Making More with Less! A Case Study in Converging Wireline and Wireless Network Infrastructures Using Distributed Access Architectures

A Technical Paper prepared for SCTE/ISBE by

Hugo Amaral Ramos
Chief Technologist CALA
ARRIS
hugo.ramos@arris.com

John Ulm
Engineer Fellow, CTO – Network Solutions
ARRIS
john.ulm@arris.com

Zoran Maricevic, Ph.D.,
Engineer Fellow, Access Technologies
ARRIS
zoran.maricevic@arris.com

Jose Tavares
Engineer
ARRIS
jose.tavares@arris.com

Claudio Albano
Engineer
ARRIS
claudio.albano@arris.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Introduction

The maturing of the telecommunications industry has led to a consolidation trend. This consolidated telecom companies often have two completely separate infrastructures to maintain: wireless and wireline. With this, both a challenge and an opportunity emerge. In order to maintain competitiveness and lower both CAPEX and OPEX, the operator must converge infrastructures and associated functions.

At the same time, the evolution of technology is huge. New technologies such as DOCSIS Remote PHY (RPHY), Remote MAC-PHY (RMACPHY), RF over Glass (RFoG), and Fiber to the Home (FTTH) will help enable this convergence.

This gives operators the possibility of selecting among an immense quantity of options. However, this can also generate lots of doubts, such as how to make the right decision regarding a future proof infrastructure, while at the same time having the most cost effective, high quality delivery and access network.

A wrong technology decision could be catastrophic for anyone in an industry that is highly competitive. Operators in the Caribbean and Latin America (CALA) region are even more hard pressed since the ARPU and the restriction in CAPEX is often a big burden. The CALA operators may have only one chance to get it right:

“CALA has normally one bullet to shoot the target, aiming right is really crucial.” Author unknown

With the challenges that CALA faces, we analyze a regionally specific case in the CALA market in which the requirements for the planning and deployment of new technologies, such as RPHY, RMACPHY, RFoG, and FTTH are somewhat specific to CALA. Requirements specific to typical CALA deployment areas are very high density and lower bandwidth services plans compared to the market in the USA. Consequently, a larger number of subs per service group (SG) are required to make the implementation economically viable.

This case study analyzes some actual underserved cities in the Caribbean and Latin America region, with the goal to profitably enable the delivery of high speed data and other services in a sustainable way by helping the operators to get the best synergy from the wireless and wireline infrastructures.

The paper offers an analysis of various network technology options to serve dense urban areas with High Speed Data and other services while leveraging already deployed mobile infrastructure assets. This is accomplished using new Distributed Access Architectures (DAA) technologies such as Remote PHY.

These options all use the existing mobile backhaul infrastructure, IP Radio Networks (IPRAN) and Node Base locations. They vary in the type of access network that is deployed (e.g. FTTH, RFoG, N+0, N+X) and where the Remote DAA elements are deployed (e.g. node or shelf in cabinet). The case study shows a comparison of all options, highlighting a high level normalized total cost of ownership (TCO), technical requirements, benefits, limitations, concerns, considerations, and future proof analysis.

Study of a Convergence Between Wireline and Wireless Infrastructure Using New Technologies

1. Requirements of CALA and Some Difference vs NA Region

Some different challenges and requirements between the Caribbean and Latin America region and North America exist, such as the enviroment, the economic challenges, and also types of required services. Understanding these differences is important in order to decide which technologies to deploy. In the following paragraphs we can find some of these differences and see how these differences can make an impact.

One important consideration for an adoption of a new technology is the environment in which this technology will be used. A very-dense or ultra-dense environment is typical in the CALA region in the deployment of telecommunication networks today. As noted in Figure 1, some cities in CALA have ultra-dense concentration such as Sao Paulo in Brazil with a density of 7,913.29inh/km^2 (20,495.3inh/sq. mi) and a huge population of approximately 22 Million persons. Similarly Mexico City is 6,000inh/km^2 (16,000inh/sq. mi) without as much distribution and spread like the North America (NA) region. These differences show a gap of requirements for deploying new technologies such as DAA.

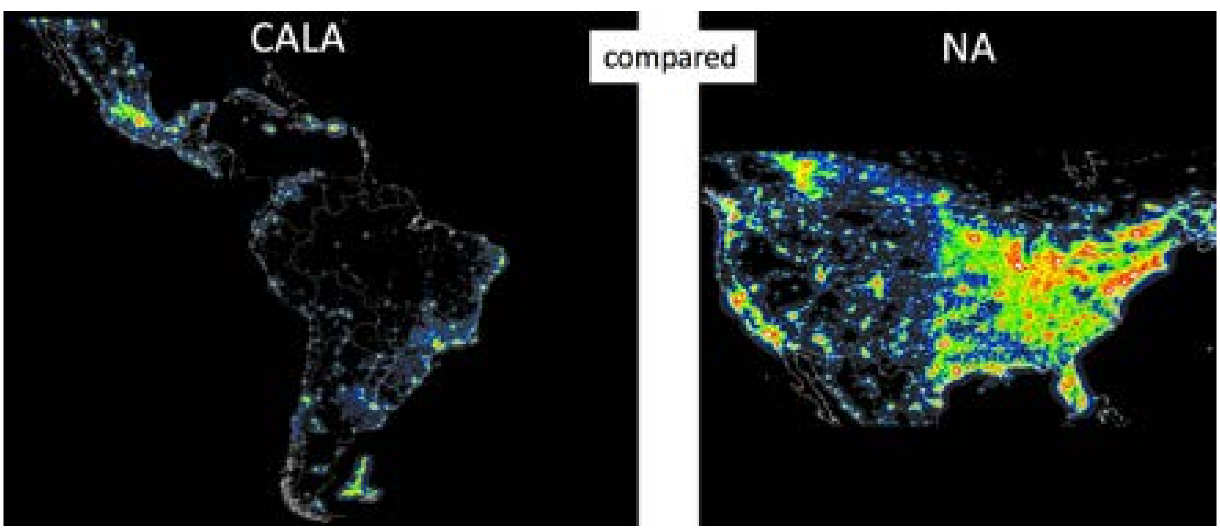


Figure 1 – Light View in Dark Comparing the Concentration between CALA vs NA Region

Another important environmental observation of the region is the type of construction employed. In CALA, the typical implementation is via aerial construction, using poles. One ugly observation identified in the region is the robbery of units and cables in the streets. This sometimes can eventually put some constraining forces against the idea of distributed architectures (DAA), since the fear to put more expensive equipment in the field is significant and justified.

Figure 2 – Photo of a Stolen Optical Unit, Optical and Copper Cables in a Yarn String

Another critical consideration is economical; specifically, how the industry in the region makes revenue, profit, investments, and how the plant is operated and maintained. CAPEX restriction is always strong in the region, mainly due to the FX rate and limited average revenue per unit (ARPU) compared to the North American market. Sometimes the CALA ARPU can be one fifth compared to U. S. market. This is why the CALA region cannot make the wrong selection of standards or technology, nor experiment with hype technologies that are nontraditional initiatives, because there is often no margin for error.

There are a few operators in the CALA region that have a unique position in the market where they have a massive deployment of both wireline and wireless networks and also a dominant market share. These operators are starting to question how convergence opportunities can be deployed, and are beginning to generate initiatives in this direction.

The economic situation in CALA also limits the types of services required in the region. While it varies from country to country, essentially the maximum speed offered in the market is 250 Mbps today. The 1 Gbps speeds that are deployed in U. S. are maybe two years delayed and probably will be deployed for only a small part of only high tier customers.

On the other hand, the demand for data is still projecting very strong growth with the compound annual growth rate (CAGR) in downstream ranging from 45 to 50% Year over Year (YoY). This shows that the requirement for higher data speeds is important to this region. Any solutions considered must be able to grow in a sustainable way, converging infrastructure and gaining synergies.

2. Challenge and Use Case of CALA

Service providers are asking: “What technology should we deploy in greenfield scenarios?” One particular concern in CALA is how to deploy a cost-effective and future proof solution to address the challenges already presented. Should they invest in FTTH and make a revolutionary step? If they do not make this revolutionary step, will they be able to have a future-proof solution? Or will they have a major cost over-run problem in the near/medium term?

Our convergence case study focuses on an under-served city in the region as a typical environment to find a solution to answer these questions. Thinking pragmatically, yet also with a different and more holistic view, how can we solve the environmental and economic constraints while being more effective to maintain sustainability to the service provider?

For this use case, a small under-served city has a density of approximately 6,000inh/km^2 (16,000inh/sq. mi). While there is currently no wireline broadband infrastructure, there is a 3G mobile infrastructure in place. Our challenge is to use this typical environment and find a solution to deploy video and data services. We focused our analysis on a 25,000 HPs area, which can be replicated and used as a possible "template blueprint" solution over the entire region.

The first option for consideration was the "business as usual" (BAU) HFC implementation. The necessity of deploying new buildings and infrastructure for headend or Hubs was a big challenge. Therefore, it was very hard to make a profitable business case using this type of solution for these cities. The business challenge becomes a civil engineering problem due to time to deploy new buildings, cooling systems installations, and all important considerations that a new equipment rooms require. The implementation cost is also prohibitive to sustain any offering in these small and medium cities. The ongoing costs required to maintain these infrastructures further exaggerate the difficulty of establishing a viable business case.

The next option considered is based on using new Distributed Access Architecture (DAA) technologies. This looked much more promising.

The service offerings considered for the case were up to 100 Mbps, 30% subscriber penetration and 400 kbps average broadband usage in the busiest hour in the peak of consumption. Digital TV was also included, consisting of 100 SD H.264 programs and 72 HD H.264 programs, for the analysis of the growth and capacity models.

With an important consideration that most of these cities have a mobile infrastructure in place and some of these operators already own these infrastructures, our idea is to use and converge these infrastructures, gaining important time in implementation, significant synergy in maintenance, and making this implementation as cost-effective as desired. The typical architecture used in the region to deploy HFC and mobile infrastructures is analyzed in the next section.

3. Technical Implementations of Converged Cable and Mobile Networks

3.1. Typical Fixed Access Infrastructure in CALA

Typically, CALA cable operators use a traditional HFC business-as-usual implementation using 6MHz ITU-T.J83 annex B for video and data, DOCSIS standards and Analog Modulation (AM) based optical nodes in their networks. The average number of subs per service group (SG) in the region is around 1,000, which is much higher than what is typically seen in North America.

It is worth emphasizing the fact that the CALA deployments are typically in a very-dense urban area. Usually the distances between the headend/hub and the node are less than 10 km (6.25 miles) for 99% of the cases.

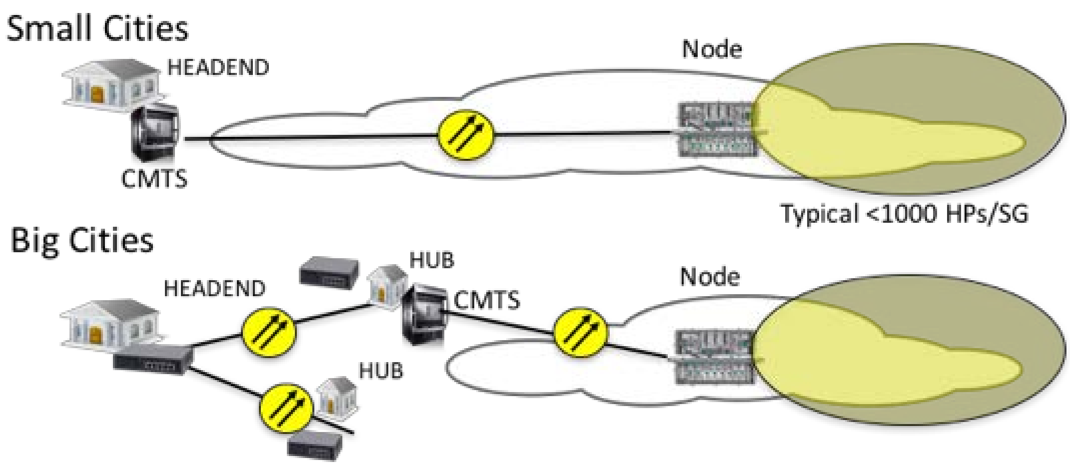


Figure 3 – Typical Cable Access Infrastructure Implementation

One important consideration to the network evolution towards distributed architectures is that the requirements of the region are different from the big MSOs in North America. As shown in figure 4, the CALA operators need to be cautious about the relative maturity of these technologies before massively deploying anything new.

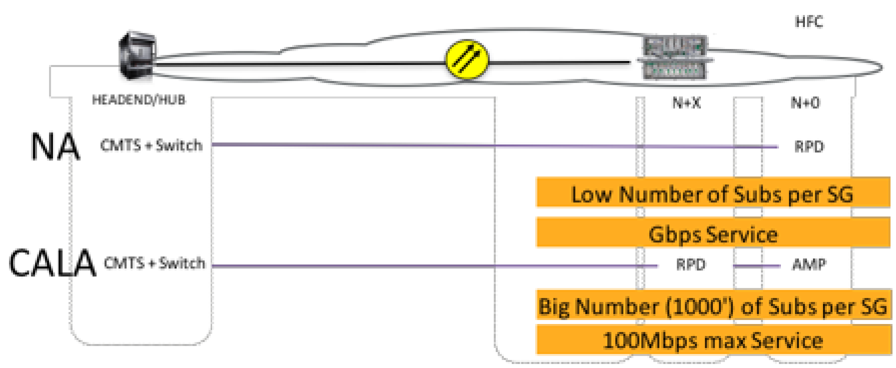


Figure 4 – Example of Planning and Implementation Differences With RPHY Technology Requirements Between CALA and NA

3.1. Mobile Typical Access Infrastructure in CALA

Figure 5 shows a typical mobile access architecture as utilized in the region. It is comprised of two parts: the IP radio access network (IP-RAN); and the radio access network (RAN). The IP-RAN provides a unified layer of services to deliver important applications, such as synchronization using IEEE1588, QoS, Security and Monitoring to the radio access network (RAN). The second part, the RAN, is the ring of NodeB, eNB, or radio base station (RBS).

These architectures are planned and deployed in a ring topology that provides high availability for the services delivered. That availability is what makes this topology the most recommended and widely adopted IP-RAN/RAN topology in the region.

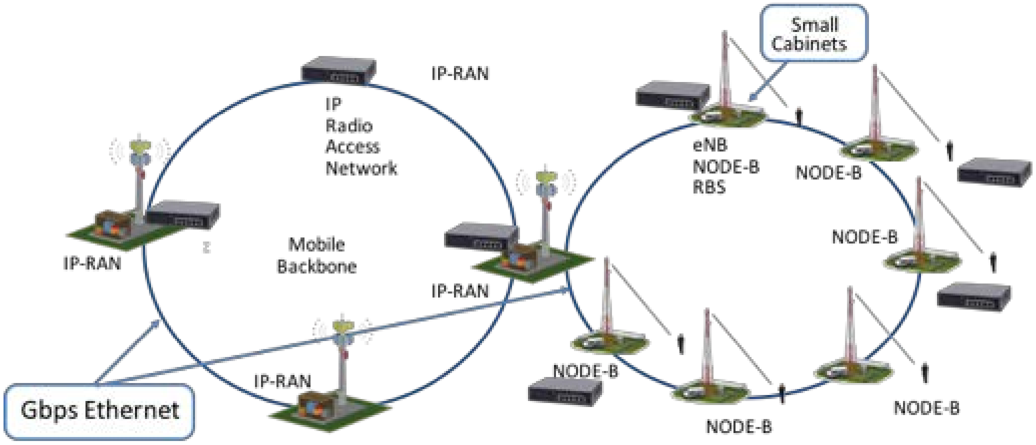


Figure 5 – Typical Mobile Access Infrastructure

4. Options Analized to Converge the Infrastructures with Important Consideration and Synergies

4.1. Options

Understanding how the architectures are deployed, our case study then evaluated four options to converge and use the already in place mobile infrastructure. All of these options use DAA to enable the service offering of fixed High Speed Data (HSD) broadband and Video services.

The major difference between these four options is characterized using two variables: the location of the R-PHY; and the number of RF amplifiers. This is shown as a 2-by-2 matrix in the table below. The location of the R-PHY module could be at the "eNodeB location" or at the "segmentation node". The number of RF amplifiers is partitioned into either an N+0 passive HFC plant or an N+X active HFC plant with a small number of amplifiers in cascade (e.g. N+1 to N+3).

Table 1 – Options in Two Important Dimensions

	RPD in Field	RPD @ eNodeB Location
N+X	#1	#3
N+0	#2	#4

A high-level architecture diagram of the four options is shown below in figure 6. It illustrates where the Remote PHY device (RPD), switches, and access network equipment are installed.

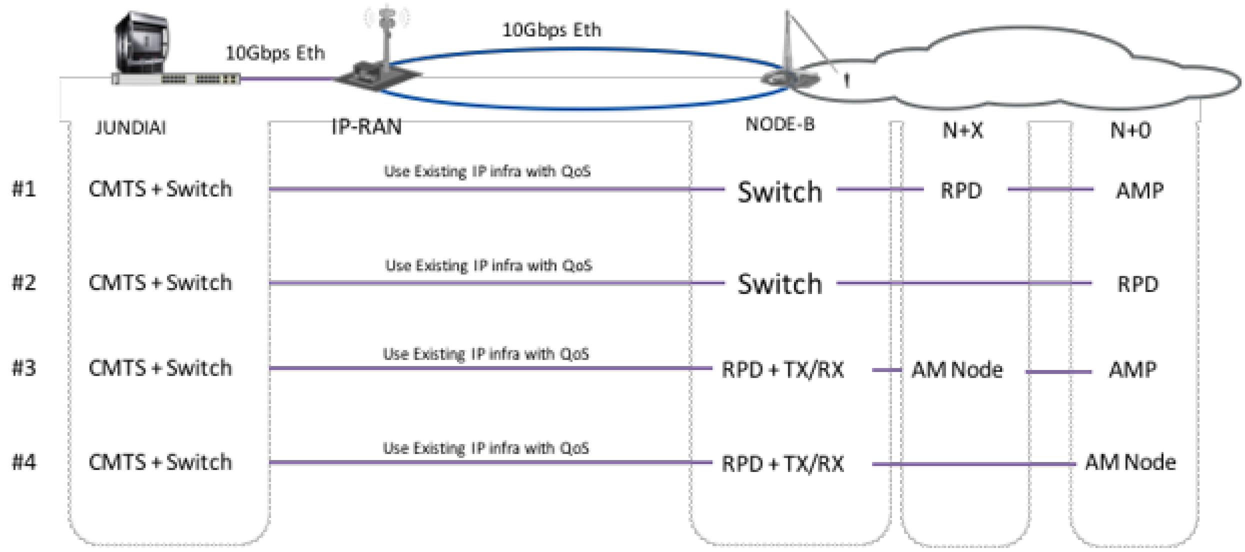


Figure 6 – DAA Technological Options Identified

4.1.1. Option #1 – RPD in the Field with N+X Coaxial Architecture

- A remote CMTS Core contains the DOCSIS MAC function and controls the DOCSIS PHY in the RPD located in a node in the field
- All infrastructure used to get from the remote CMTS Core to the eNB location is Ethernet and is a shared connection with the mobile infrastructure
- From an Ethernet port in the eNB location, an optical SFP with 10km reach is used to connect to the RPD in the field
- From the RPD there is an active N+X coaxial network architecture (e.g. N+1 to N+3)

4.1.2. Option #2 – RPD in the Field with Fiber Deep N+0

- A remote CMTS Core contains the DOCSIS MAC function and controls the DOCSIS PHY in the RPD located in a node in the field
- All infrastructure used to get from the remote CMTS Core to the eNB location is Ethernet and is a shared connection with the mobile infrastructure
- From an Ethernet port in the eNB location, an optical SFP with 10km reach is used to connect to the RPD in the field
- From the RPD there is a passive N+0 coaxial network architecture

4.1.1. Option #3 – RPD in the eNB Location with BaU HFC N+X architecture

- A remote CMTS Core contains the DOCSIS MAC function and controls the DOCSIS PHY in the RPD located in the eNB location
- All infrastructure used to get from the remote CMTS Core to the eNB location is Ethernet and is a shared connection with the mobile infrastructure.
- From the eNB location a BaU HFC TX and RX is used with traditional AM optical nodes in an N+X coaxial network architecture

4.1.2. Option #4 – RPD in the eNB Location with BaU HFC N+0 Fiber Deep architecture

- A remote CMTS Core contains the DOCSIS MAC function and controls the DOCSIS PHY in the RPD located in the eNB location
- All infrastructure used to get from the remote CMTS Core to the eNB location is Ethernet and is a shared connection with the mobile infrastructure
- From the eNB location a BaU HFC TX and RX is used with traditional AM optical nodes in an N+0 coaxial network architecture

4.2. Synergy in Timing and IP Switching Considerations in an RPHY solution

With the evolution of the HFC network to a DAA (Distributed Access Architecture), the IP switching is reviewed with the focus on the future evolution to network function virtualization type of infrastructures. The traditional 3-layer architecture of IP routing and switching is being questioned, changing from the core, aggregation and access topology to Spine Leaf architecture. This new architecture is being used in the data center environment and is viewed by the industry as a future-proof implementation.

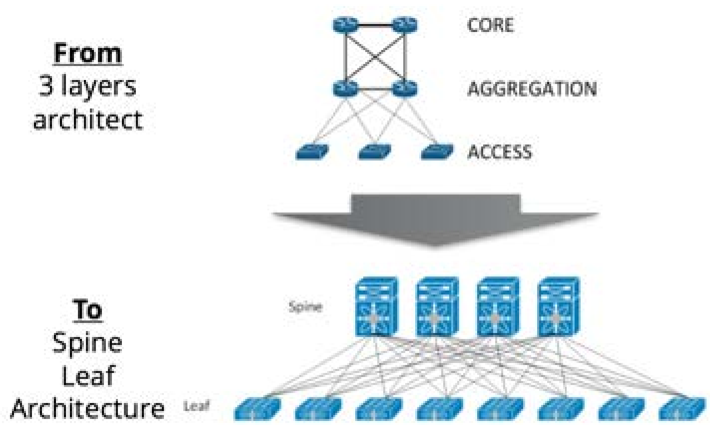


Figure 7 – IP Switching Changing from 3-layers Architecture to Spine Leaf Architecture

The Spine Leaf architecture is the IP switching layer between a MAC core that will be instantiated at Headends, hubs, remote locations, and the Remote PHY device, and that will be installed in the field.

These new elements need to be considered during the traffic engineering phase and must support all the traffic required by the end user including signaling information. Also, MSOs will need to think about the traffic demand growth. The selected IP switch design should be able to easily address this traffic demand growth. In addition to traffic needs, MSOs will need to consider redundant topology and security. More and more, IP network engineering and HFC network engineering will be working collaboratively to design new HFC network.

Some specific features will be required and must be considered in the IP switching design. The IEEE1588 timing protocol needs to be supported in the switches. This implies the addition of an IEEE1588 timing server. One interesting aspect to be considered in the convergence is that mobile networks already have this server deployed today to provide timing to the eNodeB. To utilize the server as is in place is a great opportunity of operational synergy. IPv6 support will be required as well.

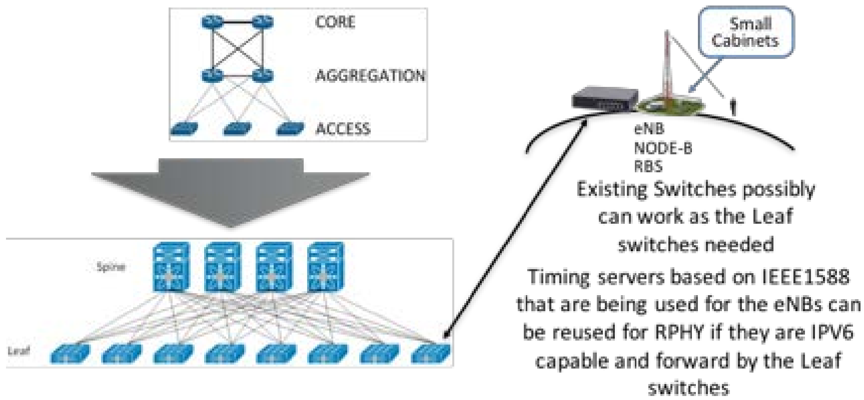


Figure 8 – Usage of Exisiting IP Switching to the Leaf Switch and Provide Sync to RPD

4.3. Important Synergy Gains due to the Unification of Two Infrastructure Layers

To meet our cost objectives, synergy gains are exactly what we are looking for in these solutions. One area of synergy is unifying two infrastructure layers together. This is very important. It is critical to converge to a single layer since this analysis is for greenfield areas with new service offerings.

Taking a look in the planning of nodes to provide fixed broadband and video to this city and the deployed mobile infrastructure makes a compelling case to unify the infrastructure as in the next figures 9, 10 and 11:

- Figure 9 is a supposed infrastructure deployment thinking only about the HFC fixed in mind
- Figure 10 uses an example of an existing mobile infrastructure and
- Figure 11 provides the example of the opportunity to unify the infrastructures

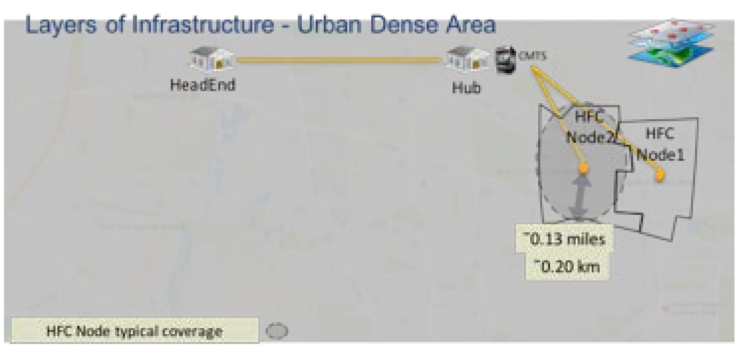


Figure 9 – Example of an HFC Nodes Implementation with a Fixed Services Layer Only

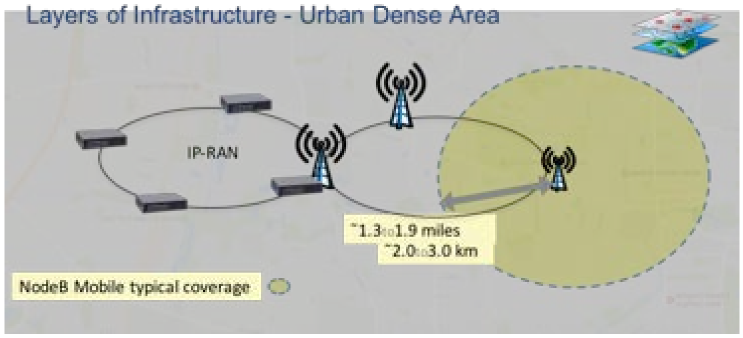


Figure 10 – Example of an Existing Mobile infrastructure

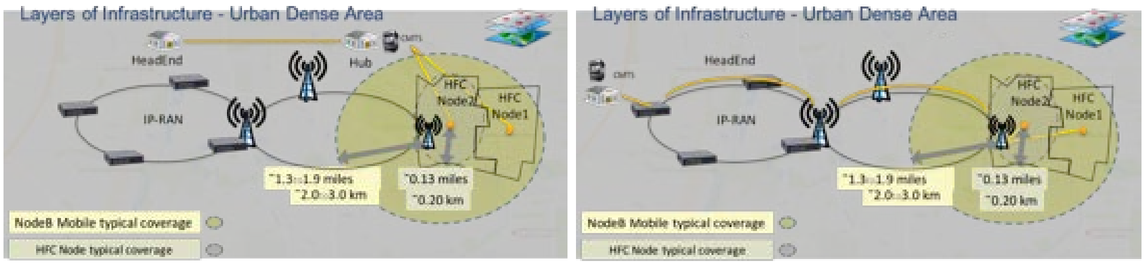


Figure 11 – Opportunity to Unify the Layers

There is a huge opportunity of synergy by unifying the layers of infrastructure. This allows us to:

- Simplify the deployment
- Make a more cost-effective implementation
- Help lower the OPEX and simplify operation
- Help to make the evolutionary step more dynamic

4.4. Network Capacity Planning

Network designs are more cost sensitive in the CALA regions compared to typical North American operator networks. One of the key factors that drives the cost of the access network is the size of the Service Group (SG). The larger the SG, the more an operator can amortize the shared costs. The size of the HFC SG is in turn is determined by the services offered and the available HFC spectrum. This section explores some of the options available for this case study.

4.4.1. Services Offered

It is important to recognize that these areas do not have typical broadband services today. They may currently be limited to just 3G data services. Any broadband services being provided by the new network will be a giant leap forward, even if those broadband service data rates are significantly below other broadband services around the globe.

The majority of users are expected to have a downstream (DS) High Speed Data (HSD) service that is in the 10-25 Mbps range. In some regions, 25 Mbps service has become the minimum acceptable capacity for broadband services. The corresponding Upstream (US) HSD service might be in the 2-5 Mbps range. These data rates are sufficient for the subscribers to have a true broadband experience and stream High

Definition (HD) content into their home. Our network capacity analysis assumes that at least 75% of the subscribers will have a 25 Mbps/5 Mbps (DS/US) service.

An important cost factor is the CPE equipment required. For 25 Mbps/5M bps service, a 16x4 DOCSIS 3.0 modem would be the most cost effective while also providing excellent future growth capabilities. These modems would allow an operator to also offer higher HSD service tiers for premium revenue over time. The 8x4 modems are just slightly less expensive but have one half the capacity, which may limit future growth. For our analysis, we will assume 20% of the subs have 50 Mbps/10 Mbps service and 5% of the subs take the 100 Mbps/20 Mbps service tier.

The above service tiers are the minimum HSD service tiers that we would recommend that the CALA operators support. With newer DOCSIS 3.1 technology, it may also be possible to offer up to 1 Gbps service tiers provided there is sufficient spectrum available. This will allow the operator to offer additional services to businesses, elite residential customers, and/or may be used for wireless backhaul such as 4G/5G &/or WiFi.

As a minimum, the CALA operator will offer an HSD service with sufficient capacity to enable their subscribers to access Over-the-Top (OTT) video services. The operator may also decide to offer their own managed digital video service. They may already have the video infrastructure and set-top boxes (STB) in place for a legacy video service. This kind of offering might support roughly 100 unique video programs and might also support Video on Demand (VOD) services. Since this uses a Distributed Access Architecture over a shared Wireless/Wireline regional network, there is no plan to support any analog video services over the converged infrastructure.

Some progressive operators may decide to offer their video services using IP Video distribution rather than legacy HFC video. This would also allow the video service to be offered over the wireless network and other access networks such as PON. IP Video increases the capacity requirements for DOCSIS. 8x4 modems may not have sufficient capacity for IP Video. This provides another reason for using a 16x4 modem to simultaneously support IP Video.

4.4.2. HFC Spectrum Utilization

Often in brownfield scenarios, an operator is limited by the available HFC spectrum, such as 550 MHz or 750 MHz. However, for this CALA Convergence case study, a greenfield HFC system is being built. This means that the coaxial portion of the HFC will be designed from the beginning with proper components and spacing to optimally support 1002 MHz to 1218 MHz.

The basic HSD service tiers will use DOCSIS 3.0 bonding. Since we are trying to maximize the number of subscribers per SG, the operator should start with 32 bonded 3.0 channels. This consumes 192 MHz of spectrum.

Since there are no older deployed STB in a greenfield, the digital video service is assumed to be deliver ed using H.264/MPEG-4 encoding technology. This reduces the spectrum in half from older MPEG-2 only STB. A reasonable 100 SD/HD program digital video service with VOD could be offered in 21 QAM channels, or 126 MHz of spectrum.

The HSD + digital video services only consume 318 MHz of spectrum out of a possible 1218 MHz. This means that there is plenty of spectrum for future expansion and potentially other services.

It turns out that digital video STB and DOCSIS 3.0 modems only support up to 1002 MHz. With an HFC designed for 1218 MHz, a DOCSIS 3.1 OFDM downstream channel could be put above 1002 MHz without conflicting with 3.0 HSD or digital video services.

Another interesting decision is choosing the best upstream split. DOCSIS 3.0 only supports up to 85 MHz upstream, while DOCSIS 3.1 can optionally support a 204 MHz upstream that enables a 1 Gbps US service tier. Since the system is not constrained by spectrum, we recommend the 204 MHz US split with the DS starting at 258 MHz. This would allow the operator to also offer a 1G symmetric service over the HFC utilizing existing DOCSIS 3.1 technology.

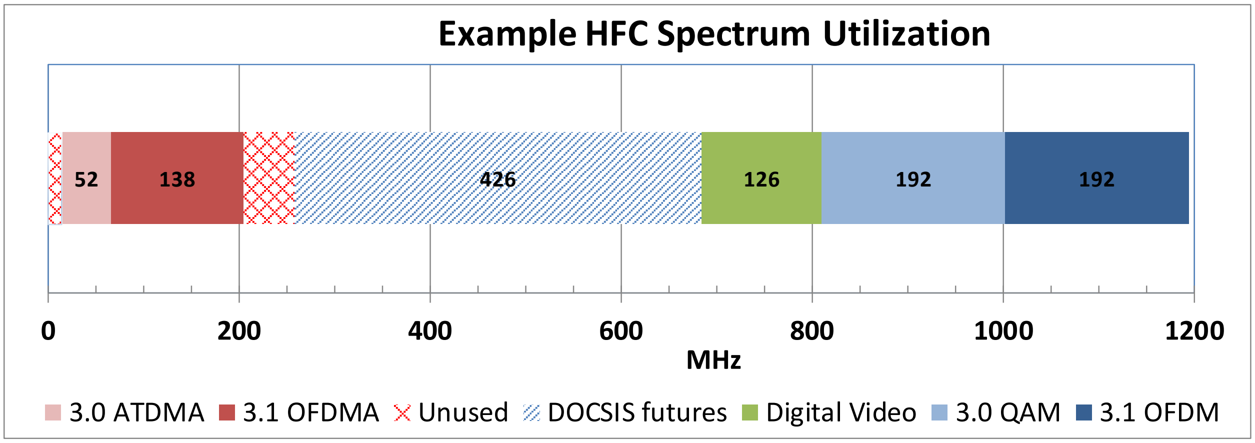


Figure 12 – Example HFC Spectrum Utilization

In this example, the digital video and DOCSIS 3.0 DS channels have been put in the 684 MHz to 1002 MHz range to compile with a possible future migration to DOCSIS Full-Duplex (FDX). A DOCSIS 3.1 OFDM channel is placed above 1002 MHz to offer 1G DS services on day one.

In the upstream, eight DOCSIS 3.0 ATDMA channels are supported with the rest of the 12-204 MHz upstream being used by a pair of DOCSIS 3.1 OFDMA channels. This also enables 1G US services on day one.

Note that the spectrum from 258 MHz to 684 MHz is not initially used, yet is available for future DOCSIS expansion. This spectrum could be used in several different ways. First, some, or all, of the excess spectrum could be used for DOCSIS 3.0 expansion as user traffic continues to grow. This could help eliminate or defer Service Group splits in the future, saving the operator costs down the road. Alternatively, some of this excess spectrum could be used for additional DOCSIS 3.1 OFDM channels to offer higher service tiers (e.g. 2.5 Gbps DS service).

Finally, some, or all, of this excess spectrum could be used by DOCSIS FDX to offer multi-Gbps symmetric services. Note that use of FDX would also need to coincide with a migration to an N+0 passive plant in the future. This corresponds to Options #2 and #4 above.

4.4.3. Capacity Modeling

For this paper, the network capacity requirements were simulated using the ARRIS Network Capacity modeling tool. To minimize costs, a downstream SG with 1,000 subscribers was paired with two upstream SGs each with 500 subs. It is not desirable to make the US SG any larger to limit the amount of noise funneling in the upstream. If this had been an older brownfield, then the US SG might have had to be even smaller.

Since broadband usage in CALA has been running a couple years behind typical North American usage, the average subscriber usage during peak busy hour (Tavg) is assumed to be 400 Kbps per sub. The higher HSD tiers would have more usage than this and the basic tier would be slightly less than this. Based on other ARRIS research, Tavg is assumed to grow at 40% Compounded Annual Growth Rate (CAGR).

For the modeling a legacy digital video service is considered, as it would use more spectrum than an IP Video service. The digital video VOD service assumes that there would be a peak usage of 5% during peak busy hours.

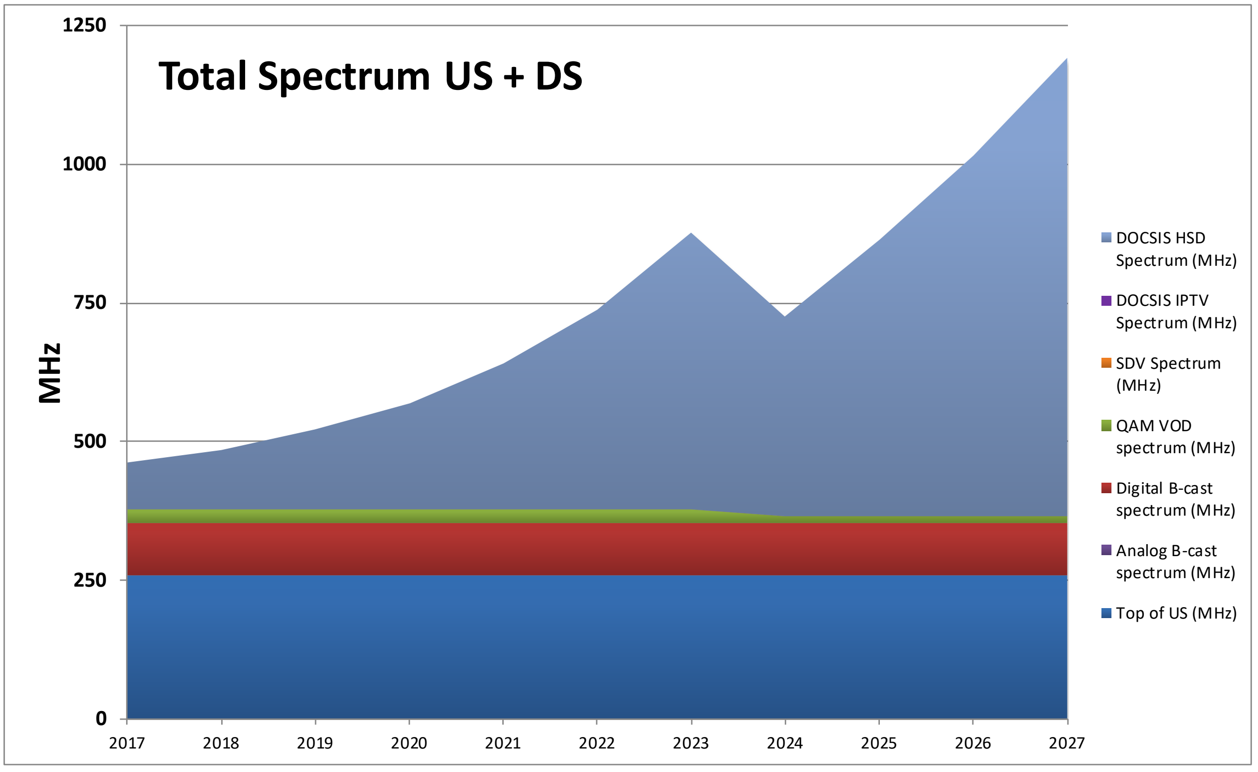


Figure 13 – Network Capacity Model Results

These results only consider the DOCSIS 3.0 subscribers. By the year 2021, the 32 bonded 3.0 channels have been completely consumed and additional 3.0 capacity is added from the "DOCSIS Futures" spectrum. By the year 2024, this spectrum eventually becomes filled as well.

Initially the model assumes that the SG is split and is now 500 subs per DS, 250 subs per US. By 2026, additional action is needed again. Either another SG split is required, or alternately DOCSIS 3.1 capacity could be used if enough of the subscribers have been migrated to D3.1 modems.

Perhaps the most important conclusion from this section is that it is feasible to have a 1000 sub DS SG that is viable for the next 8-10 years before the access network needs any segmentation. This allows the operator to install the most cost effective access network now, but with segmentation in mind for the next decade. The operator should design their HFC greenfield with the ability to segment easily in the future without requiring a significant fiber or plant investment.

4.5. Trade-offs in Selecting the N+0 vs N+X Implementations

Figure 14 shows topology of a common HFC network [source: HFC wiki]. A regional optical transport ring, in the upper left corner, performs a function of redundant-routes connecting the distribution Hubs, a function similar to that of IP-RAN described above. Fiber links are also the means of connection from distribution Hubs to the optical nodes, with the coaxial cable coming out of the node, through a cascade of RF amplifiers, in order to either extend the reach or to overcome RF splitting losses. The “0” and “X” in N+0 and N+X denote the length of the RF amplifier cascade. For the network of Figure 14, the X = 4, since there are 4 RF amplifiers in a cascade emanating out of the top-most and bottom-most optical nodes.

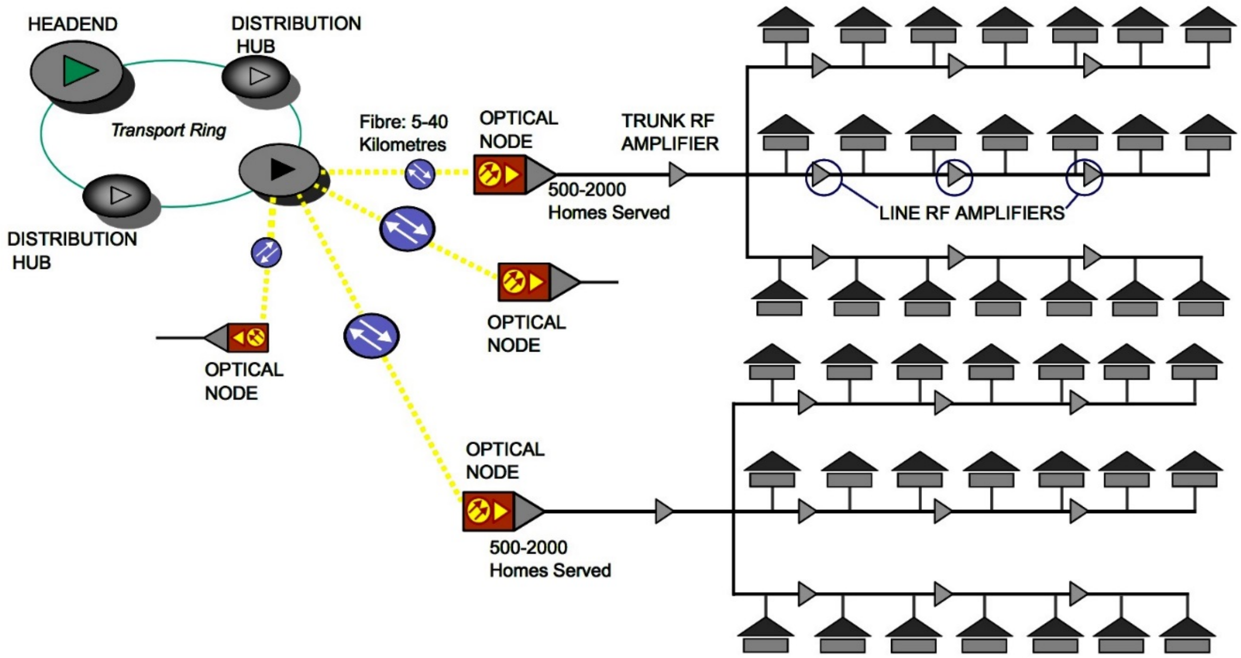
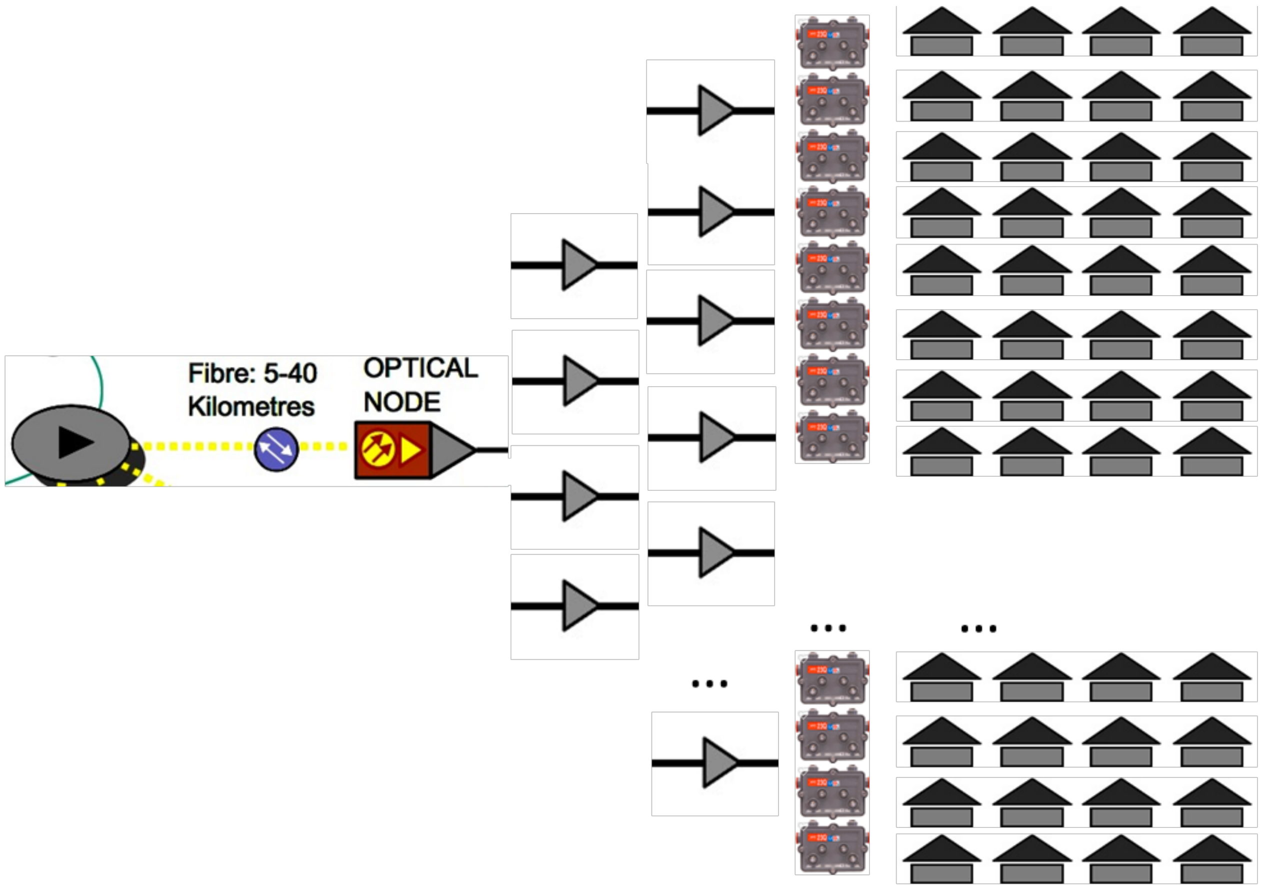


Figure 14 – Topology Overview of Hybrid Fiber Coax (HFC) Network Architecture

True insight into flexibility of HFC can be gleaned from a “pyramid depiction” of the same topology, as shown in Figure 15. Optical nodes typically have 4 coaxial outputs and are followed by no RF amps, as in N+0 case, or with up to ~30 amps, in N+X case. Each RF amp may feed 4-8 taps, and each tap may have 4-8 drop ports. At one extreme, 1 node, x 4 RF outputs, x 4 taps, x 4 drops, results in 64 home-passed coverage, which could be set as a very small service group, with all the capacity to be shared among those

64 homes that have signed up for the services. At the other extreme, 1 node, x ~30 RF amps, x 8 taps, x 8 drops, results in as many as 1,920 homes-passed!



Resulting multiplier:	**1 - 4**	**4 - 30**	**4 - 8**	**4 - 8**
Resulting Service Group Size:				**~64 to 1,000+ HP**

Figure 15 – "Pyramid Depiction" of a Common HFC Network Topology

In figure 15, one fiber link serves 1-4 node segments, followed by 4-30 RF amps, each serving 4-8 taps, each with 4-8 ports, and giving "dynamic range" for the resulting service group of 64 to 1,000+ homes passed.

Distance covered, capacity delivered, and cost per home passed are definitely affected and traded against each other. Nevertheless, the "dynamic range" of this topology is <u>simply powerful</u>. Perhaps the most impactful consequence of this flexibility is network's unmatched ability to scale as needed, and more importantly for the operator to "pay as you grow" just as the network capacity augmentation is needed.

Those "skilled in the art" of architecting the cable access plant will remember that cable plant was all coax before it became "Hybrid Fiber Coax". As fiber became a great distance-coverage enabler first, and then cost / power / performance advantageous later, the "N+X" cascade of RF amplifiers following the fiber/coax node kept reducing from as many as 15 down to as few as zero! Furthermore, Deep Fiber architecture, long advocated by ARRIS for low "total cost of ownership" [Fiber Deep 5 Years Later], establishes a "clean slate" starting point for establishing cost-effective, high-capacity, low power flexible network. Yet the most valuable attribute of N+0 may be its future-proof promise, is that each node can be turned into an RPD / DAA, with further segmentation, if so required, or full-duplex functionality, or even turned into all-fiber network, of either PON or RFoG type.

DOCSIS FDX enables multi-Gbps symmetric services over HFC. This is very powerful. It also requires a passive N+0 HFC plant. In our case study, some options assume that the operator starts with the most cost effective N+X HFC implementation, where x is a small number (e.g. N+3). The FDX services may be well targeted and not required across the entire footprint. If this is the case, then the operator may want to surgically upgrade a particular active component using Fiber to the Last Active (FTTLA) with FDX capable technology while leaving the remainder of the plant alone. An operator may choose to pull extra dark fiber at the same time the coax is built; or simply use conduit that would easily allow the fiber to be pulled to the last active at a later point in time when needed.

4.6. Future Proof Considerations about the Options Identified

We started this paper with a "one bullet" analogy, and how crucial it is for CALA operators to "aim right". To continue this analogy, why not use a silver bullet as well? Since CALA operators need to get it right first time, they should also consider the ability to offer symmetrical gigabit broadband on day one. Deploying costly Fiber to the Premise (FTTP) network on day one is not economically feasible. However, symmetrical gigabit is achievable by using HFC and choosing the proper downstream / upstream RF frequency split, 204/256 MHz as outlined above, as well as leveraging everything the DOCSIS 3.1 will offer.

By constructing this new Fiber Deep HFC network, CALA operators will be unencumbered by aging plant and historical RF splits. Some of the North-American operators, whose "last mile" cable plant was built long ago, with the RF frequency split already implemented and with a topology that was optimized then, are thinking along the same lines, even though it's going to be much more work for them to modify the network. Most of them will have to upgrade every active in order to support a new RF splitting ratio. [Stoneback-Slowik].

Thus, the proper RF frequency split selection enables CALA operators to offer and advertise the gigabit symmetrical service availability today. Later, as more and more consumers decide to spring up to gigabit symmetrical service offerings, there will be no need to touch the physical plant topology. The operator only needs to add CMTS / RPD capacity on the headend side and DOCSIS 3.1 modems on the CPE side.

As shown in the capacity plan model, the network will require re-planning to fit the capacity growth required over the years. As any operator manager knows, it is desired for these changes to be as dynamic and as streamlined operationally as possible. The options shown give operators the ability to selectively change the RPD from the eNodeB location to the field in a N+X configuration or change from a N+X configuration to a N+0 design selectively – in a pay as you grow model.

Changing from the eNodeB to the field is already streamlined, since the infrastructure of the optical node is already installed and the change from the optical node to a RPD is simple. Evolving from the RPD installed in the optical node location (N+X) to a N+0 location could also be simplified if the design of the coaxial and amplifier is made using four output amplifiers, as shown in Figure 16 below.

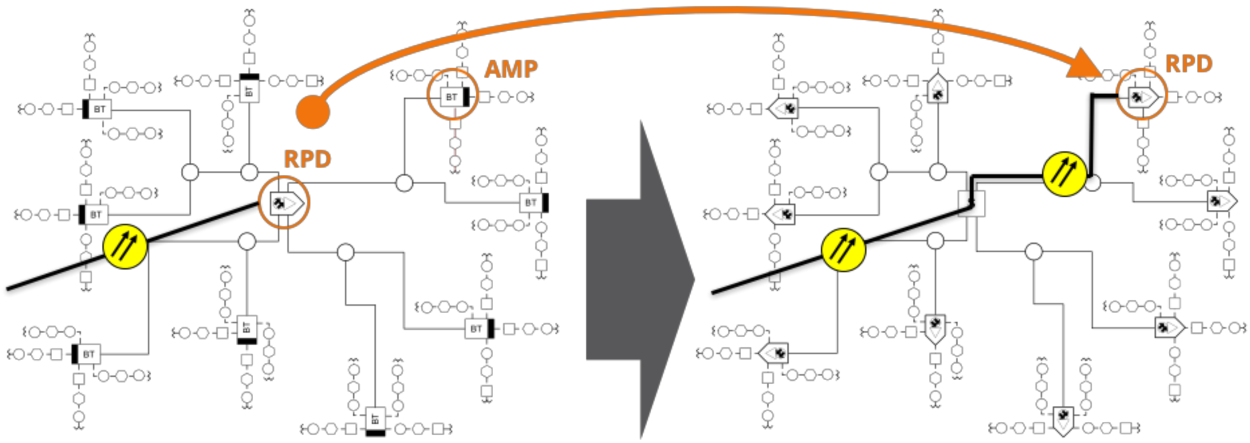


Figure 16 – Usage of a 4-Output Design to Simplify Evolution

Since this will be greenfield construction, it will also be prudent for the operator to consider other future expansions that might be coming within the next five to ten years. Some things to consider include: DOCSIS FDX, FTTH, and wireless backhaul (e.g. 4G/5G, Wi-Fi).

Similarly, an operator may want to provide FTTH services to select users and businesses. As they build out their N+X or N+0 HFC network, they should make sure that it can easily transition to FTTH as needed. As above, this can be done by laying additional dark fibers during the initial construction or by providing conduit that allows fiber to be easily deployed later when needed.

Looking into the future, the need for bandwidth is also growing in the mobile side where the types of service offerings and powerful devices are driving requirements never demanded nor delivered previously. Since mobile devices are powerful handheld computers, new applications with unimagined features to be launched and camera interfaces with more and more pixels will create a need to grow the network even faster, to support capacity, and to pursue higher quality of service.

Today's architecture of mobile macro nodes will not be sufficient for this growth. The need to construct new eNodeB locations will be required and will again generate big constraints. The construction for new antennas placements requires both the premises to support such placements and also power and backhaul links. This takes both time and money to deploy. One of the features that HFC always had is a great way to grow selectively by node splitting, something that cannot be as easily done in the wireless networks of today.

In the future as the RMACPHY evolves as a solution, based on discussions with the industry and standard bodies and becomes more standardized, this could be considered as a trustable option of convergence and can be a good topic to be included in further discussions. Another interesting aspect of the discussion is that 5G is being strongly considered to use mmWave and implementation of small and micro cells will be required. Conquering of the demarcation point (where these small cells will be installed with the place, power, and backhaul) will be a battle for the service operators and will be also a huge factor in providing successful services.

One interesting approach to conquering these demarcation points is to use deploy HFC for the wireless node split. Here the demarcation point uses spaces inside the strand mount equipment (Optical nodes, RPDs and AMPs) which already installed in the aerial deployments where placements can be made in the street level, power and also backhaul. Also, the usage of street furniture will be an important option where the installation is underground.

The convergence presented here will help to address this opportunity for the future evolution of the mobile network. The usage of the HFC is already unified in terms of infrastructure. The mobile sites will help to connect to new radios to be installed inside the strand mount equipment installed in the HFC network. The usage of the RPHY solution will have an advantage due to the option to include these new radios in the future in this equipment. The technology requirements for the RPHY node to enable this “wireless demarcation point” possibility in the forthcoming products are being strongly considered, and feature prominently in today’s plans.

4.7. Cost, Power and Capacity Comparison

The four options were compared based on relative cost, power and capacity and results shown in Figure 17. The lowest in each category was set to 1.0 and the others are shown proportionately. As a refresher, the four options are shown again in the table below.

Table 2 – Options Remembered

	RPD in Field	RPD @ eNodeB Location
N+X	#1	#3
N+0	#2	#4

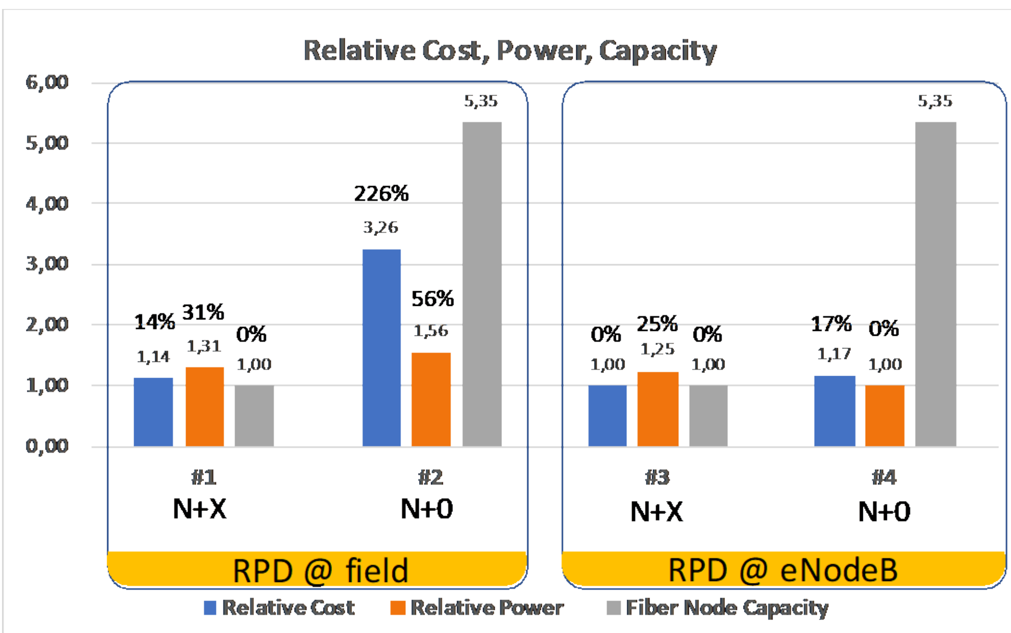


Figure 17 – Relative Cost, Power & Capacity for 4 Options

Option #3 has the lowest total overall costs as it uses N+X HFC architecture with a minimal number of RPD. Options #1 and #4 are very close in costs, coming within ~15% of the Option #3 costs. From an energy consumption perspective, Option #4 is the greenest solution. The other solutions require between 25% to 60% more energy. Finally, from a potential capacity perspective, the N+0 HFC architecture for Options #2 and #4 provides more than five times the potential capacity than the N+X HFC architecture of Options #1 and #3. Looking across these combined factors, Options #4 is intriguing as it reduces power consumption and provides the potential capacity of N+0 for only a slight increase in costs over Option #3.

In addition to the above, there are other benefits to the N+0 options. These push the fiber even deeper, so they align better with a wireless micro-cell strategy. This will become more important over time with the introduction of 4G/5G services as well as widespread WiFi hotspot services. The N+0 options also leave the door open to a future DOCSIS FDX and/or Extended Spectrum migration that can support multi-Gbps symmetrical services. This migration can be done as needed selectively on a node by node basis. It does not require the cost of upgrading the entire HFC architecture.

Conclusion

Convergence has been a word overly used in our industry. However, it is the name of the game now that the industry is becoming mature and strongly competitive. In this paper, we attempted to highlight options available to the CALA service providers that are pragmatic solutions ready to deploy today and we took a peek into the next decade, underlining important concerns to take in consideration to make the right decision now to be future proof.

The evolution of DAA, using digital Ethernet communication, provided us the opportunity to demonstrate how unifying the mobile and fixed infrastructure is possible. And the synergy generated by this is huge, not only in terms of CAPEX, but also OPEX and the simplicity of maintaining the network.

Starting with RPD in the eNodeB location and evolving to the field in a N+X and then to N+0 selectively by service groups seems likely to be a logical move. This way of growing networks (node splitting) has proven to be the success factor to the service provider that deployed HFC. The technology and the designs proposed here will help the operators in the region to continue to grow their network capacity selectively.

New technologies being developed today like DOCSIS FDX will require changes in the MAC layer and the PHY layer and deploying R-PHY solution today in a controlled environment such as a eNodeB location could help service providers to streamline operationally the upgrade, when this technology becomes available in the near future.

As the RMACPHY evolves as a solution, based on discussions with the industry and standard bodies and becomes more standardized, this will be considered as a trustable option of convergence and can be a good topic to be included in further discussions.

Finally, mobile services will continue to become more and more important over time. As the operator builds its N+X HFC, it should do so with an eye towards wireless migration and utilizing the HFC access network for 5G & Wi-Fi backhaul. The location of HFC actives and the availability of the HFC power should take into account the needs of both 5G and Wi-Fi wireless distribution.

Abbreviations

3G	Third generation wireless
4G	Fourth generation wireless
5G	Fifth generation wireless
ARPU	average revenue per unit
AMP	Amplifiers
BAU	Business as Usual
bps	bits per second
CAGR	compound Annual Growth Rate
CALA	Caribbean and Latin America
CMTS	Cable modem termination system
DAA	Distributed Access Architecture
eNodeB, eNB	Evolved node B
FX Rate	Foreign exchange rate - A value of two currencies relative to each other
FTTH	Fiber to the home
HFC	Hybrid Fiber-Coax
Hz	Hertz
IP-RAN	Internet Protocol – Radio Access Network
ISBE	International Society of Broadband Experts
N+0	Optical node + zero number of amplifiers in the coaxial
N+X	Optical node + X number of amplifiers in the coaxial
QoS	Quality of service
RAN	Radio Access Network
RPD	Remote Phy Device
RPHY	Remote Physical Interface
RMACPHY	Remote media access control and physical interface
SCTE	Society of Cable Telecommunications Engineers
SG	Service Group
YoY	Year over Year

Bibliography & References

[CLOONAN_2014] "*Predictions on the Evolution of Access Networks to the Year 2030 & Beyond*"; T. Cloonan, M. Emmendorfer, J. Ulm, A. Al-Banna, S. Chari, The Cable Show NCTA/SCTE Technical Sessions Spring 2014

[HFC wiki] https://en.wikipedia.org/wiki/Hybrid_fibre-coaxial

[Fiber-Deep 5 Years Later] *"Case Study: Fiber-Deep, 5 Years Later"*; Jeff Gould, Suddenlink and Joseph P. Lanza, Aurora Networks, Communications Technology; October 15, 2008

[Thinking Green] "Thinking Green Strengthens the Case for Fiber Deep in Cable"; ARRIS/ Aurora White Paper 16, July 2009

[Stoneback-Slowik] *"Making Rational HFC Upstream Migration Decisions in the Midst of Chaos"*; Dean Stoneback and Fred Slowik, 2013 NCTA/SCTE Spring Technical Forum

[HFC Green] *"Giving HFC a Green Thumb"*; John Ulm and Zoran Maricevic, SCTE Journal of Energy Management, Volume 1, Number 2, October 2016

