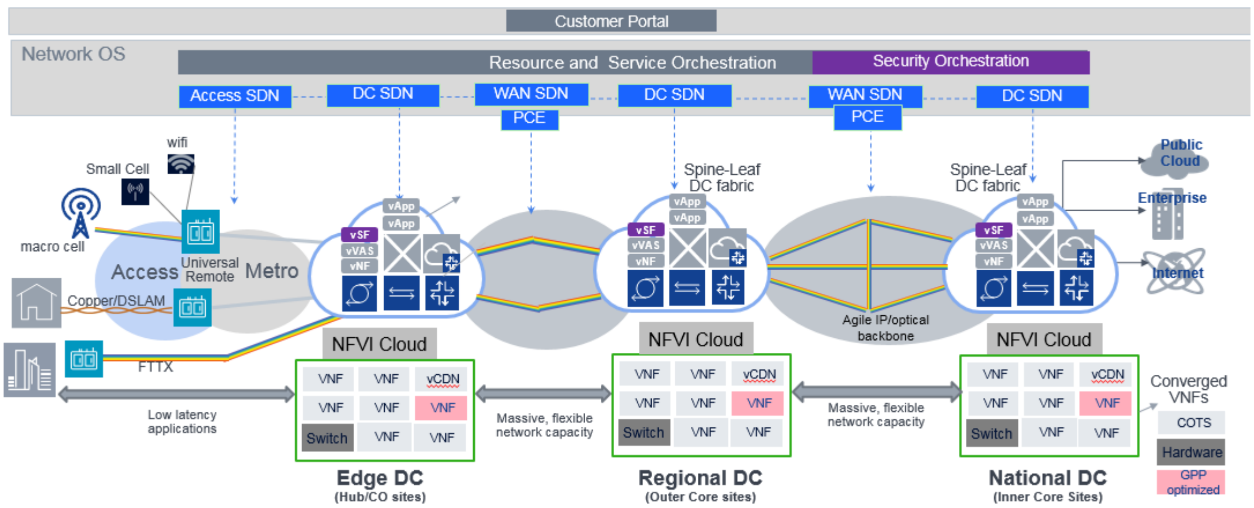

Figure 11 - End-to-end architecture overview.

Within these hierarchies, the applications, most of the time, will not be the same, so the scalability requirements of these three types of sites (and the different sub-types within Edge's DCs) must also be different. The NFVI[42] cloud for each level will vary at least the number of instances of each application, the constitution/structure of the components and the dimensions of each one of them. In this way, functionalities now supported on routers and specialized hardware, will be disaggregated, moving some of them to VNF[43] form over computing servers. Temporally, there will be hybrid scenarios requiring coexistence of services mounted on legacy PNF[44] and VNF, until complete transition to the disaggregated model, including PNF just where it makes sense. The fundamental change of this model implies decoupling the innovation cycles of the modules and functional blocks that constitute the infrastructure and services. In turn, this disaggregation should lower entry barriers for new players. Both aspects should make it possible to reduce the TTM of new services and products and lower their TCO and the infrastructure that support them.

An additional aspect to consider is related to the physical limitations that different types of sites could have, both from an operational and TCO point of view. This includes accounting for the criticality of the

[40] Control and User Plane Separation.
[41] This generic definition has a series of non trivial technical aspects to be solved. An example can be the deployment of the control nodes of the VIM and the volume of infrastructure to be deployed in the smaller DC sites.
[42] Network Function Virtualization Infrastructure.
[43] Virtual Network Function.
[44] Physical Network Function.

information to be protected. The characteristics of a National DC will not be the same as those of a DC Edge. Generally, this last type of site is restricted in aspects related to building infrastructure, such as, for example, possibilities to increase physical space and energy capacity (considering refrigeration as a contributor to energy consumption). Again, the volume of customers, traffic, demand for services and products, etc. is what will determine the needs in each case.

Based on the proposal, there will be different NFVI scales for each type of DC hierarchy, but all of them will have a common infrastructure that will respond to a consolidated framework for the administration and management of resources and automation of specific tasks that will, in turn, allow the consistency in the orchestration of end-to-end services and products. As shown in Figure 11, there will be several SDN controllers covering various technological domains (SDN for access, SDN for DC, SDN for transport network and its sub-domains –i.e. optical and IP), but all of them under the aforementioned framework of reference and defining a hierarchical vision that facilitates the orchestration.

Finally, in order to determine the impact of all the proposed optimizations on the final target architecture, an analysis was performed comparing the PMO with the FMO. The results of this analysis is shown in Figure 12.

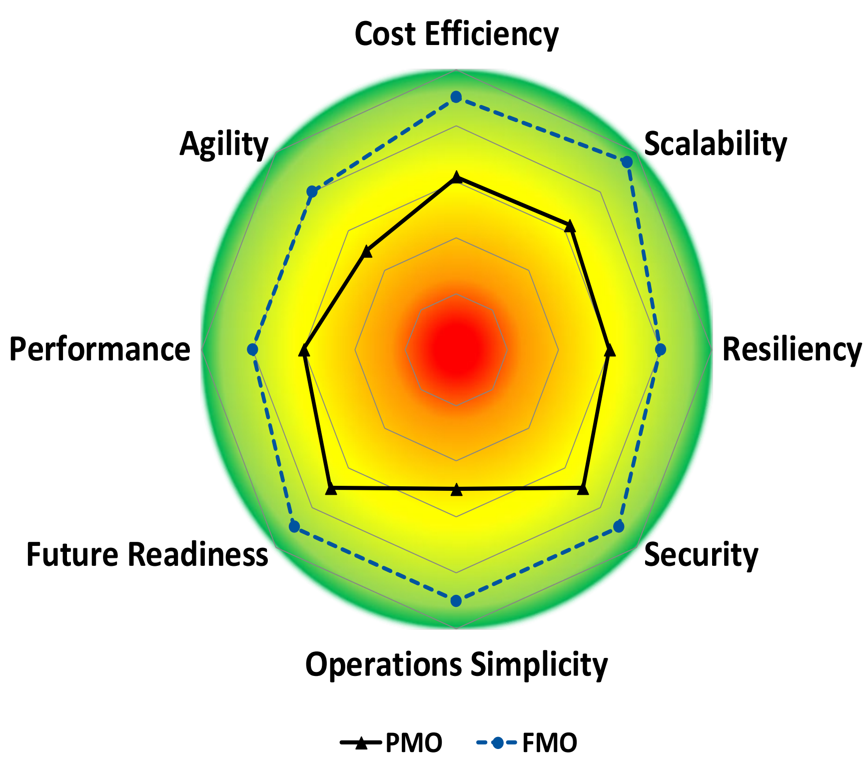

Figure 12: FMO vs. PMO comparison.

The figure shows a qualitative comparison of the PMO vs. the FMO, with the focus on comparing against the key characteristics/attributes listed in section 2.2: Cost Efficiency, Scalability, Resilience, Security, Operational Simplicity, Future Readiness, Performance and Agility. It can be seen that the future target architecture (FMO) will have superior characteristics across all measured dimensions compared to the present one (PMO).

3.6. SDN Use Cases

In this section, two use cases of SDN application in the transport network are presented. These use cases are presented to illustrate the evolution process until achieving the complete orchestration highlighted by the FMO.

On the one hand, in Figure 13, the new architecture is shown optimizing the use of links to Internet providers (also called Tier I). The challenge in this case is to be able to manipulate the downstream traffic to our network based on a certain condition (congestion of some of these links, a certain level of desired balance, optimization of OPEX and/or the service based on a preferred provider or some other condition). For this purpose, an automated solution based on the analysis of the customer's arriving traffic and then the SDN controller selectively diverting the traffic by manipulating network prefixes on the IGW devices is proposed.

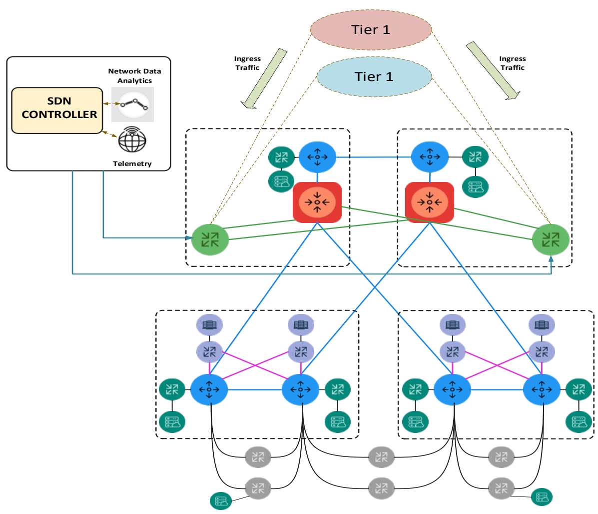

Figure 13 - Optimization of the links use to Tier I.

On the other hand, Figure 14, also based on the FMO, shows a potential use case of SDN in combination with traffic engineering. In this case, in the event of a network failure, the delivery of traffic from the CDN results in the circulation of traffic through a sub-optimal path, with higher TCO due to the need to deploy more infrastructure and transport capacity and with higher latency degrading, eventually, the user experience (QoE). Given this scenario, the solution is based on a combination of traffic engineering to configure a explicit route that passes through certain devices[45] (others than those defined by the IGP SPF[46]) complemented by the automatic manipulation of network prefixes. Everything done through the SDN controller.

[45] Basically through Segment Routing Explicit Route Object (SR-ERO) according to the FMO definitions.
[46] Shortest Path First algorithm.

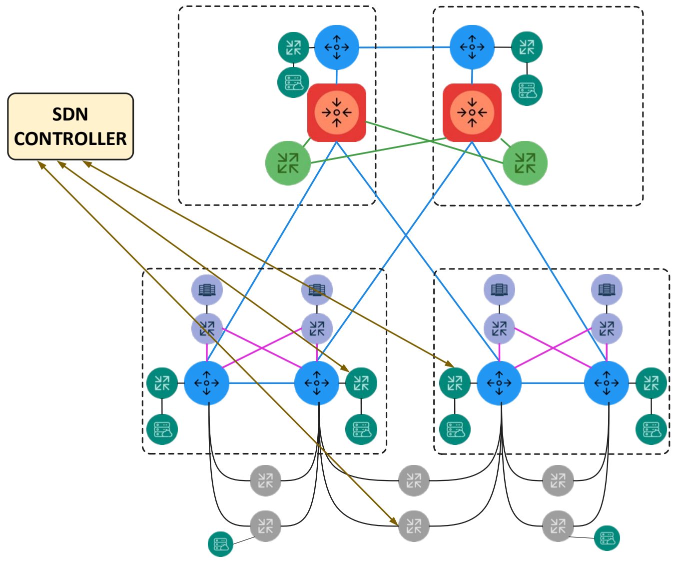

Figure 14 - Traffic engineering with SDN controller.

4. Summary

The paper can be summarized as follows:

- An architecture is defined, including its topology. The architecture and topology are optimized from the point of view of the traffic matrix and with sufficient flexibility to adapt to eventual changes to it (driven by multiple factors, i.e. current and new services and products evolution, traffic capacity, etc.).
- This architecture is also optimized from the TCO point of view.
- At the IP layer, the FMO will work with IS-IS as a link state IGP with a control plane based on Segment Routing for MPLS, which will enable traffic engineering support.
- In the meantime, the trends and deployments observed in the industry will be analyzed to determine the convenience to migrate to IPv6 and SRv6 without affecting the services and products currently being offered to our clients (based on our evaluation, these technologies are not mature enough for deployment).
- PEs are connected through iBGP via RR receiving only the default route and the networks marked as internal routes for both IPv4 and IPv6 (6PE and 6vPE). The IGP contains in its topological database only the infrastructure prefixes.
- The FRT should only be present in the IGW nodes.
- In the new architecture, both the Inner and Outer core nodes only have the function of switching MPLS labels for packet forwarding. Therefore, they do not run BGP (practically they do not need a IP data plane, only the IGP control plane as support for MPLS).
- On the optical layer, the links between Inner and Outer core nodes will use a DWDM network, with ROADM CD (Colorless-Directionless) nodes, upgrade to FlexiGrid, a control plane that allows the restoration of links and connections through three, disjoint optical paths.
- ONLY core fiber will be used for these connections.
- These three disjoint optical paths between Inner and Outer core nodes, provide high availability. This will allow the support of two simultaneous failure scenarios, considering the joint behavior of the IP and optical layers.

- The distribution of the optical domains that allow the scalability of the platforms and the co-existence of vendors should be analyzed. This definition and vendor strategy will be evaluated in future work.
- The limitations of the G.653 fiber should also be overcome as long as they reach their capacity limits. This fiber type presents particular challenges.
- For the rest of the fibers, capacity limitations will be solved with greater capacity in the channels or lambdas, being the same determined by the traffic evolution and the TCO.
- IP and optical layers should work together in an incremental process of integration that allows the multilayer concept for restoration, capacity and network use optimization, etc.
- As a strategy to improve performance and TCO, content and services should be distributed as close as possible to the end customer, in order to optimize latency, improve customer QoE and minimize transport costs.
- Finally, the framework that allows end-to-end orchestration of the services and products must be defined. It will be leveraged in technologies such as SDN, NFV, SR, Network Slicing and trying to define and deploy the appropriate level of components disaggregation for a CSP Tier 2. This has to be done to decouple this components and functional blocks and improve their innovation cycles, facilitate competition, achieve greater levels of flexibility, agility and automation to allow the ultimate objectives of significantly improving the TTM and reduce the TCO of the network.

Abbreviations

4Play	Quad Play Products
5G	5th Generation Networks
AFI	Address Family Identifier
ARPU	Average Revenue Per User
ASN	Autonomous System Number
BFD	Bidirectional Forwarding Detection
CDN	Content Delivery Network
CAPEX	CAPital Expenditures
CSP	Communications Service Provider
DC	Datacenter
E2E	End To End
FMO	Future Mode of Operation
IGP	Interior Gateway Protocol
IGW	Internet Gateway
IoT	Internet of Things
IP	Internet Protocol
IP|IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
LER	Label Edge Router
LDP	Label Distribution Protocol
LSR	Label Switching Router
MPLS	Multiprotocol Label Switching
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure

OPEX	OPerational EXpenditures
OTT	Over the Top
PMO	Present Mode of Operation
P Router	Provider Router (LSR)
PE Router	Provider Edge Router (LER)
QoE	Quality of Experience
QoS	Quality of Service
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RTT	Round Trip Time
SDN	Software Defined Network
SPRING	Source Packet Routing In NetworkinG
SR	Segment Routing
SR-ERO	Segment Routing Explicit Route Object
SRv6	Segment Routing IPv6
TCO	Total Cost of Ownership
TTM	Time To Market
VNF	Virtual Network Function
WAN	Wide Area Network
DWDM	Dense Wavelength Division Multiplexing

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