Access Transformation – Technology Basics

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Executive Summary

Broadband service trends have gone through a significant evolution and there is no sign of this slowing down. In the early days of the internet all interactive applications were text based and file-sharing was considered a background task! Since then waves of innovation and application adoption have pushed subscriber demand.

A first evolution wave hit in the 1990's with the introduction of search engines and multi-media browsers. In the early 2000's distributed file and content sharing dominated demand, taken over quickly in the late 2000's by broadcast and over the top video streaming combined with the upsurge of social media. The latest *connected living* innovation cycle - driven by the *Internet of things* and *real time cloud-based application*s - propels the need for both upstream and downstream bandwidth[1]. The impact of the broadband service evolution is considered the trigger for the third industrial revolution[2].

As a result, overwhelming pressure is put on a service providers access network to keep up with this steep broadband demand curve. Luckily the broadband service innovation is balanced by an equally if not faster technology innovation cycle.

This paper focuses on the technical evolution of the access network. It describes methodologies to evolve the capacity of an access network and how these methodologies are applied in copper, fiber and wireless networks. We will explain the similarities in transformation strategies of multiple access technology families and how to plan for an increasingly hybrid and converged access network.

WHAT IS THE PROBLEM?

Broadband service demand is increasing exponentially. In addition, competitors are disrupting the market by introducing leapfrog offers that far exceed bandwidth demand. To meet these challenges technology is being evolved at a breakneck speed.

In such a fluid transformation, a well-managed access network technology evolution is a must for any operator.

Selecting the right technology evolution path is critical to ensure competitiveness and profitability.

Key Words: PON, DOCSIS, HFC, Wireless, Access Transformation

KEY TAKEAWAYS

- All access technology families have similar upgrade paths
- Innovation can extend the life of a technology family
- Deploying fiber closer to the subscriber is a common trend in all types of access networks
- Wired and wireless handoffs are a common theme in many deployments

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Introduction

This paper is focused on the access part of service providers data communication delivery networks. More specifically how these access networks have evolved and can further evolve to keep up with customer demand. The access network is the part of the network providing direct connectivity to subscribers. As shown in the figure below, different access technologies and architectures are being deployed today. Let us first look at some key characteristic of these access architectures.

- HFC (Hybrid Fiber Coax): HFC is mostly deployed by cable operators. This technology, initially deployed for broadcast video distribution, transfers triple play services on the coax infrastructure. HFC architecture uses fiber cable from the distribution hub to an active optical node in the outside plant, and coax cable from the optical node to the subscribers. HFC is a shared point to multipoint (P2MP) architecture meaning that all active subscribers on a link share the available upstream and downstream bandwidth. The data communication protocol deployed on HFC is DOCSIS (Data Over Cable Service Interface Specification). Multiple versions of DOCSIS protocol are deployed in the cable operator networks.
- xPON (Passive Optical Network): A passive optical network is a P2MP architecture that uses fiber cable to connect subscribers from the OLT (Optical Line Terminator) in the distribution hub/Central Office (or from a cabinet in the outside plant) to the ONT (Optical Network Termination) at the subscriber location. A single fiber from the OLT is split using passive optical splitters to several subscribers. Typical split ratios deployed in the field are 1/32 or 1/16. There are different PON standards, each with different physical and MAC layer definitions. Most deployed PON standards today are: GPON, EPON, 10G-EPON, XGS-PON, and NG-PON2.

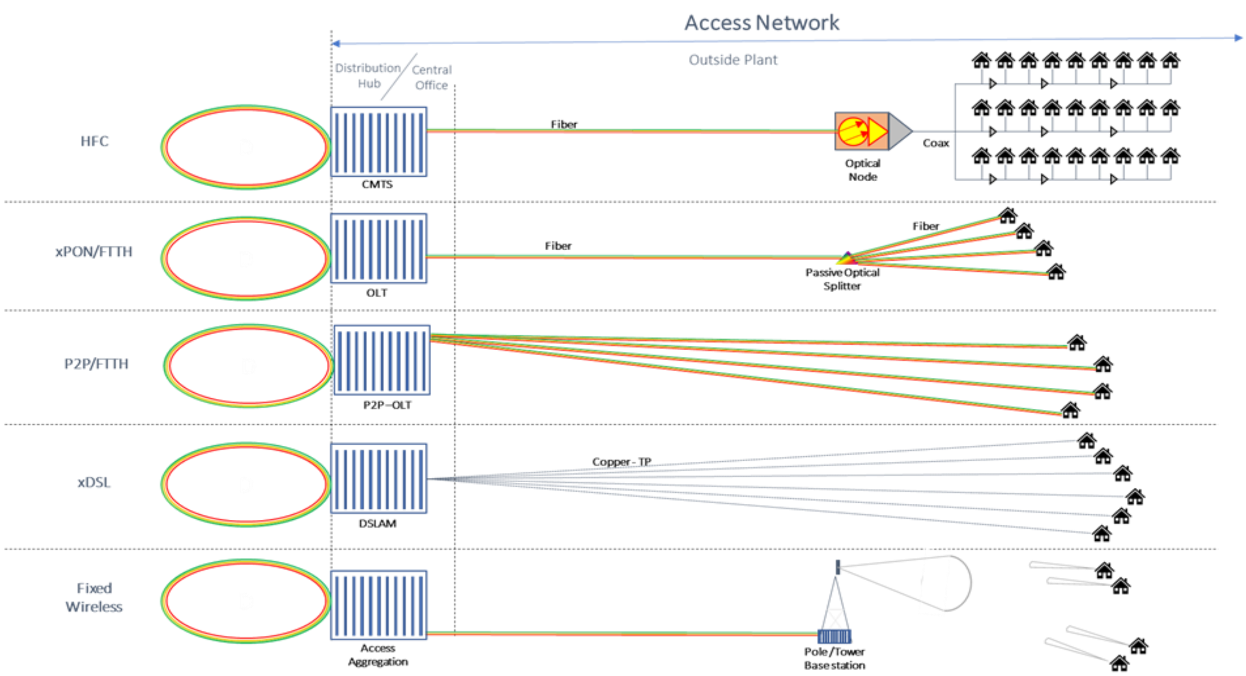
Transformation in a nutshell

Access transformation involves not only the technology transformation, as discussed in this paper, but also includes strategic, financial and operational considerations. In the future, we will introduce you to these other aspects of the transformation. In the meantime, if you want to get a hint of what's to come, refer to [3].

In a nut shell, for an access transformation you need to consider the –

- *Strategic needs* which includes the strategic and customer needs
- *Financial constraints* which restricts the amount at your disposal to invest
- *Operational challenges* that brings realistic market conditions in perspective, and
- *Technological options* that are at your disposal to meet the above needs

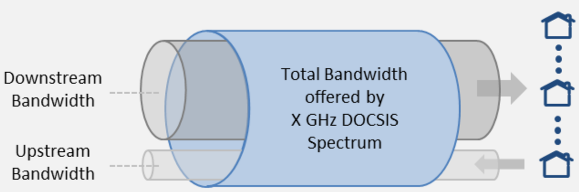
These four pillars together decide how effective a transformation strategy is to meet the long-term vision of a provider.



- P2P – FTTH (Point-to-Point, Fiber-To-The-Home): A point-to-point medium is, as the name suggests, a dedicated physical connection to each subscriber. In P2P-FTTH, each subscriber connection is a dedicated fiber from the access-switch in the distribution hub/Central Office (or from a cabinet in the outside plant) to the subscriber termination point. Most fiber access P2P network use a version of the Ethernet protocol family.
- xDSL (Digital Subscriber Line): Mostly deployed by Telco operators, xDSL is adding data services onto the copper twisted pair infrastructure that was initially deployed for traditional voice services. xDSL is a P2P technology where each subscriber connection is a dedicated copper pair from the DSLAM (Digital Subscriber Line Access Multiplexer) in the Central Office (or from a cabinet in the outside plant) to the subscriber termination point. There are multiple xDSL standards deployed in access networks today.
- Fixed Wireless: This is more of a category than an individual technology. The category refers to using wireless technology to connect to a fixed subscriber (as opposed to a mobile client). The signal travels over the air from a tower or a pole to a fixed, in most cases outdoor antenna, at the subscriber location. Fixed wireless technologies are P2MP technologies. There are many fixed wireless solutions being deployed going from closed proprietary systems (base station and client interact with proprietary protocols) to system using open wireless mobile standards (3G, 4G LTE, pre–5G) with standard clients. Even though no wire is used to connect the subscriber, the overall fixed wireless architecture is very similar to a wired access network architecture.

The "Triangle of Truth" – HFC Use Case

Access capacity is based on three mechanisms – also known as the "Triangle of Truth[1]" – increase the available spectrum, effectively use the spectrum and reduce the spatial scope of the spectrum.



For example, let's say you are using X GHz spectrum on an HFC network. Then

$$\text{Bandwidth per sub} = \frac{\text{Total capacity of this HFC}}{\text{Total Number of Subscribers}}$$

Total downstream Capacity for a 32D DOCSIS HFC @ 256 QAM = Spectrum * Spectral efficiency = (32 * 6 MHz) * 8 bits/HZ = 1.536 Gbps

If there are 200 active subscribers (spatial scope) on this HFC network, then the average bandwidth per subscriber = 1.536/200 = 768 Mbps

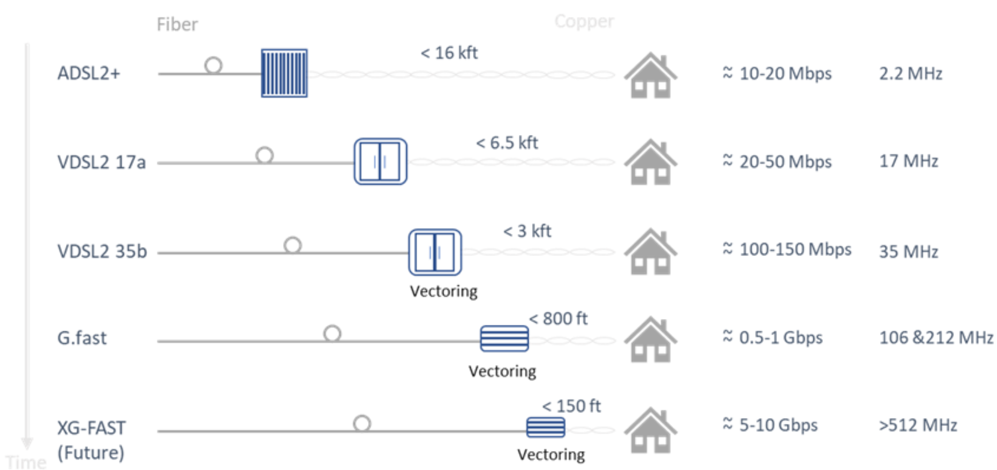
If we want to understand how we can evolve the capacity of these different access networks, we first must look at what technology or architecture components contribute to the amount of bandwidth available per end-point (subscriber). There are only three levers that can be used to increase the amount of bandwidth per subscriber: spectrum, spectral efficiency, and spatial scope. Let's start by looking at these levers in more detail.

1. Spectrum: The important factor is the width of the spectral band not the frequency (a 20 MHz wide band at the 100 Mhz range can carry the same amount of information as a 20 MHz band at the 1 GHz range). No matter the medium the goal is to make more and wider spectrum bands available, hence the push of 5G wireless to open the higher frequency domains (20Ghz and above). The obvious benefits of using higher frequency is the availability of more and broader channels; the main downside is that higher frequency signals do not propagate far, reducing the maximum distance between sender and receiver and forcing placement of access nodes closer to the end-user. On twisted pair copper every xDSL technology upgrade introduces wider spectrum usage. In HFC networks total available spectrum increased over time and more spectrum is being used by increasing the spectrum width of a channel and increasing the number of channels that can be bonded together.
2. Spectral Efficiency: How efficient is information encoded to be transmitted on the available spectrum or in other words how many bits/s per Hz can the encoding mechanism provide? The benefits of a highly efficient encoding scheme are obvious and therefore it is being introduced in any technology evolution path. The big downside is that the higher the efficiency the "cleaner" (high Signal to Noise ratio) the transmission media needs to be for the receiver to recover error free information.
3. Spatial Scope: This matter when the transmission medium from sender to receivers is point to multi-point meaning multiple end-points share the available bandwidth. Spatial scope simply put is the amount of end-points on a single medium. The more end-points on a shared medium, the less bandwidth per end-point

Even though we have three levers there are only two upgrade actions within a type of access network architecture that can be performed: a technology upgrade and an architecture upgrade action. In the rest of the paper we will examine how these upgrade actions are applied in each type of access network.

Technology Upgrade Action

As mentioned in the introduction, for all the types of access networks, there are multiple versions of the technology that were standardized over time. Each version improving drastically the maximum throughput the technology can provide over the given medium. To do so technology upgrades typically both enhance the amount of spectrum that can be used on the medium and introduce higher order modulation techniques. To make it less abstract, let's look at the technology evolution for all the access network architecture types in detail.



DSL Technology Evolution

The amount of innovation enabling more and more data over existing telephone wires [4] has been astonishing as shown in the figures. Throughput went from 10-20 Mbps with ADSL2+ introduced in 2003/2004 to 1Gbps with G.fast introduced in 2016/2017.

The increase in performance is achieved by the increase in the spectrum width as shown in the above figures combined with more efficient encoding introduced with every new technology upgrade. Along the way some other interesting signal manipulation techniques such as vectoring helped increase the available bandwidth even more. One of the issues with twisted pair copper wires in a bundle is crosstalk which reduces the effective throughput on a pair far below the theoretical maximum for that technology. Vectoring processors consider all the signals travelling in a bundle and can through calculation effectively remove the crosstalk, bringing the throughput per pair back-up close to the theoretical maximum.

The downside of the technology evolution as shown in the figures is that the maximum distance over the copper wire is drastically reduced with every upgrade. This has forced operators to fundamentally change the deployment model. Telco operators used to deploy DSL from large DSLAMs hosted in the central office and send data over long copper loops to all the subscribers. With the introduction of VDSL2, suddenly not enough houses were within the maximum distance from the central office forcing the operators to deploy smaller DSLAMS in cabinets in the outside plant. Typically, these VDSL2 cabinets are fed with fiber cable from the central office. As a result, these deployment models are called Fiber-To-The-Node (FTTN). Going beyond VDSL2, smaller and smaller cabinets need to be installed closer and closer to the subscriber reducing the length of the copper and increasing the length of the feeder fiber. This evolution process is also known as a "Fiber Deep" strategy.

The new deployment models in a fiber deep strategy are sometimes named after the location where fiber is terminated. Examples are Fiber-To-The-Curb (FTTC), Fiber-To-The-Home (FTTH), Fiber-To-The-Building (FTTB) etc.

HFC Technology Evolution

Similar to DSL, as shown in the table on the right, DOCSIS underwent an aggressive technology evolution path and in each step provided access to more spectrum and introduced higher order modulation techniques ([5], [11]).

DOCSIS	Released	DS/US Bandwidth	Modulation	DS Capacity	US Capacity
2.0	2001	8x6MHz/4x6.4 MHz	QAM	380 Mbps	154 Mbps
3.0	2006	32x6MHz/6x6.4 MHz	QAM	1500 Mbps	230 Mbps
3.1	2013	192MHz/96 MHz	OFDM/OFDMA	1800 Mbps	900 Mbps
Full Duplex	2017	Symmetrical	OFDM/OFDMA	5-10Gbps	5-10 Gbps

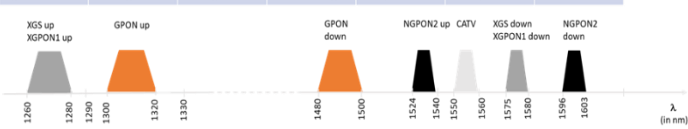
Using DOCSIS over cable in conjunction with "legacy" video service, presents both a challenge and opportunity in assigning more spectrum to the DOCSIS protocol. With available spectrum on the coax shared between video and DOCSIS, operators need to first optimize downstream video delivery by converting video channels from analog to digital to free up bandwidth. Ultimately cable operators have the option to move to IP Video and deliver all services through the DOCSIS data path, making the full spectrum available to DOCSIS and removing limitations imposed by sharing the medium between multiple services. This setup allows for further extensions of the frequency range.

With the evolution of services requiring more upstream bandwidth, cable operators are looking into rebalancing the amount of spectrum allocated to upstream and downstream traffic. Adding more spectrum to upstream is commonly known as mid-split or high-spit. In the newest evolution of DOCSIS – Full Duplex new signal processing capabilities are introduced to allow for simultaneous transmission of both upstream and downstream traffic on the same frequency.

One of the major challenges to go to higher encoding schemes on an HFC plant comes from the use of active amplifiers to cover the distance needed from the distribution hub to the subscriber. The number of amplifiers (x) between the node and the subscribers is denoted as an N+x architecture. The goal over time is to evolve the HFC plant to an N+0 architecture. To go to N+0, nodes need to be placed closer to the subscriber reducing the coax distance and increasing the length of the feeder fiber (= going Fiber Deep). Going to N+0 is one the reason cable operators are embracing a fiber deep architecture.

Another ongoing evolution in the HFC plant is - going from a centralized (CCAP) architecture with analog signals from the distribution hub to the subscriber to a distributed Remote Phy Device (RPD) architecture. In an RPD architecture, the analog signal to the home is generated by the RPD device. Data from the distribution hub to the node uses standard L2 ethernet over fiber.

	GPON	XGS-PON	NG-PON2 (TWDM)	EPON	10GE-PON	100GE-PON
Standard	ITU-U G.984 (2003)	ITU-U G.9807-1 (2016)	ITU-U G.989 (2015)	IEEE 802.3ah (2004)	IEEE 802.3ah (2009)	IEEE 802.3ca (TBD)
Downstream	2.5 Gbps	10 Gbps	4/8 * 10 Gbps	1 Gbps	10 Gbps	TBD
Upstream	1.2 Gbps	10 Gbps	4/8 * 10 Gbps	1 Gbps	10 Gbps	TBD



PON Technology Evolution

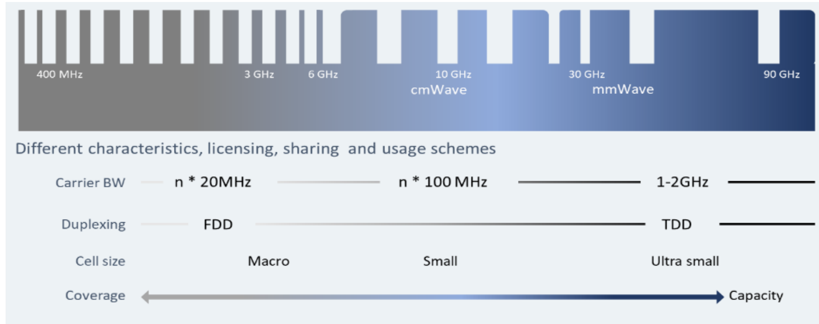
The figure on the left shows the evolution in bandwidth of the different PON technologies over a single upstream and downstream wavelength[6]. In addition to increasing the amount of bandwidth on a single wavelength, new standard approaches are looking at stacking multiple wavelengths on the fiber and further increase the total bandwidth on the fiber from an OLT point of view (an ONT would still tune-in to only one of the wavelengths).

Another interesting observation is that the wavelength plan on the PON is carefully laid out to achieve backwards compatibility and allow multiple versions of PON to co-exist on the same cable.

Fiber networks, even at the higher throughput levels, do not impose any practical distance limitation. Optical budget and the selection of higher class optics with increased receiver sensitivity allow for reach up to 20 km. Upgrading typically does not require the OLT to be moved closer to the subscriber.

Fixed Wireless Evolution

Fixed wireless started as a piggyback solution on mobile networks by connecting fixed end points to a mobile network infrastructure to offer basic internet access services. Due to the success and promise of wireless access capabilities, dedicated fixed wireless infrastructures are being introduced rapidly ([7], [8], [9], [10])



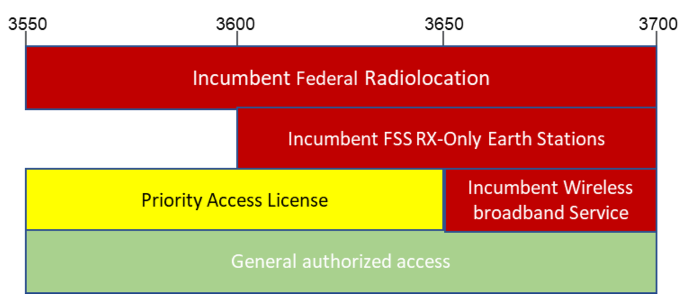
Even more than in wireline networks, spectrum comes at a premium in the very regulated wireless world. Large chunks of the wireless spectrum range are licensed or dedicated to specific use. Only small parts of the spectrum range are unlicensed and can be used by anybody. The fixed wireless solutions being deployed are either using standard 4G LTE over licensed spectrum or proprietary solutions in the unlicensed spectrum. Unlicensed spectrum solutions have gained a lot of traction with wireline service providers who typically do not own nor want to invest in acquiring spectrum.

Proprietary Solutions (Unlicensed Spectrum)

These are typically closed solutions with proprietary extension on WIMAX or other protocols. Deployment of these solutions today are mostly in the 5.8 GHz or 3.65GHz spectrum range. A key characteristic of these soltutions is the use of directional antennas on both the tower and the receiver. With directional antenas multiple sectors can be defined on a single tower allowing for reuse of the same frequency bands in each sector.

Early deployments started with 40 MHz wide channel bands with 64 QAM delivering up to 250 Mbps per sector (1G per tower). A second generation is already being deployed using wider 80 MHz bands with 256 QAM delivering 750 Mbps per sector making it suitable for serving serve triple play subscribers. Further evolution steps are bonding bands from different frequency ranges together to get the maximum out of all available spectrum.

Side Note on CBRS (Citizens Broadband Radio Service)



The CBRS band is a 150 MHz wide spectrum band (from 3.550GHz to 3.7Ghz) defined as a semi-licensed spectrum where base stations and customer devices must operate under the authority and management of a centralized Spectrum Access System (SAS). Both proprietary and LTE based wireless solutions are implementing CBRS band solutions[8].

4G LTE and 5G Standardized Solutions

In the current licensed spectrum between 700 MHz and 2.5 GHz, 4G LTE is being used to deliver broadband solutions. With the limited available bandwidth in the current licensed band, additional LTE standards have been developed to allow for the use of the LTE protocol in unlicensed spectrum to compete with higher bandwidth solutions. Licensed Assisted Access (LAA) defined as part of LTE Advanced Pro standard is one LTE solutions that uses unlicensed spectrum. LAA requires an anchor frequency in a licensed band and uses carrier aggregation in the downlink to combine LTE in unlicensed spectrum with LTE in the licensed band.[7]

Alternatively, another LTE standard, MulteFire[9], defines the standalone operation of the LTE protocol in unlicensed spectrum bands.

In anticipation of the introduction of 5G, some of the 5G improvements such as 4x4 and 8x8 MIMO (Multiple-Input Multiple-Output), 256 QAM on small cells, and more aggregated carriers are being introduces in 4G. The new 5G wireless standard promises to tackle several areas including extreme broadband (massive bandwidth), massive machine to machine communication (massive number of short lived connections) and critical machine communication (extreme low latency).

In the fixed wireless context, the most interesting evolution path is extreme broadband. The 5G standard will be defined across the complete spectrum shown in Figure 5 and provide further improvements on MIMO, higher order encoding and carrier aggregation.

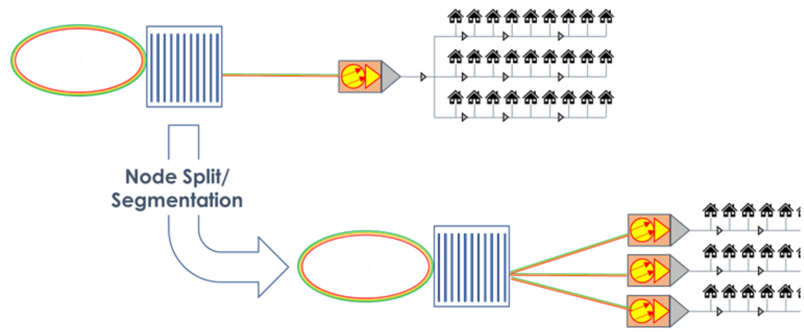
Early pre-5G deployments in the mmWave spectrum at 28 GHz are already quickly moving past the trial stage and into commercial deployments.

Architecture Upgrade Action

An architecture action here is defined as a change in the access network topology. An architecture action can be used to address the 3rd lever, spatial scope, to increase the bandwidth per subscriber by reducing the number of subscribers on a shared medium. Another reason to execute an architecture action is to enable a technology upgrade by reducing the copper distance from the access network element to the subscriber.

HFC Action - Node Spit/Segmentation

A node split, sometimes called node segmentation, is the action of introducing new fiber fed nodes in the outside plant and distributing the subscribers over the new nodes as illustrated in the figure.

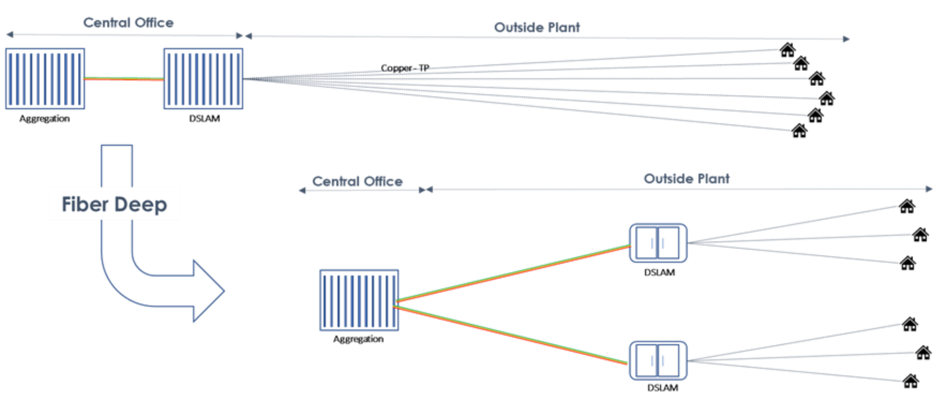


The benefits of executing a HFC node split are:

- ✓ Increased bandwidth per subscriber
- ✓ Reduced distance between node and subscriber
- ✓ Reduced number of active amplifiers
- ✓ Fiber deeper in the access network

A specific case of a node split is an N+0 split, where enough new nodes are created to make sure that all subscribers can be reached without the need for active amplifiers on the coax. The amount of subscribes on N+0 nodes is typically so small that further splitting is not considered as a viable option.

It is common for a node in an HFC architecture to go through multiple node-splits before ending up in N+0 state.



DSL Action - Remote DSLAMS

With DSL being P2P, spatial scope cannot be improved. The only reason to perform an architecture action in a DSL network is to reduce the loop length (distance from DSLAM to subscriber), almost always in combination with a technology upgrade, to enable higher throughput to the subscriber.

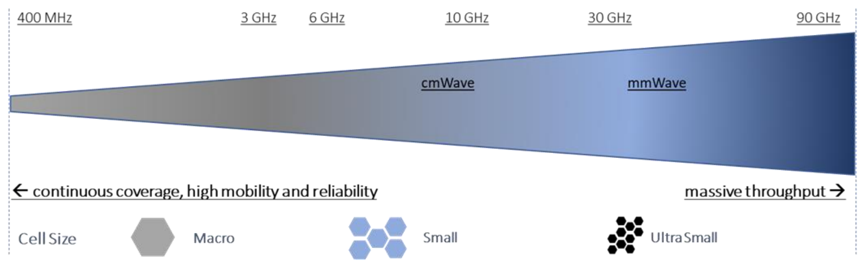
Remote DSLAMS are deployed in the field and fiber fed from the nearest aggregation device with P2P fiber, P2MP fiber or fiber rings. In the outside plant these can be larger DSLAMs deployed in a cabinet or vary small remote DSLAMs in a sealed enclosure.

Fiber Action - A Different Animal

The architecture actions described in a copper world above do not apply to deployed FTTH architectures. For both P2P and PON FTTH distance is not a practical limitation so there is no need to move active equipment deeper into the outside plant. PON networks are designed from the initial deployment with a low split ratio and a flexible outside plant passive splitter architecture with the intent to accommodate different split ratios in the future. Reducing the physical split ratio, in most cases involves reconfiguring connection in splitter panels and OLT ports rather than moving physical equipment.

With the introduction of multiple wavelengths in Time and Wavelength Division Multiplexed Passive Optical Network (TWDM-PON) and the fact that an ONT can only tune into one of these wavelengths, the spatial scope for each wavelength is effectively reduced.

Fixed Wireless Action - Small cells, Frequency Overlay



Architecture actions are even more important in wireless than in wireline networks.

Much like in wireline networks, deep fiber architecture actions are becoming commonplace for two reasons.

Firstly, to reduce the number of subscribers sharing the spectrum. In the mobile wireless networks small cells are introduced in a Macro cell coverage area to provide more bandwidth per active subscriber. Secondly, wireless signal propagation and material penetration drops of very steeply in the higher frequencies. This is prominent with the usage of the cmWave and the mmWave access technologies as shown in the figure above.

Another network architecture action being considered is to have antennas in multiple frequency domains serving the same sector on a tower. With each client designed to tune into only one of the frequencies the number of subscribers per frequency decreases and the bandwidth per subscriber increases.

Network Convergence

The access architecture models described in this paper are single technology architectures. In real networks often a combination of access technologies needs to be used to reach the subscriber. The access technology used to backhaul traffic can be different from the technology used to reach the customer customer premise equipment(CPE).

As an example, in Multi Dwelling Units (MDU) service providers do now always have the rights to install or replace cabling in the building and are forced to use the existing wiring ro reach each living unit. FTTH service providers will in this case use PON access technoloy to a MDU-ONT in the building and use a copper technology such as VDSL or HFC to go from the MDU-ONT to each individual living unit.

Another very interesting example is mobile backhaul. For macro cells (even to a certain extent for small cells) dedicated fiber connections exist for every single cell to bring traffic back to the metro and core networks. With the proliferation of cell locations that are needed in full small cell coverage and especially in ultra-smalls cell deployments, dedicated fiber build outs become unpractical giving rise to the use of existing access networks to backhaul cell traffic.

In the past when fixed-mobile convergence was discussed, it was mostly converged IP infrastructure in the edge, metro or core of the network. Lately converged access networks are gaining a lot of traction giving rise to hybrid access networks.

Conclusions

Every single access network technology discussed in this paper went through an impressive evolution to keep up with customer demands. For most technologies it seems that we are nowhere close to the end of the evolution road. Looking closer at the transformation methodologies for each of these fundamentally different access technology families, it turns out that there are remarkable similarities.

The most important observation is that no matter the access technology, the move to push fiber closer to the subscribers is an unstoppable trend. With all technology families benefitting from having fiber deep in the network, the fiber assets will not become a stranded investment.

For the longest time it was the industry wide expectation that the end goal for all access networks is Fiber-To-The-Home. Lately the wave of innovation on copper and wireless access capabilities have challenged this expectation. The wired and wireless access convergence is fueled by the fact that the end devices are becoming more wirelessly connected and the burning deployment questions of where the hand of wireless handoff to wired access will happen.

Why is all this important?

Understanding all the network transformation option is important as there is no well-defined path or best option to evolve an access network over time. A network transformation path that is not finely tuned can waste millions and increase churn. Having a comprehensive and flexible long-term transformation plan is mission critical in such a competitive world.

The access network is directly impacted by growing customer demand, budgetary limitations and the availability of next generation access technologies. Creating a strategic transformation requires a highly efficient capital investment plan with many iterations of what-if scenarios.

Creating a transformation plan is a multidimensional problem of balancing demand drivers, introducing right access technologies with budgetary and operational constraints. This planning is influenced by customer broadband needs, capacity constraints, corporate strategy, current and emerging competition, operational expense minimization, and technology innovation. Such a complex plan should be conducted at a node level while keeping end to end strategic integrity. This complexity is why we decided to create a toolset to reduce the complexity and allow you focus on the strategy.

Jibe is a breakthrough Interactive Planning Toolset used to generate and analyze multi-year access network transformation plans, which fulfills growth requirements, strategic objectives, and operational (financial and execution) constraints. The flexibility and speedy execution of Jibe gives you the opportunity to create and refine various deployment strategies, resource requirements, and financial impact analysis across the entire footprint of your network.

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