MAKING MORE WITH LESS! A CASE STUDY IN CONVERGING WIRELINE AND WIRELESS NETWORK INFRASTRUCTURES USING DISTRIBUTED ACCESS ARCHITECTURES

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INTRODUCTION

The maturing of the telecommunications industry has led to a consolidation trend. 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 (R-PHY), Remote MAC-PHY (RMAC-PHY), 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 number 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.”

With the challenges that CALA faces, we analyze a specific case in that market in which the requirements for the planning and deployment of new technologies, such as R-PHY, RMAC-PHY, RFoG, and FTTH are somewhat specific to CALA. These requirements are very high density and low bandwidth services plans compared to the market in the USA. Consequently, a larger number of subscribers per service group (SG) are required to make the implementation economically viable.

This case study analyzes some actual underserved cities in the CALA region, with the goal to profitably deliver 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 Architecture (DAA) technologies such as Remote PHY.

These options all use the existing mobile backhaul infrastructure, IP radio networks (IP-RAN) 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

Requirements of CALA and differences vs. the NA region

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

One important consideration for an adoption of a new technology is the environment in which the technology will be used. A very dense or ultra dense environment is typical in the CALA region and must be taken into consideration 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 people. Similarly Mexico City is 6,000inh/km^2 (16,000inh/sq. mi) without as much distribution and spread like the NA region. These differences show a gap of requirements for deploying new technologies such as DAA.

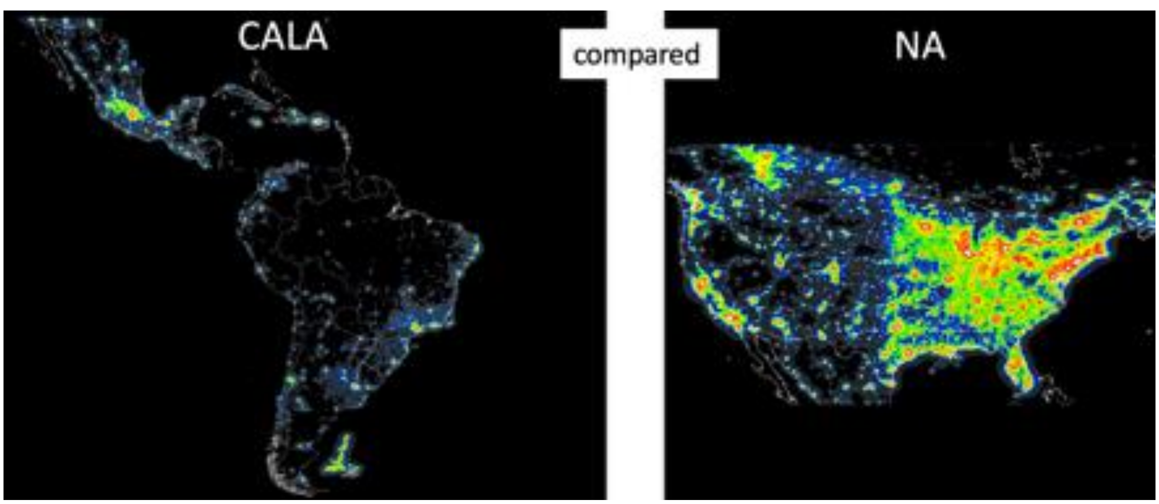


Figure 1 – Light View in Dark Comparing the Concentration between CALA vs. NA Region

Another important environmental characteristic of the region is the type of construction employed. In CALA, the typical implementation is via aerial construction, using poles. However, the robbery of units and cables in the streets is causing resistance to the idea of DAA since more expensive equipment in the field would be at risk.

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 generates revenue and profit, makes investments and maintains and operates the plants. 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 the U. S. market. It's for this reason that the CALA region cannot afford to select the wrong 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 focus on convergence opportunities and are beginning to embark on initiatives in this area.

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 today is 250 Mbps. The 1 Gbps speeds that are deployed in the U. S. are about two years delayed and will most likely be deployed for only a small part of high tier customers.

On the other hand, the demand for data is still very strong with the compound annual growth rate (CAGR) in downstream ranging from 45 to 50% year-over-year (YoY). This indicates 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.

Challenge and use case of a CALA city

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 take 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?

Thinking pragmatically, yet with a holistic view, how can we solve the issues caused by environmental and economic constraints while helping the Service Provider better maintain sustainability? Our convergence case study focuses on an underserved city in the region, which represents the typical environment, to answer these questions and find a solution.

For this use case, a small underserved 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 homes passed 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 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 exacerbate the difficulty of establishing a viable business case.

The next option considered is based on using new Distributed Access Architecture (DAA) technologies. This approach seemed 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 during peak 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 plan is to use and converge these infrastructures to gain time savings in implementation, generate significant synergy in maintenance and make this implementation as cost-effective as possible. The typical architecture used in the region to deploy HFC and mobile infrastructures is analyzed in the next section.

Technical implementations of converged cable and mobile networks

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 subscribers 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.

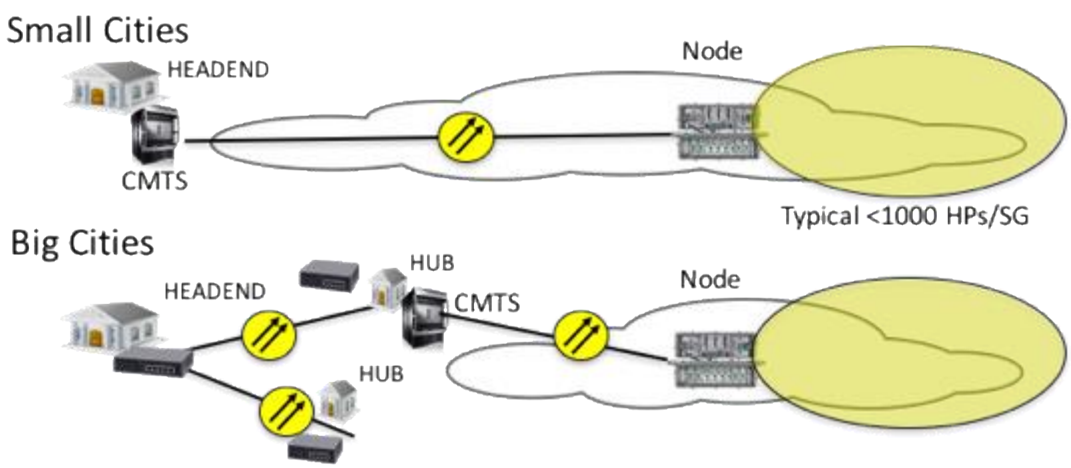


Figure 3 – Typical Cable Access Infrastructure Implementation

One important consideration in the network evolution towards distributed architectures is that the requirements of the region are different from the large 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.

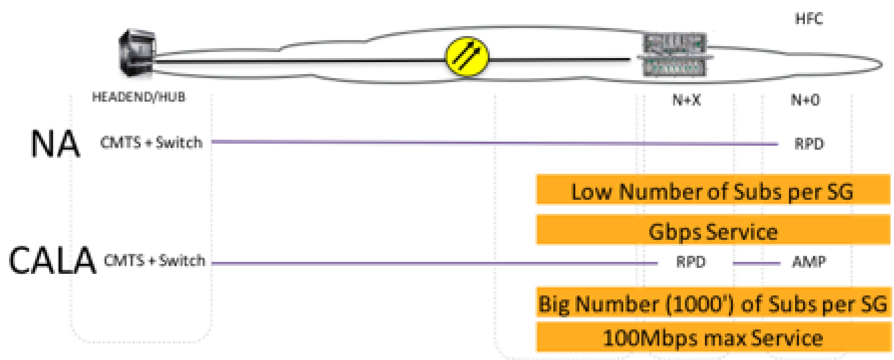


Figure 4 – Example of Planning and Implementation Differences With RPHY Technology Requirements between CALA and NA

Mobile typical access infrastructure in CALA

Figure 5 shows a typical mobile access architecture as utilized in the region. It comprises 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 IEEE 1588, QoS, security and monitoring to the 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.

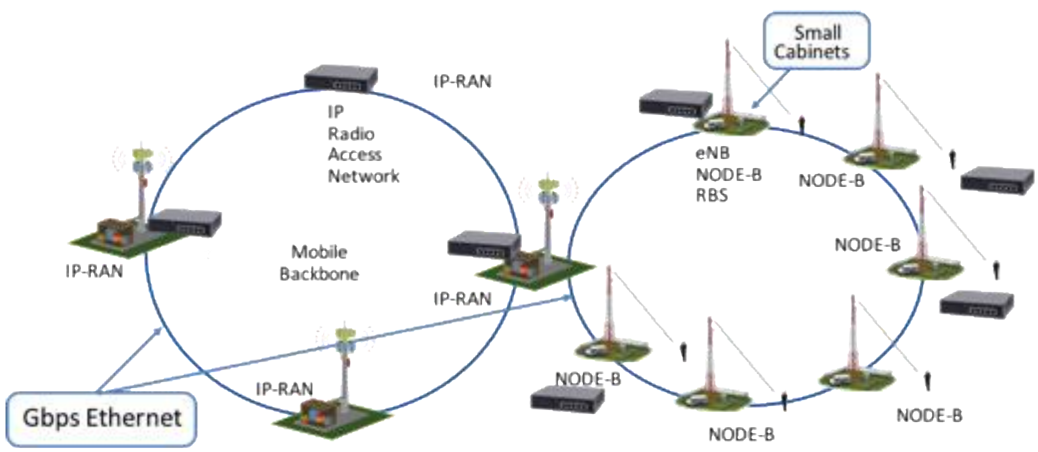


Figure 5 – Typical Mobile Access Infrastructure

Options analyzed to converge the infrastructures with important consideration and synergies

Options

Understanding how the architectures are deployed, our case study then evaluated four options to converge, using the existing mobile infrastructure. All of these options leverage 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 in the matrix 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.

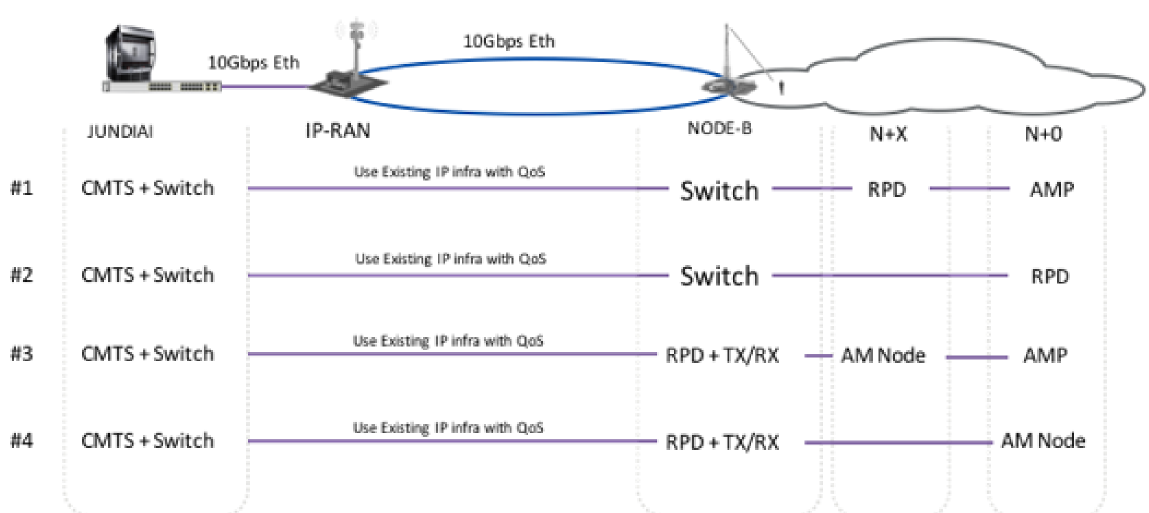


Figure 6 – DAA Technological Options Identified

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 10 km 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)

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 10 km reach is used to connect to the RPD in the field
- From the RPD there is a passive N+0 coaxial network architecture

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

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

Synergy in timing and IP switching considerations in an RPHY solution

With the evolution of the HFC network to a DAA, the IP switching is reviewed with the focus on the future evolution to network function virtualization type of infrastructures. The traditional three-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.

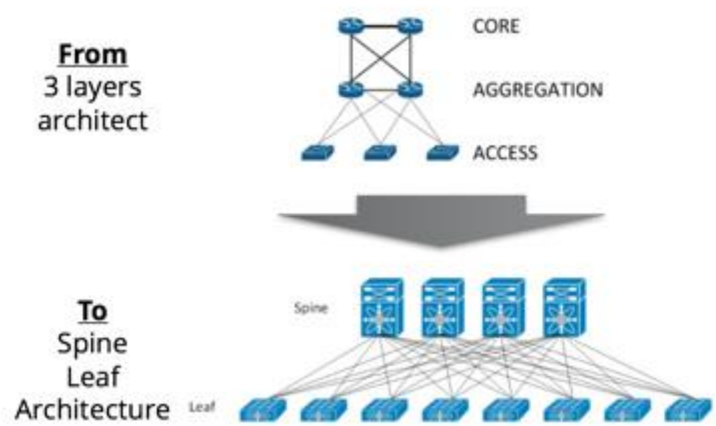


Figure 7 – IP Switching Changing from 3-layers Architecture to Spine Leaf Architecture

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 consider the traffic demand growth, which the selected IP switch design should be able to easily address. 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 networks.

Some specific features will be required and must be considered in the IP switching design, such as support for IPv6 and the IEEE 1588 timing protocol. The latter requires the addition of an IEEE 1588 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 existing server as is, poses a great opportunity of operational synergy.

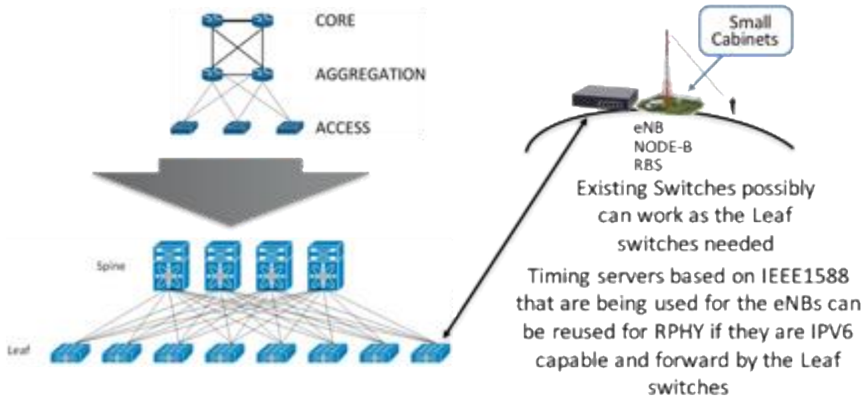


Figure 8 – Usage of Existing IP Switching to the Leaf Switch and Provide Sync to RPD

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 very important area of synergy is unifying two infrastructure layers. It is critical to converge to a single layer since this analysis is focused on greenfield areas with new service offerings.

The planning of nodes to provide fixed broadband and video to this city, and the deployed mobile infrastructure make a compelling case to unify the infrastructure as in Figures 9, 10 and 11:

- Figure 9 is an infrastructure deployment with only the HFC fixed services layer in mind
- Figure 10 uses an example of an existing mobile infrastructure
- Figure 11 shows the opportunity to unify the infrastructures

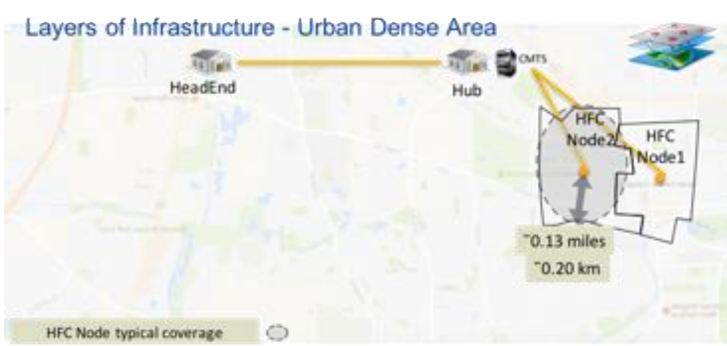


Figure 9 – Example of an HFC Nodes Implementation with a Fixed Services Layer Only

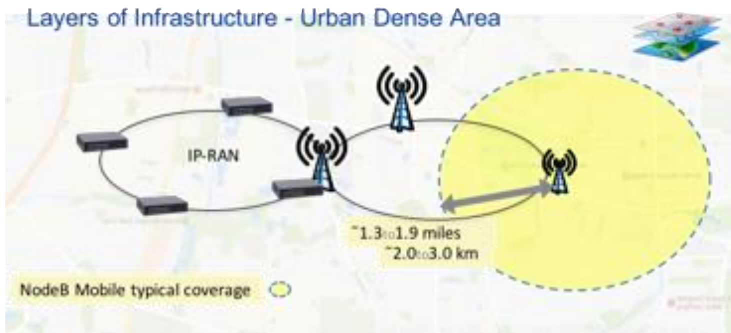


Figure 10 – Example of an Existing Mobile Infrastructure

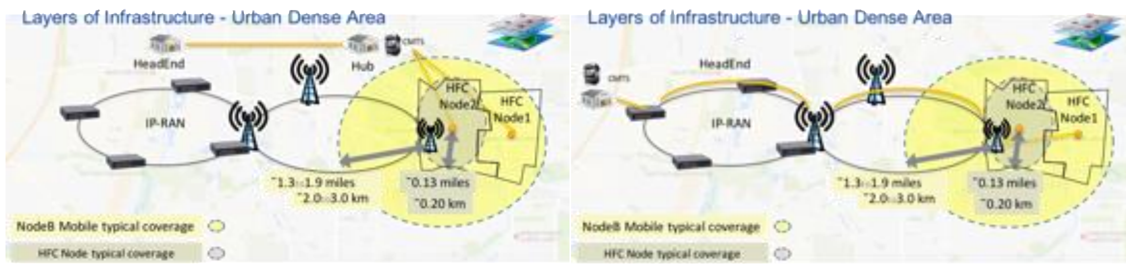


Figure 11 – Opportunity to Unify the Layers

Unifying the layers of infrastructure offers a significant opportunity. This allows us to:

- Simplify the deployment and operation
- Make a more cost-effective implementation
- Lower the OPEX
- Make the evolutionary step more dynamic

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 influences 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 in turn is determined by the services offered, and the available HFC spectrum. This section explores some of the options available in this case study.

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) 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/5 Mbps 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 subscribers have 50 Mbps/10 Mbps service and 5% of the subscribers 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 and/or Wi-Fi®.

As a minimum, the CALA Operator will offer an HSD service with sufficient capacity to enable its subscribers to access over-the-top (OTT) video services. The Operator may also decide to offer its own managed digital video service. The video infrastructure and set-top boxes (STB) may already be 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 DAA 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. However, IP video increases the capacity requirements for DOCSIS, so 8x4 modems may not have sufficient capacity to deliver the service. This demonstrates another reason for using a 16x4 modem to simultaneously support IP video.

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 previously deployed STBs in a greenfield, the digital video service is assumed to be delivered using H.264/MPEG-4 video encoding technology. This reduces the spectrum by half from older MPEG-2 only STBs. 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 DS 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.

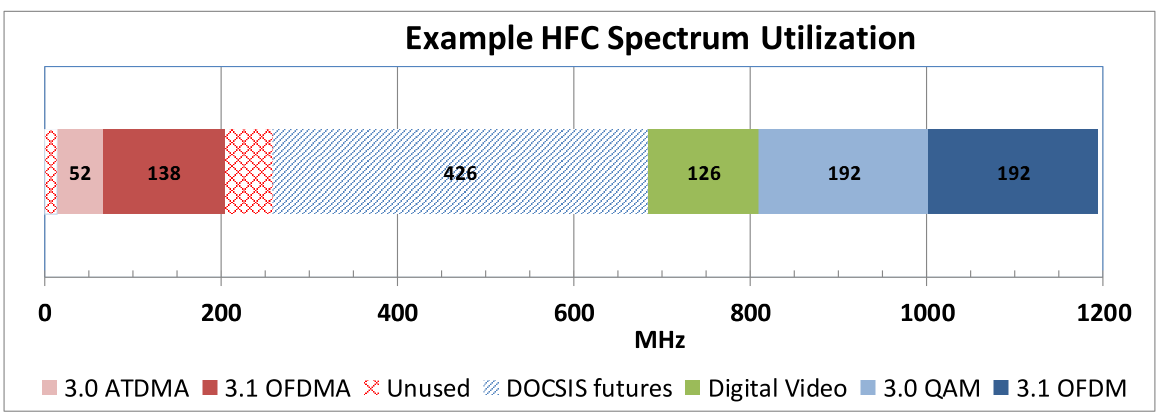


Figure 12 – Example HFC Spectrum Utilization

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.

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 the peak busy hour (Tavg) is assumed to be 400 Kbps per subscriber. The higher HSD tiers would have more usage and the basic tier would be slightly less. Based on other ARRIS research, Tavg is assumed to grow at 40% compound 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 VOD service assumes that there would be a peak usage of 5% during peak busy hours.

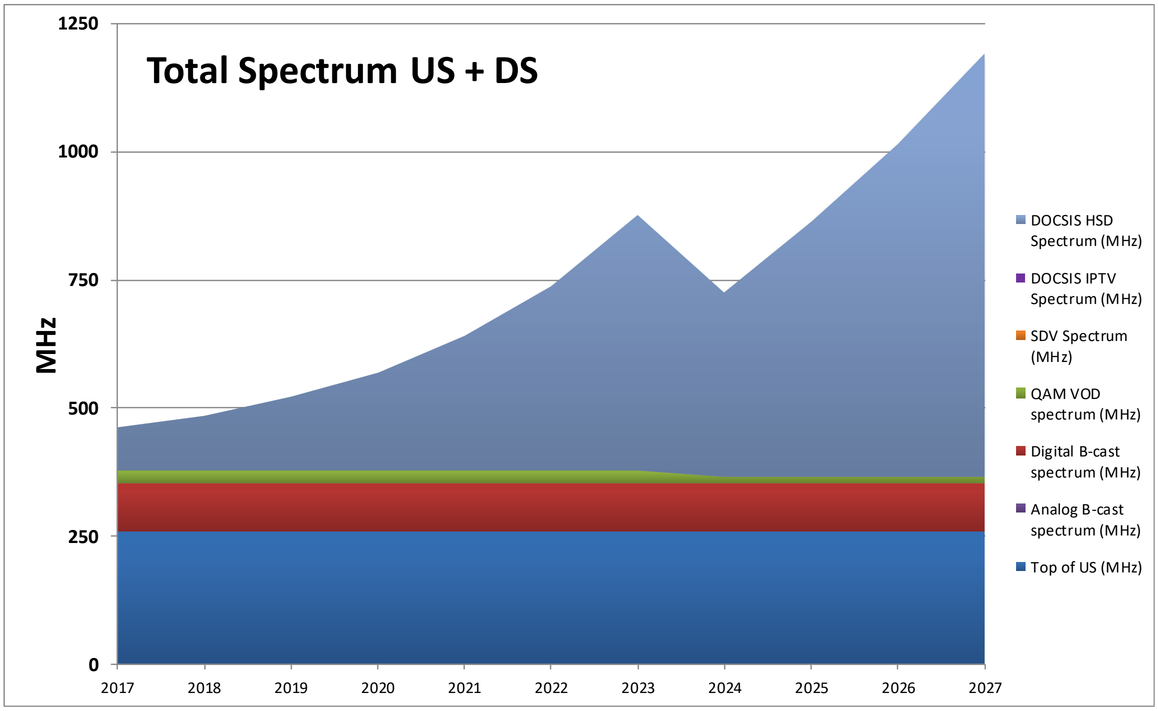


Figure 13 – Network Capacity Model Results

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 subscribers per DS, 250 subscribers 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 subscriber DS SG that is viable for the next eight to 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 its HFC greenfield with the ability to segment easily in the future without requiring a significant fiber or plant investment.

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.

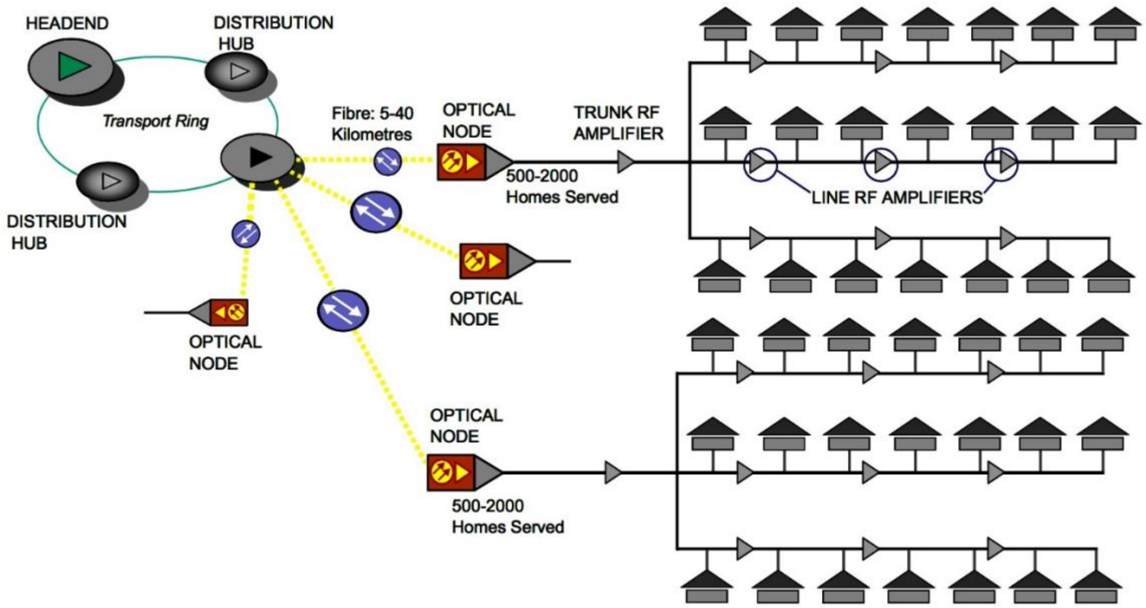
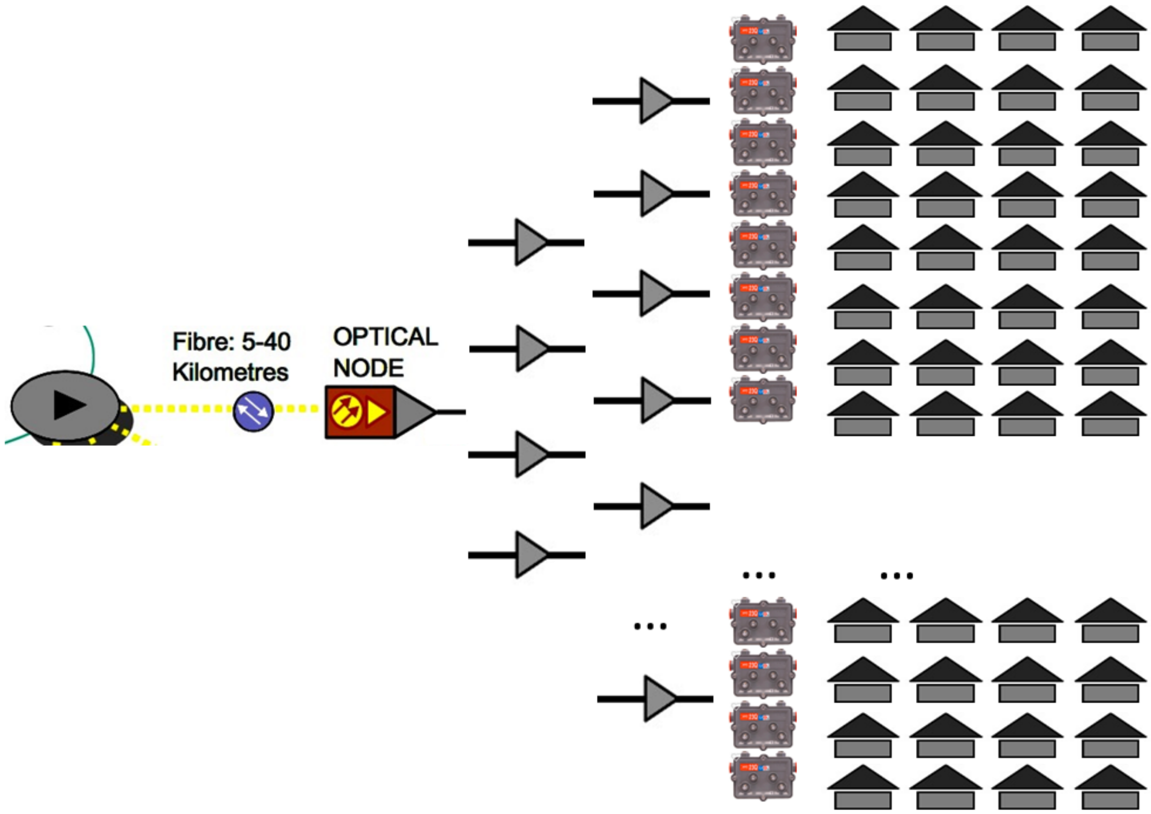


Figure 14 – Topology Overview of Hybrid Fiber Coax (HFC) Network Architecture

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 simply powerful. 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 a cost-effective, high-capacity, low power flexible network. Yet the most valuable attribute of N+0 may be its future proof promise, that each node can be turned into an RPD / DAA with further segmentation, 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.

Future proof considerations about the options identified

We started this paper with a "one bullet in the chamber" analogy, and how crucial it is for CALA operators to "aim right the first time." 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 a 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 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 at that time, are thinking along the same lines. Even though it's going to be much more work for them to modify the network, most of these Operators 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, these changes should be as dynamic and as streamlined 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.

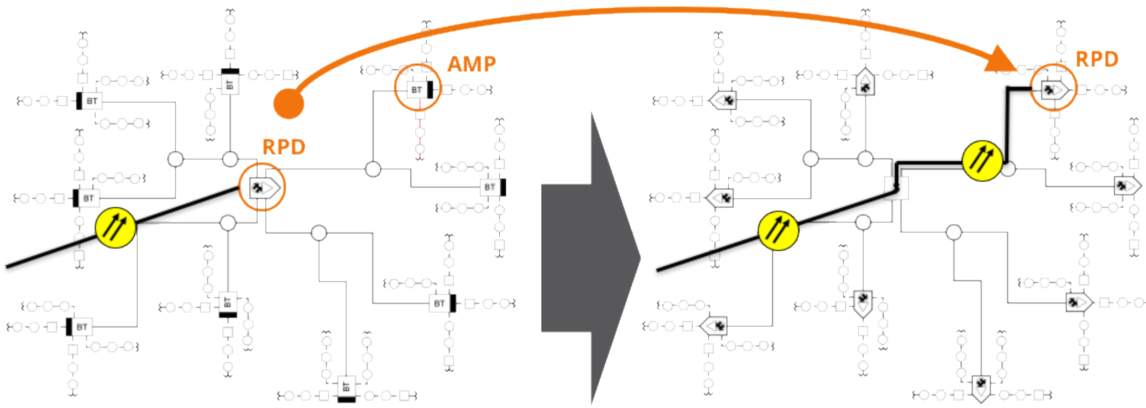


Figure 16 – Usage of a 4-Output Design to Simplify Evolution

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 10 years. Some things to consider include: DOCSIS FDX, FTTH and wireless backhaul (e.g. 4G/5G, Wi-Fi).

Similarly, Operators 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 to the future, the need for bandwidth is also growing on the mobile side where the types of service offerings and powerful devices are driving requirements never before in demand or delivered. Since mobile devices are powerful handheld computers, new applications with unimagined features and camera interfaces with more and more pixels will create a need to grow the network even faster to support capacity and deliver 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 create significant constraints. The construction for new antenna placements requires both the support such placements on the premises and also support for power and backhaul links. This deployment takes both time and money. One of the long-standing benefits of

HFC is that it can be used for selective growth by node splitting, something that cannot be as easily accomplished with the wireless networks of today.

In the future, as RMAC-PHY evolves as a solution and becomes more standardized, it may be considered as a reliable option of convergence, and will likely be the topic of discussion amongst industry organizations and standards bodies. Another interesting aspect of the broader discussion is that mmWave is the promising candidate for making 5G a reality where 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 HFC for the wireless node split. Here, the demarcation point uses spaces inside the strand mount equipment (optical nodes, RPDs and AMPs) which is already installed in the aerial deployments and where it can be placed at the street level, power and backhaul. The usage of street furniture will also be an important option where the installation is underground.

The convergence presented in this paper will help to address the opportunity for the 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 within the HFC network. The usage of the R-PHY solution will have an advantage because of the option to include these new radios in this equipment. The technology requirements for the R-PHY node to enable this “wireless demarcation point” possibility in forthcoming products are being strongly considered, and feature prominently in today’s plans.

Cost, power and capacity comparison

The four options were compared based on relative cost, power and capacity with the 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 1 – Options Remembered

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

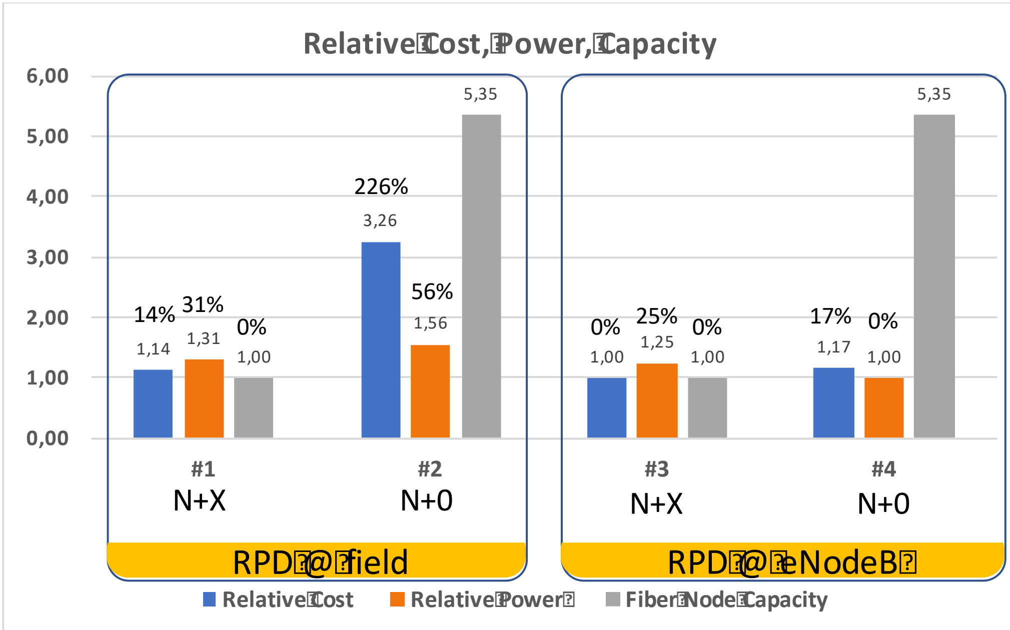


Figure 17 – Relative Cost, Power & Capacity for 4 Options

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% and 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 those mentioned 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 Wi-Fi 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 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 highlighted options available to the CALA Service Providers that are pragmatic solutions ready to deploy today. We also took a peek into the next decade, underlining important concerns to be take into consideration when making the right decision now that will yield benefits into the future.

The evolution of DAA, using digital Ethernet communication, provided us the opportunity to demonstrate that unifying the mobile and fixed infrastructure is possible. The synergy generated by this unification is significant, 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 an N+X and then to N+0 selectively by service groups, seems to be a logical move. This way of growing networks (node splitting) has proved to be the success factor for 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, as needed.

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

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 and 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

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