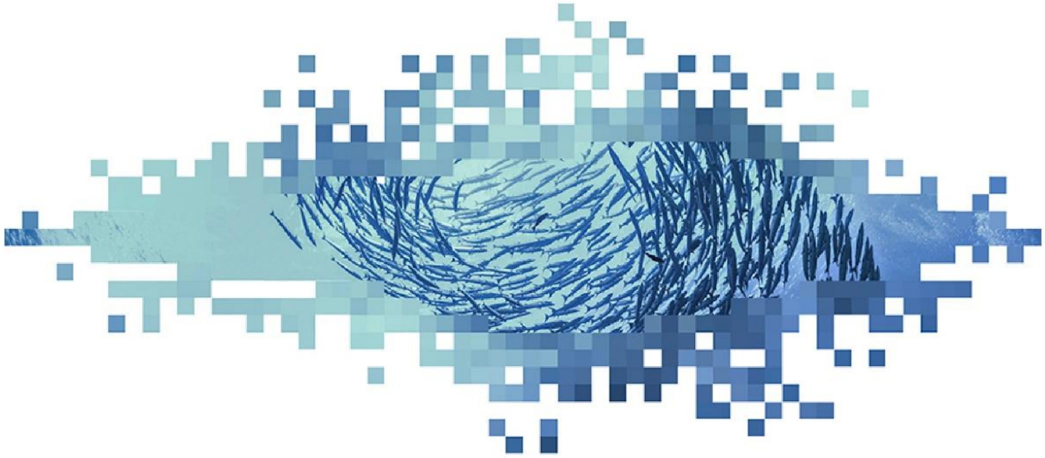

INTERCEPT

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Economic and Implementation Evaluation of Lancet Series eHFC xPON Hybrid Transport of DOCSIS 3.0 & 3.1 and Ultra Wide Band Data Channels in FTTT Architectures

Economic and Implementation Evaluation of Lancet Series xPON Hybrid Transport of DOCSIS 3.0 & 3.1 and Ultra Wide Band eHFC Data Channels in FTTT Architectures

Extending the Spectrum of HFC Networks

Cost Effective Wide Scale and Opportunity Driven Deployment of HSD Services

Scope and Abstract

The objective of this paper is to evaluate the comparative costs and performance of Intercept eHFC Lancet Series Optical Taps, an xPON/HFC hybrid transport in which both xPON and legacy CATV video and DOCSIS data transmissions are shared over the same physical infrastructure/optical distribution network utilizing WDM transport technology. The resulting architecture and related technology described and detailed in the paper merges xPON generated data throughput with traditional DOCSIS data in a single unified interface, following a conventional distributed or split tapped architecture scheme wherein several data/video subscribers can be serviced from a single optical to RF device. In addition, the paper will evaluate utilizing Ultra Wide Band (UWB) frequencies to carry the xPON data, CATV video and DOCSIS data signals over coaxial media for the subscriber drop, utilizing lower order PSK based modulation and TDMA for the coaxial segment of the near passive network for the UWB transmission, and conventional OFDM/QAM Modulation for the DOCSIS frequencies. We will also evaluate future capacity planning, subscriber contention and take rate models for high speed next generation data services, as well as the physical capacity of FTTLA as compared with FTTT architectures for expanded bandwidth operation and future services. The paper will focus primarily on the economics of implementation relative to net effective throughput as well as long term network capacity considerations for near passive hybrid architectures.

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1. *Baseline Considerations for FTTLA DOCSIS Deployments*

As cable service providers evaluate approaches to next generation architectures which can cost effectively deliver gigabit and symmetrical gigabit data services across a broad universe of subscriber groups, there is one consistent feature of every architectural approach, whether it is HFC Near Passive Architectures, or Node plus Zero, FTTH, FTTT, Remote PHY or Full Duplex DOCSIS 3.1 implementation: The Construction of Optical Fiber to the Last Active (FTTLA) as a minimum level of optical fiber penetration into the physical plant, whether expressed in terms of PON networks as the ODN, or in terms of HFC Networks as OSP.

The cost and requisite transport mechanisms of running fiber strand in sufficient depth and quantity to accommodate future capacity in the multi gigabit range as measured on a per active session basis is a constant in all cost formulas to be considered in today's architectural approaches.

As such, this paper will consider and detail as a baseline cost for all Use Cases, the cost of fiber construction to the last active, using real world measurements and averages for subscriber densities. The cost of transport equipment in the Outside Plant/ODN, as well as the modulation and other related equipment in the Headend/Hub will vary depending on the various approaches as we will also detail and evaluate based on cost and performance. Below is a simplified baseline cost for this consideration and will be used to build upon and modify as necessary for the Use Case in question. Other variables include the segment of the network downstream of the location of the last active, including but not necessarily limited to: the cost of additional cabling from the last active to the subscriber premise, the cost of any additional customer premise equipment, or upgrades to any existing CPE, as well as the labor involved in these factors.

It is important to note that this paper aims to define the economic viability relative to performance for the various approaches mentioned for wide scale residential services deployment and not for highly targeted throughput goals for a small percentage of subscribers, unless otherwise specified.

As such, this paper will also evaluate the economic considerations in achieving higher take rates among residential subscribers for gigabit level high speed data services.

Various scenarios will be used for comparison, including:

Node + Zero/FTTLA architectures

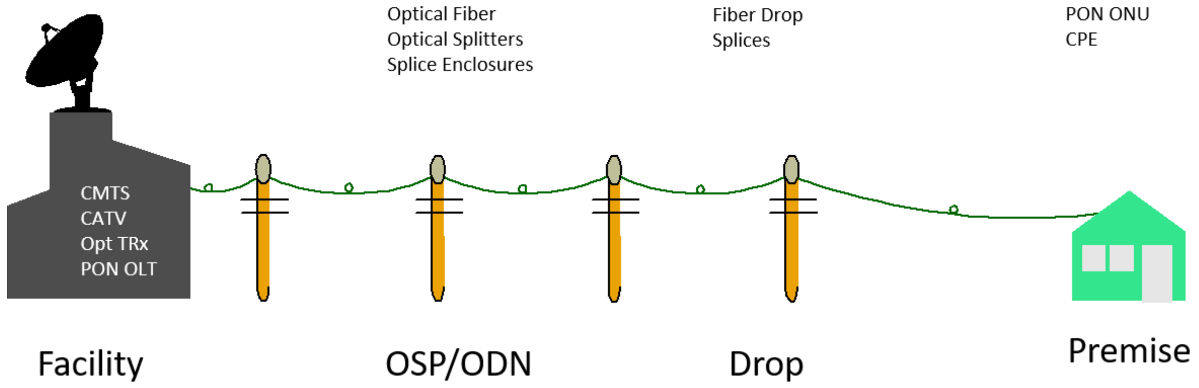
Node + Zero architectures with Remote PHY technology in the Access Node and Headend/Hub

FTTP using xPON (GPON or EPON) as an overlay to existing HFC CATV/DOCSIS infrastructure

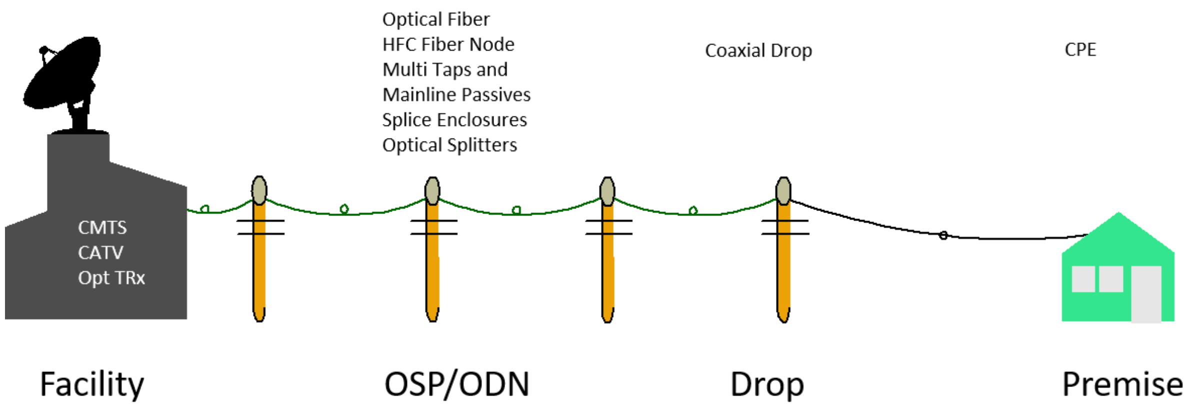
Intercept eHFC Lancet Series Optical Taps in FTTT architectures

Baseline costs of ODN, OSP, Premise and Drop for FTTLA, FTTT and FTTP Architectures

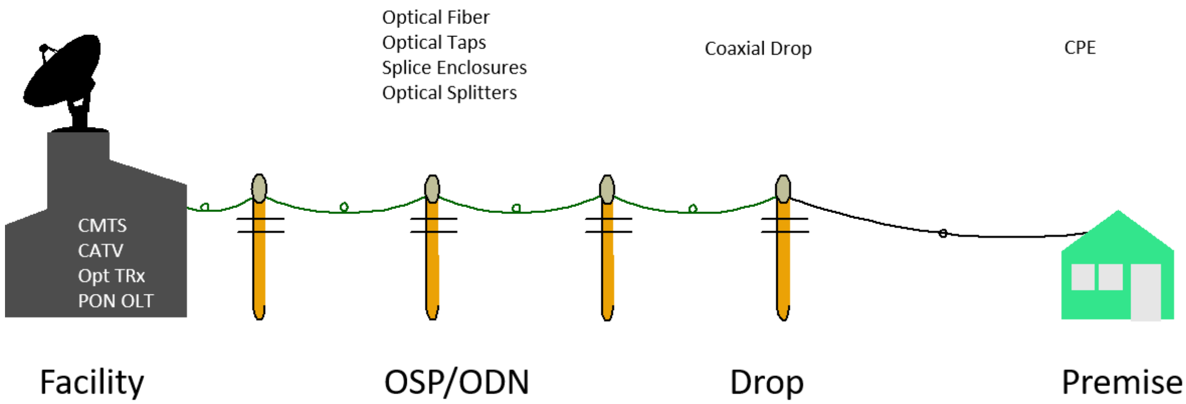
Network Segment Definitions for the architectures considered:



1. FTTP Baseline Deployment Cost Categories



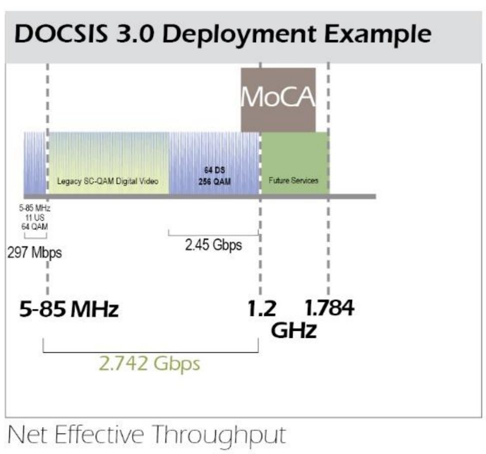
2. *HFC FTTLA/Node + 0 Baseline Deployment Cost Categories*



3. *FTTT*

Baseline Deployment Cost Categories

Fig. 1. Baseline data spectrum allocation and spectral net effective output: DOCSIS 3.0 standard 64 downstream 256 QAM channels, 11 upstream 64 QAM channels, considering a 5-85 MHz US channel frequency allocation. [EM][SD]



[SD][DCL]

HFC Node + 0 Typical

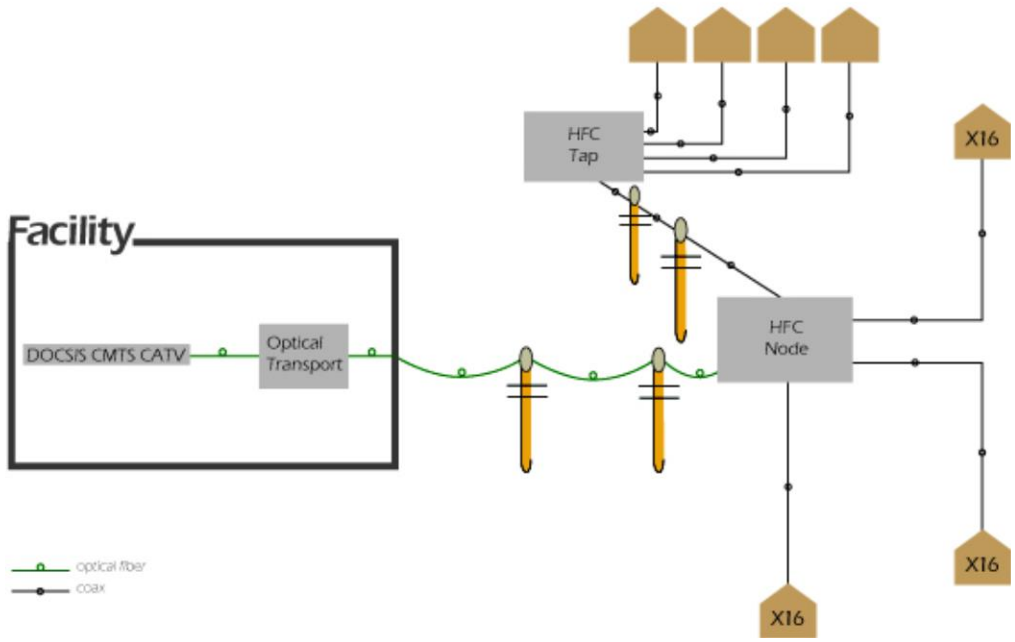
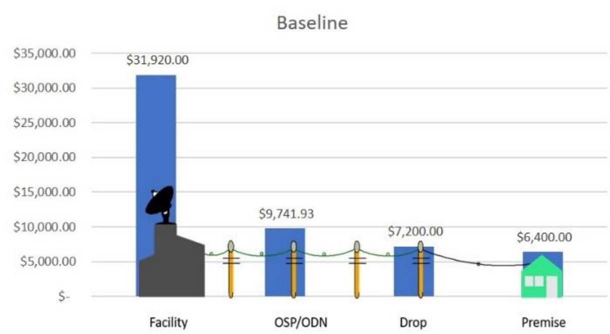
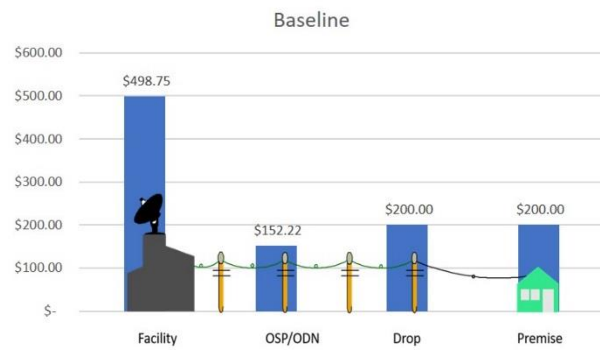


Fig. 2. Baseline Node + 0 architecture
64 HHP per node
Subscriber density of 124 HHP per mile
Subscriber penetration of 50%
Total subscribers 32

DOCSIS 3.0
150 Mbps Downstream
20 Mbps Upstream

64 DS 256 QAM Data Channels
11 US 64 QAM Data Channels





Total Node Deployment Cost: $55,262

Total Cost per Subscriber: $1,727

Cost/Mbps/Subscriber: $0.629

Cost/Mbps/Simultaneous session at peak network contention: $1.26

Cost/Throughput Calculation formulas:

Cost/Mbps/Subscriber:

C(Total deployment cost for 64HHP SG or equivalent)/T(Total Mbps of DOCSIS Bonding group size + xPON PHY if applicable)/S(# of Subscribers)=c(Cost per Mbps per Subscriber)

C/T/S=n

Cost/Mbps/Active Session:

n/r(contention ratio)=s(Cost per Mbps per Active session at contention)

*e.g. n/r(50%) = n/ ½ = n*2= s*

Note: Contention will be calculated at 50% of subscriber group for all use cases and further explained in detail in ***Section 11. Considerations for increasing take rates for gigabit and HSD services – contention and frequency planning models for next generation data services***

Note: Facility and OSP/ODN cost calculations are per HHP. Drop and premise costs are per subscriber for all Use Cases

The above considerations will be used as a baseline for Node + 0 deployment costs measured against Net Effective Throughput, and any investments above the baseline will be considered as "Incremental" with reference to both the investment and resulting net effective throughput increase achieved as a result of the investment.

Final calculations will be made on a Total Cost, Cost per Subscriber, Cost per Mbps per Subscriber, Cost per Mbps per Active Data session at peak contention, and Cost per Incremental Mbps per Subscriber (for Brownfield scenarios only) as will be explained in more detail.

Fiber Construction:

The costs of fiber construction in this paper assume FTTLA (Fiber to the Last Active) as an embedded minimal cost of Node Zero architectures, and considers an average density of 124 HHP/plant mile for the cost of access fiber to every potential subscriber within the network's reach. This benchmark assumes that FTTT deployment can be reached within the considered density of 124 HHP/mile. More specifically, the assumption relies on a reasonable approach where fiber outlays and distribution architecture implemented as part of a migration from a Node N scenario to a Node 0 scenario will likely consider future capacity and reach required for implementation of PON as a last stage architecture. Additional splice enclosures required for individual FTTT scenarios are not considered due to the high variability of topologies in real world applications. For Cable Service providers starting from a Node N scenario, the additional costs of running fiber to the last active should be considered, but also adjusted from the baseline fiber construction costs accordingly, to arrive at the established baseline for the Use Cases evaluated. A benchmark cost of $15,000 per plant mile has been used for a baseline cost of fiber construction as the paper generally follows many of the baseline cost considerations of brownfield migration evaluated in a publication of the SCTE Spring Technical Forum 2016 [EM]. This cost is shared among all potential subscribers or Households Passed (HHP) – which will be considered as 64 in all scenarios. The cost of fiber construction may vary considerably depending on geography and associated municipality costs for permitting and variations in construction labor and equipment.

Coaxial Infrastructure:

The use cases in this paper assume that existing legacy HFC infrastructure is in place between the traditional node location or the last active and the subscriber premise. For drop infrastructure, the cost of coaxial drop installation will be considered for greenfield scenarios only, as may be required.

Powering and Maintenance:

The use cases in this paper assume that the legacy coaxial infrastructure is capable of delivering powering requirements via coaxial media to the tap device location. A case study will be referenced for comparison of powering requirements of Node + N and Node 0 Architectures, and assumed as typical for existing powering infrastructure. Costs of construction for all scenarios do not consider the cost of additional power supplies or relocation of existing power supplies, as may be needed for FTTLA migration from Node + N as well as FTTT implementations.

DOCSIS Central Office Infrastructure and CMTS costs

This paper will assume baseline costs of generating QAM channels and servicing subscriber cable modems using DOCSIS compliant CMTS in the central facility, headend or hub, for the scenarios which include DOCSIS as either a component or the sole source of data delivery. Because the costs of QAM data channels can vary depending on the amount of spectrum and respective channels which are allocated to data delivery and throughput targets, the paper will use both a baseline for a typical implementation as well as a modular cost of adding QAMs to the frequency plan based on the best available cost data. The typical frequency plan will be based on the following:

For DOCSIS 3.0 implementation

For a conventional DOCSIS 3.0 implementation, the cost of QAM channels relative to throughput is well understood. For the purposes of this paper, we will use the cost of $399 per 6 MHz QAM per *Infonetics* research published data for 2014 [EM]. This cost accounts for the related CMTS costs and modulation equipment required for the delivery of a single 6 MHz QAM modulated data channel per DOCSIS 3.0 published standard.

For DOCSIS 3.1 implementation

Because the specific costs for DOCSIS 3.1 implementation are still not well understood or established due to a paucity of large scale deployments, and because with DOCSIS 3.1 the concept of a 6 MHz QAM channel no longer applies, we will use the DOCSIS 3.0 *Infonetics 2014* cost as a basis for adjustment to the DOCSIS 3.1 cost on a relative basis, considering the following better understood cost factors for the improvements available in the DOCSIS 3.1 standard.

1. A 6 MHz QAM channel will be used as a cost basis, but adjusted for the DOCSIS 3.1 spectrum plan and achievable modulation order per the Use Case in question.
   a. Each 6MHz QAM will represent a proportionate amount of spectral output as calculated for a 192 MHz DOCSIS 3.1 standard OFDM channel, using 25 kHz spacing across all cases, and adjusted accordingly for the modulation order per the specific use case, and as allowed for in DOCSIS 3.1. [SD]
2. Because it is expected that DOCSIS 3.1 equipped CMTSs will be more efficient than legacy DOCSIS 3.0 CMTSs, the paper will consider a coefficient of 0.7 (30% efficiency improvement estimated) when calculating cost vs throughput for DOCSIS 3.1 implementation scenarios.
3. For brownfield and migration evaluations, a comparison will be stated of the total costs, and a delta will be calculated as an incremental cost for upgrades as opposed to new installations.
   a. Note that for the relevant Use Cases, the cost of establishing a new CMTS is not factored as an additional cost to any recent investments in legacy CMTS technology, but as an equal investment, without penalizing the investment for unrealized returns or amortization of the legacy equipment. Each operator should consider the benefits of the additional expense of new CMTS equipment on a case by case basis.

e.g. A single 192 MHz OFDM channel achieving an average QAM order of 1024 QAM will be costed as follows: 0.7(192/6)*399= $8,937.00

…and producing a spectral output of 8 bps/Hz or 192*8*10^6 = 1536 Mbps before subtracting PHY overhead

In variable terms:

d(n*32)*399=t

where:

d=DOCSIS 3.1 efficiency coefficient

n= the number of 192 MHz OFDM Channels allocated to data service delivery in the Use Case frequency plan

t=total cost of CMTS capacity

and for spectral output:

m*(n*192)*10^6= g

where:

m=the bps/Hz for the specified modulation order achievable in the scenario

g=the total Net Effective spectral output in Mbps

For Remote PHY implementations

Since neither the access class fiber node, nor the headend and hub facility costs are well known for Remote PHY implementations, it is understood that Remote PHY will reduce the headend and hub facility equipment requirements so a further coefficient of 50% or 0.5 will be used for Remote PHY comparisons, again using the *Infonetics* baseline 6 MHz QAM channel costs as a reference in the respective formulas. The cost of DAA implementations such as Remote PHY is being evaluated currently by various vendors at the time of this publication. While it is yet too early to know the precise cost impact of DAA approaches, what is well established is that initial considerations will involve distributing the CCAP layer of the DOCSIS CMTS to the Access Architecture[CLORPHY]. It is expected that this approach will reduce the cost of the CMTS components considerably and also allow for some virtualization of the signal architecture, which will further allow for future expansion once the transition to R-PHY has been made. The 50% coefficient used in the evaluations in this paper therefore assume that the CCAP layer will represent 50% of future CMTS costs, and will be the function of R-PHY that is distributed to the access network.

The cost of the Remote PHY capable fiber node will be similarly increased for analysis, with the assumption that the headend and hub modulation functionality to reside in the access node will come at a increased cost as compared with conventional fiber nodes. A coefficient of 3 will be used for the cost of the access equipment, using a standard market value for Cisco GS7000 and/or Arris 6100 class fiber nodes, or similar, in a 1X4 configuration.

Premise equipment

For DOCSIS 3.0 implementation

Premise equipment will be considered as incremental unless otherwise specified.

For DOCSIS 3.1 implementation

Premise equipment costs will be assumed as not yet deployed and added to the incremental cost of the investment for the use case in question, in addition to any CPE unique to the referenced Use Case.

For xPON implementation

The cost of the fiber drop as well as any and all CPE equipment necessary for the PON implementation will be considered as new and incremental to the investment.

Coaxial drop

$225 labor and materials, excluding CPE for comparison purposes. [EM]

RF Taps

Existing for legacy up to 1002 MHz networks, or upgraded as needed for extended frequency operation based on the Use Case scenario.

Cable Modems

A DOCSIS 3.1 cable modem with VoIP eMTA will be considered at $250 per unit for relevant use cases.

A DOCSIS 3.0 CM with VoIP eMTA will be considered at $200 per unit for relevant use cases.

PON ONU

xPON and RFoG ONUs will be considered at $225 per unit for relevant use cases

Fiber drop Installation

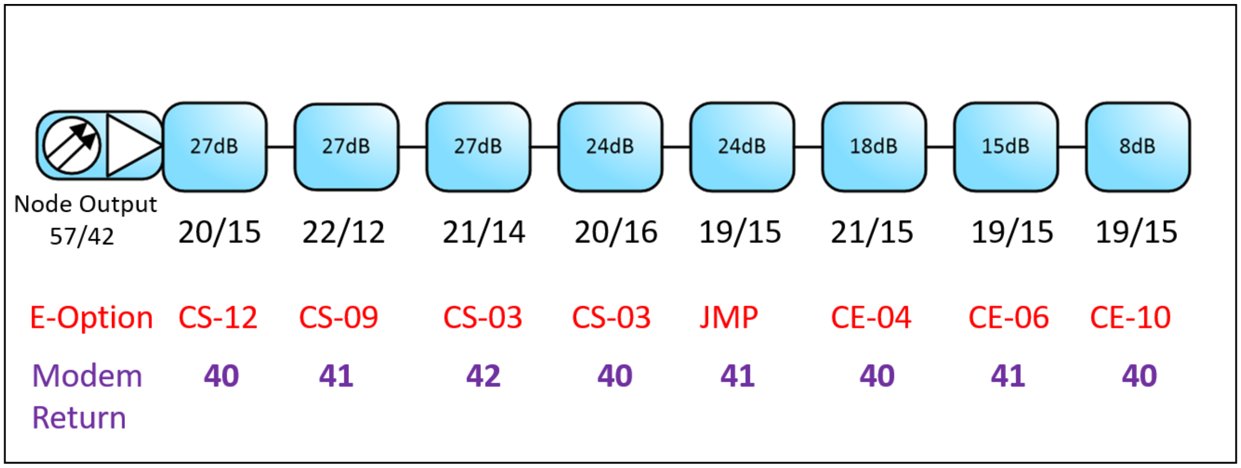
$375, materials and labor, excluding xPON/RFoG ONU equipment for relevant use cases, in addition to fiber splice labor. [EM]

2. **Node+0/FTTLA and FTTT architectures, a comparison**

The primary economic advantage of Node+0/FTTLA architectures is the reduction in operational costs, including but not limited to powering of the network, due to the significant reduction in the number of actives per service group and in the network overall. However, the near passive nature of the network limits signal reach when considering high frequency transmission for DOCSIS 3.1 above 1 GHz. The average service group size therefore is also limited and depends greatly on subscriber density and topology for the service area. A high-end average of 64 HHP has been found to be useful in determining the viability of a particular service group size for Node+0 implementation and the design of tap cascades, which are susceptible to issues of reach from the central access node, as well as the number of tap offs which are serviceable in any given group, due to the cumulative insertion loss which is exacerbated by the high frequency transmission. A larger SG size of 128 HHP however is considered economically optimal for near passive architectures, but achieving this size SG has been difficult and represents only a small percentage of deployed networks at the date of this publication. Various strategies have been considered and are being evaluated for extending the reach of node service areas, including express cable runs from RF node ports that reduce cumulative losses in a given tap cascade, in addition to improving network signal loss and Signal to Noise Ratio (SNR) and Modulation Error Ratio (MER).

A long-term advantage of Near Passive Networks such as Node+0 deployments is of course the passive nature of the last leg which theoretically would lend itself to any future transmission platform that could become available. Upgrades could then be either centralized at the fiber node, or ideally accomplished via software upgrades or other virtualization of capacity which is scalable without the need for network component upgrades.

In today's Node + 0 implementations, a typical Node + 0 tap cascade with return signal conditioning is detailed below for reference. We should note that cascade depth is highly variable and strings of fewer taps have been reported as common in Node + 0 deployments.



Δ High Tap to Low Tap =19dB
Δ Modem Upstream = 2.0dB
Δ +/- 2dB Amplifier Levels = 4.0dB
Δ +/- 1dB Temperature Change = 5.0dB

Above: FTTLA Tap Cascade model using Antronix Milenium MGT-2000-SEU-G2 Series 1.2 GHz Multi Taps with E-Option Return Signal Conditioning implemented for improved end of line SNR performance

Actual average cascade depths taken from FTTLA deployment sampling are utilized for economic modeling and reflect an average of 16 HHP per RF leg, or 4 tap depth from access node, with a 4 port per tap average configuration. [RCRG]

DOCSIS 3.1 allows for extended frequency operation out to 1784 MHz for a full spectrum deployment. Factors that limit the service group size of 1218 MHz Node + 0 deployments would also limit the service group size for 1784 MHz implementations. At the time of the publishing of this paper, there are no 1784 MHz capable multi taps and line passives or gain chips available commercially for such a deployment.

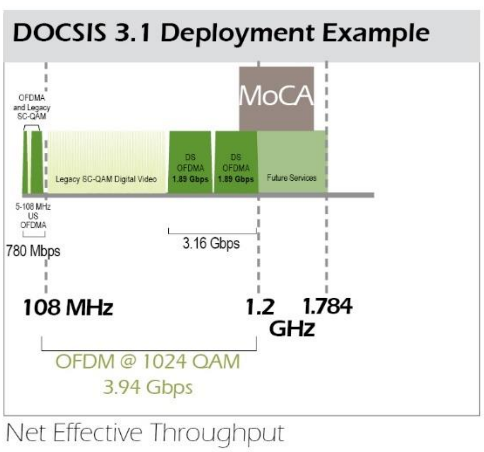
In any case, whether in a 1218 MHz or a theoretical 1784 MHz deployment, a reduction in SG size correlates inversely with the cost of implementation on a per subscriber basis.

The approach taken by cable service providers who would otherwise lean towards a Node + 0 implementation in all cases has been either to drop in a low output and relatively lower cost access node to service groups below the viability threshold of between 32 and 64 HHP, or to simply drop fiber strand to these premises that lie outside the topographical and signal reach of the nearest Node + 0 grouping. Cable service providers may also choose to simply split a node service group into smaller SGs, without migrating fully to a Node + 0 architecture, essentially remaining at a Node + N configuration, until the economics are more favorable for alternative options to address low density, smaller SGs.

SNR and MER performance, is also improved as compared with Node + N architectures. This is due primarily to the highly passive nature of the network and the elimination of RF actives downstream of the fiber node. In FTTT architectures, the noise and ingress in the RF plant from the node to the last tap off is reduced further, leaving only potential points of ingress at the tap ports of a single tap, since fiber strand is run directly to the location of the tap device for improved end of line MER/SNR. Since higher SNR/MER performance is required for high order modulation schemes such as QAM 4096, this becomes critical in terms of net effective throughput and overall spectral efficiency for both the subscriber grouping and for experienced data rates with contention and penetration factored in to the results, particularly for DOCSIS 3.1 implementations, whose advantages rely significantly on increased QAM modulation orders.

For example, a high performing Node + 0 deployment, with exceptional MER/SNR performance of between 34 and 36 dB SNR can achieve a QAM order of 1024 on average across all subcarriers, resulting in the equivalent of 9.6 bps/Hz.

In the below implementation and channel allocation for DOCSIS 3.1 FTTLA scenario, the aggregate throughput is 3.94 Gbps, or more accurately, 1.58 Gbps per 192 MHz DS OFDM channel, and 0.78 Gbps per 96 MHz US OFDM channel, averaging across all subcarriers and subtracting exclusion bands between channels, leaving a total spectral output of 3.94 Gbps for the frequency plan evaluated, as illustrated below [SD]:



[SD][DCL]

At full contention, considering an average subscriber penetration of 50% as detailed in the baseline assumption, and a baseline SG size of 64 HHP, this results in average throughput per active session at peak demand of 197.5 Mbps in the DS and 48.75 Mbps in the US. [SD][DCL]

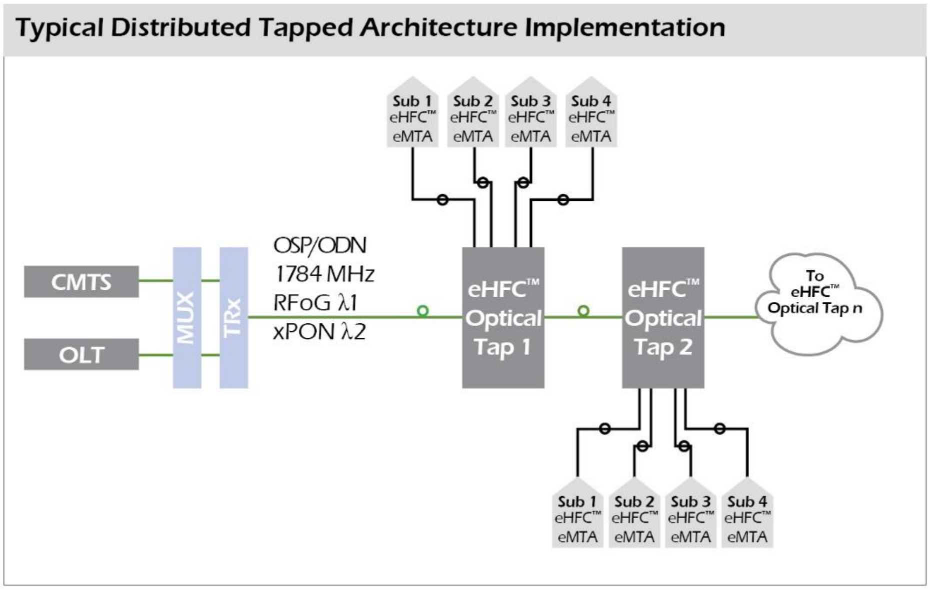
For upstream performance, there is an additional cost required in the OSP to increase the US frequency range from legacy 5-42 MHz to the 96 MHz evaluated in this example.

Of course, throughput can be enhanced significantly without modifying the architectural approach by allocating more OFDM channel bandwidth to the frequency plan, or “pay as you grow”, This is one of the main advantages of the DOCSIS standard generally but this will come at the expense of SC QAM legacy video spectrum which could be utilized for enhanced video and interactive services, and also requires the additional CMTS capacity to service the additional channels. While this is a long way from symmetrical gigabit speeds as a widely available service, or sufficient to offer this level of service to all subscribers within reach of the node while being able to preserve any legacy SC video QAM for conventional services, it is one available option for Cable Service providers Any expansion of the frequency allocation would have to be considered relative to the incremental cost of the CMTS capacity, which, while more efficient than DOCSIS 3.0, does not diminish in scale as channels are added or the plan is expanded.

By comparison, an Intercept Lancet Series eHFC FTTT implementation would overcome some of the principal scaling cost factors of a DOCSIS 3.1 Node + 0 implementation:

- ***Achieve higher SNR performance allowing for 4096 QAM to be achieved across the full DOCSIS 3.1 spectrum.***
- ***Expand frequency range to 1784 MHz in the DOCSIS 3.1 framework – allowing for higher data rates without compromising SC QAM channels.***
- ***Aggregate xPON data capacity to the DOCSIS data, allowing for more liberal use of legacy spectrum for enhanced data or other services.***
- ***Increase potential US data rates by programming Intercept xPON capacity to the US via MAC level programmable TDMA or***
- ***Enhancing DOCSIS 3.1 US data rates by aggregating eHFC data to achieve desired results, without the need to implement Full Duplex DOCSIS or related equipment upgrades.***
- ***Expand PHY via xPON upgrades in the headend or hub, rather than via expansion of CMTS equipment, saving space and related infrastructure costs.***
- ***Service HSD subscribers selectively and on an Opportunity Basis, by interlacing Lancet Series Optical Taps within a given Node + 0 cascade, without incurring the cost of optical fiber drop installation or post wiring within the premise.***

As mentioned previously however, the relative disadvantages of FTTT as compared with Node + 0 are potentially the powering costs as compared with larger and denser Node + 0 SGs, and related maintenance for the increased number of active devices within the service provider’s demarcation. These factors would have to be considered within the context of the significant additional throughput, the advantages of significant DOCSIS bandwidth expansion, and also compared with these same metrics relative to a comparable xPON FTTP deployment and its related costs and performance, as will be detailed later in this paper. Below is a typical Lancet eHFC FTTT implementation scheme for a Distributed Tap Architecture, where fiber media can be reused by splicing through the Lancet Series Tap to service downstream taps in a given cascade or tap string.



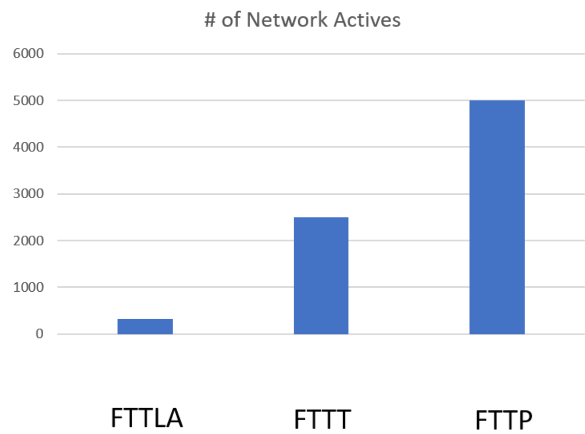
As already mentioned, one of the principal economic advantages of near passive architectures including Node + 0 is the operational savings achieved on both a yearly basis and over the lifetime of a network due to the reduction in active components downstream of the central access node and the corresponding savings in network power utilization.

In addition to the power consumption reduction, there is of course also a reduction in the number of outages and related maintenance costs which corresponds to the number of components in the outside plant access network.

For passive optical networks, including RFoG implementations, where there are no active components in the OSP or ODN, a key factor in the considered reduction in operational costs is the fact the subscriber ONU is located within the subscriber's demarcation, and the shifting of the powering budget costs accordingly from the cable system operator to the subscriber.

For other operational costs, however, the related savings are unclear because a PON or RFoG deployment adds significantly to the number of actives required for signal delivery if one considers the ONU as an active component, which, due to its high level of sophistication will need to be maintained and serviced by the cable or data service provider, regardless of where it resides relative to the subscriber's and operator's demarcation. Below is a comparison of the number of active components to be serviced within a sample 10,000 HHP deployment relative to architectural approach:

Active Components in a sample 10000 HHP Deployment



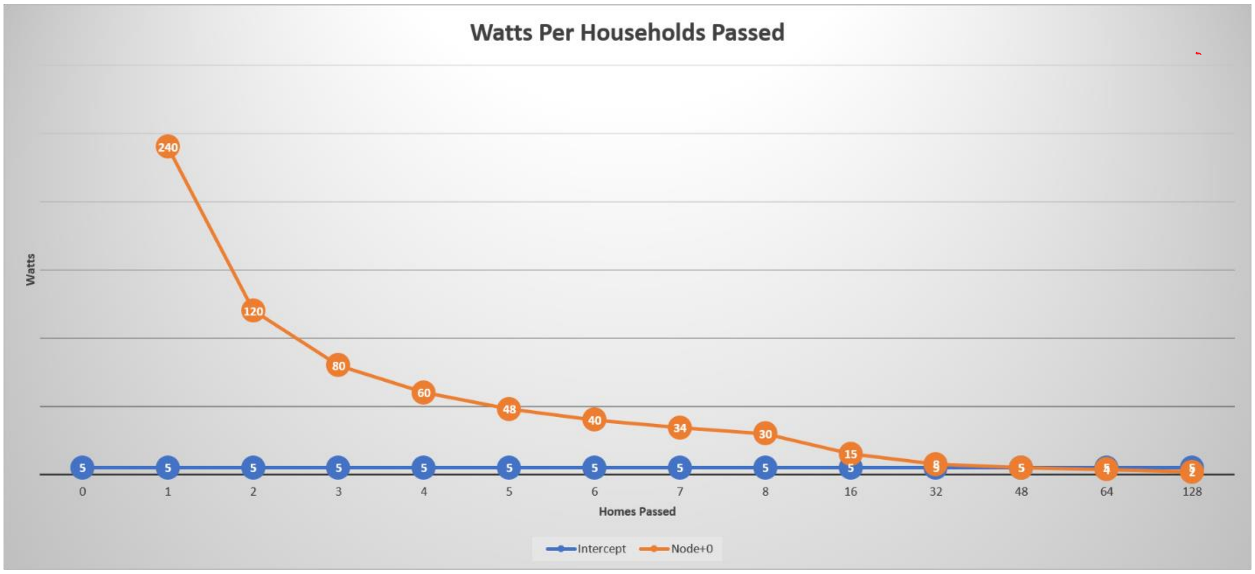
[RCRG]

While this paper does not evaluate the operational savings on this, or any other basis, it does suggest further consideration of potential operational savings based on the above reality of maintaining subscriber ONUs as compared with a tapped optical architecture.

Considering the average HHP density in the baseline, the implementation of Intercept Lancet Series eHFC Optical Taps would require one active for every 6 HHP, and result in a reduction of between 50% and 75% in the number of ONUs required for service delivery, as compared with RFoG or xPON FTTP implementations.

In addition, the number of fiber splices would be reduced by the same percentages, resulting in installation labor savings.

However, as compared with Node + 0 architectures, the powering cost threshold for parity compared with FTTT depend on the size of the Node + 0 service group baseline. Based on an estimated powering budget of 240 watts per fiber node fully equipped either for RPHY or a 4X4 segmentable configuration, the service group size parity threshold is approximately 45 HHP. In other words, for service group sizes less than 45 HHP, an FTTT implementation using Lancet Series eHFC Optical Taps results in operational savings for utility costs on a per homes passed basis. For Node + 0 service group sizes larger than 45 HHP, the Node+0 implementation is more economical in terms of utility costs on a per HHP basis. Below is a graph representing the relative savings and/or additional operational costs for the Intercept Lancet Series eHFC FTTT implementation as compared with a Node + 0 implementation and scaled for per HHP cost by service group size. Note that the sampling of Node + 0 SG sizes was taken from real world topological study and related design implementation. The sampling size was 20 nodes in a geographically and topographically consistent market, averaging 69 HHP per node, and a range of between 14 and 120 HHPs [RCRG]. Large variations in subscriber and HHP densities will affect the comparison. However, considering average SG ranges of Node + 0 for the data evaluated for this paper, a SG size above 125 HHP is likely uncommon over a larger sampling, even with necessary HHP densities available. Density variables need to be considered on a case by case basis, but as general rule, less dense areas will result in smaller SG sizes and benefit implementation of FTTT at least from a powering cost perspective, while denser areas will make the cost benefits of powering Node + 0 architectures more feasible.

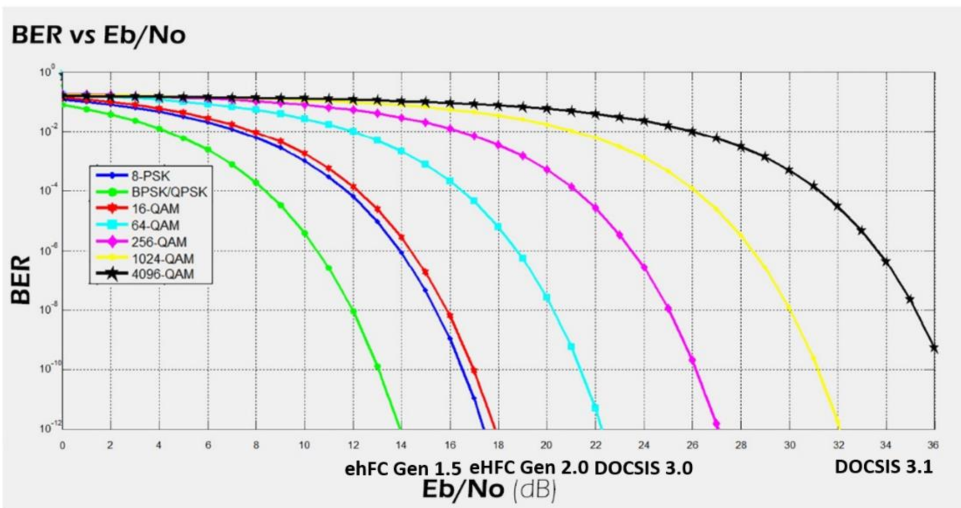


Intercept eHFC Lancet Series FTTT deployment achieves powering budget parity with Node+0 SGs of 45 HHP and reduces powering budgets for node sizes smaller than 45 HHP on average.

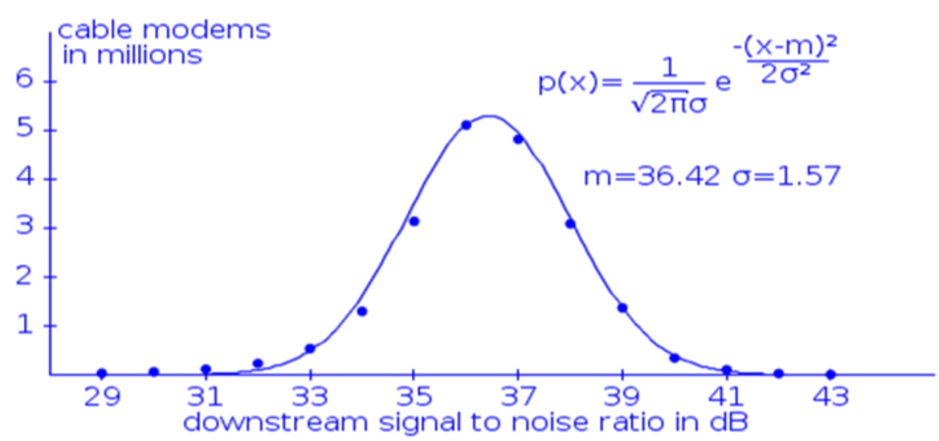
a. Near Passive Optical Networks and MER/SNR performance

For Wide Scale Deployment of DOCSIS 3.1, SNR/MER levels become critical for leveraging the high order QAM now available in the new standard. A minimum SNR level able to support QAM orders above 256 should be considered for viability of the incremental investment in DOCSIS 3.1 CMTS and platform components. While D 3.1 supports variable SNR performance and associated QAMs within the same SG, increasing the modulation order for higher performing homes and decreasing the order for lower performing homes, unless an average of better than 256 QAM can be achieved for most homes in the SG, then the investment in D 3.1 has less impact on improving data rates across the entire network.

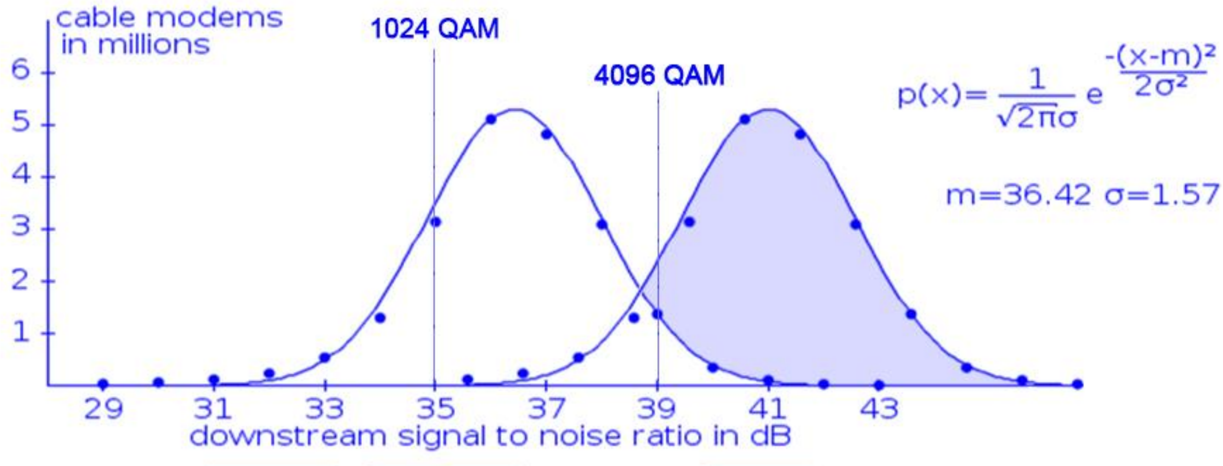
While networks will vary in performance depending on the physical length of the optical span in the ODN/HFC plant, MER/SNR performance is significantly improved in near passive architectures, with an MER/SER of 44dB widely accepted as achievable at the node location. Because an FTTT approach delivers the same performance at the tap in terms of SNR/MER as that at the node in Node + 0 architectures, and eliminates the additional noise and signal loss of downstream actives and passive devices present in either a Node + N or Node + 0 implementation, FTTT delivers improved SNR performance as compared with Node + 0, and can comfortably meet the 42-44dB MER/SNR threshold or “floor” for 4096 QAM across wide scale deployments.



QAM, OFDM and PSK Modulation SNR/MER requirements out to 4096 QAM



Variability of Cable Modem SNR performance across large deployments in FTTLA and Node+N



Estimated variability of cable modem SNR performance across large deployments in FTTT compared with FTTLA [SD]

The average SNR performance estimate above is a somewhat conservative outcome in an FTTT implementation, as Cable Modems will also likely operate at signal levels within a narrower range, in addition to improved averages across a large number of devices. This can be critically important as many if not most next generation evaluations for Extended Spectrum DOCSIS contemplate improved SNR performance as a prerequisite for any high frequency expansion of the standard[ESDCLO]. While this is a significant improvement, for eHFC FTTT implementations, throughput gains and spectral output depend more on the availability of extended frequency range than on the increased bit rate performance per Hz now achievable with 4096 QAM. However, an increase of approximately 20% in spectral output for a commensurate frequency allocation is achieved with this improvement in MER/SNR, or an increase of 2 bps/Hz, from 10 bps/Hz to 12 bps/Hz, when increasing the QAM order from 1024 to 4096 detailed in this scenario. This relative gain would also improve the performance of RPHY implementation, which improves SNR/MER performance by eliminating the QAM channel transport between the CMTS and fiber node, improving resulting MER/SNR by as much as 10dB for simulated cases.

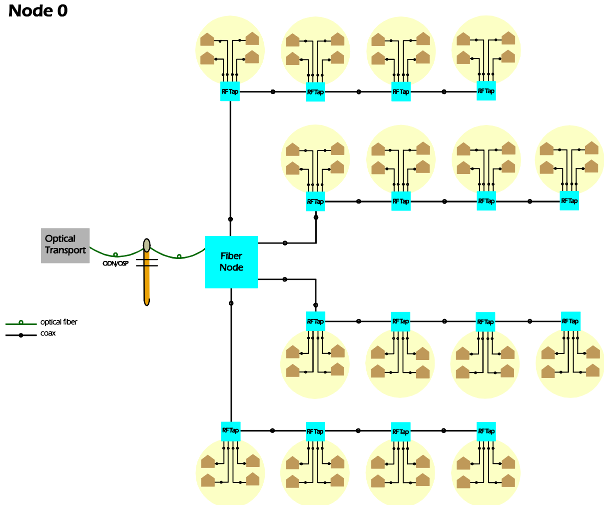
In the case of Intercept Lancet Series eHFC Optical Taps in FTTT, for the eHFC Band channel, this advantage is fully realized because channel generation occurs at the chipset PCB in the Tap, as opposed to at the headend or centralized location, as is the case with conventional DOCSIS transport architectures. The result is that the Intercept eHFC UWB data channels produce maximum spectral output across the entire channel and well within the acceptable tolerances for BPSK and 8PSK modulation schemes. This is in addition to the benefit of 4K QAM order across the entire legacy DOCSIS 3.1 data spectrum, as described above.

For 1784 MHz implementation in FTTT networks, however, while suitable from an architectural standpoint, is not currently achievable due to the lack of currently available gain chips with required linearity to support a 1784 MHz application, but could become available in the near future as Cable Service Providers look to make the most of the potential frequency range of DOCSIS 3.1, and chip designers respond to their demands.

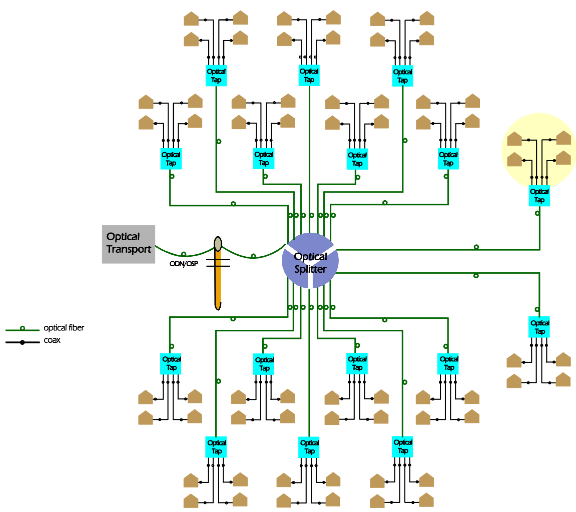
For FTTLA Networks, a 1784 MHz application is not currently viable for the same reasons, but also exacerbated by the lack of passive devices suitable to sustaining losses in the frequency range between 1218 MHz and 1784 MHz, and because of the inverse correlation of SG size with extended frequency. This frequency vs SG size dynamic in FTTLA could compromise the viability of a Node + 0 implementation of 1784 MHz, particularly as Node technology increases in sophistication and cost.

We will use 4096 QAM as the achievable order for both RPHY and Intercept Lancet eHFC FTTT applications, and 1024 QAM for conventional FTTLA implementation scenarios.

Comparative Emissions
Node 0



Comparative Emissions
FTTT



Plant noise exposure comparison of FTTT and Node+0 implementations. FTTT implementation limits ingress and noise to the fiber tap grouping only, as few as 4 ports and corresponding drops.

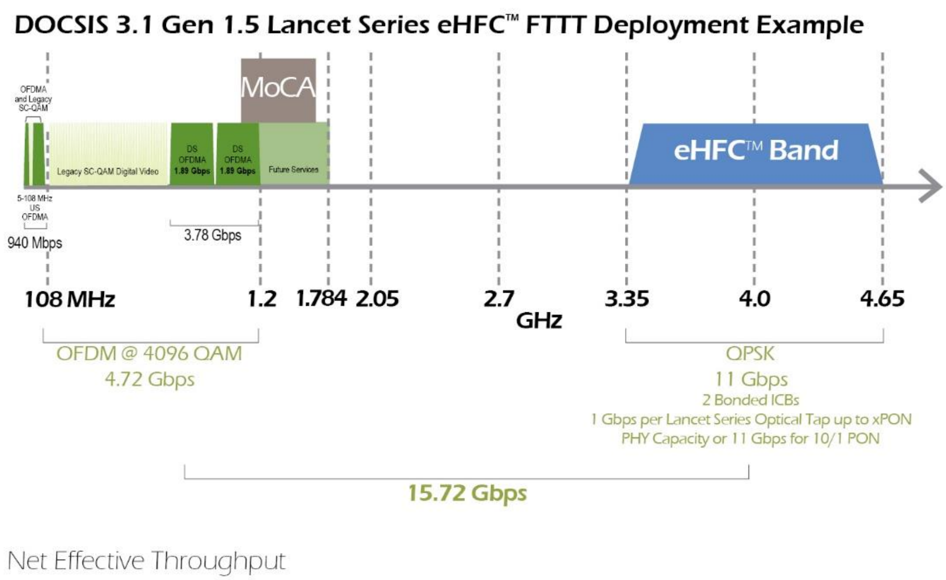
3. **eHFC Chipset architecture: Modulating UWB Channels at High Frequencies**

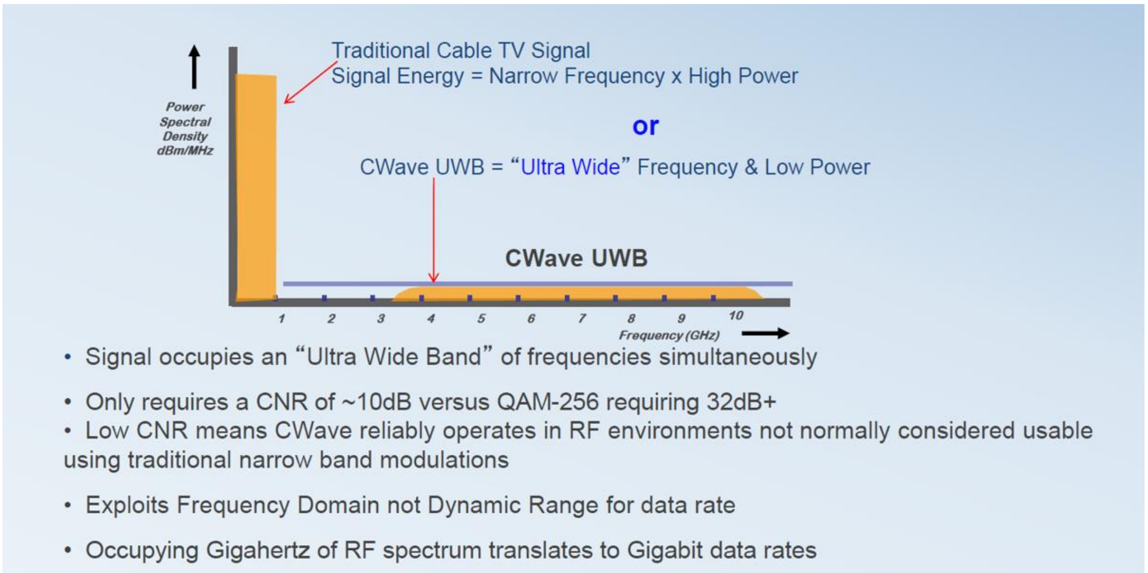
eHFC uses a chipset architecture that is optimized for modulating Ultra Wide Band high frequency channels, producing a robust link margin and large spectral output.

BPSK modulation is used in Gen 1.5 chipsets, and 8PSK in chipsets for next generation Gen 2.0 designs. These modulation schemes require only 14dB and 17dB MER/SNR respectively, as compared with 34-36 and 42-44dB SNR/MER for 1024 and 4096 QAM. The relatively low MER/SNR threshold or “floor” allows for significantly improved performance at the designated UWB Channel frequencies of between 3350 MHz and 4700 MHz for single band operation and 2050 MHz and 4700 MHz for dual band operation. While the spectral efficiency of these modulation schemes is low as compared with QAM 1024 and 4096, (1 bps/Hz and 4 bps/Hz as compared with 10 bps/Hz and 12 bps/Hz for QAM 1024 and 4096) the wide spectrum of the channel produces a significant amount of data capacity. The eHFC Gen 1.5 chipsets are orthogonally bonded or interlaced, doubling the spectral output of the single band 1350 MHz wide channel, or a total of 2700 Mbps for Gen 1.5 chipsets, with a net effective throughput of 1 Gbps. For Gen 2.0 the raw spectral output is 8 Gbps, with a net effective throughput of 4 Gbps per tap.

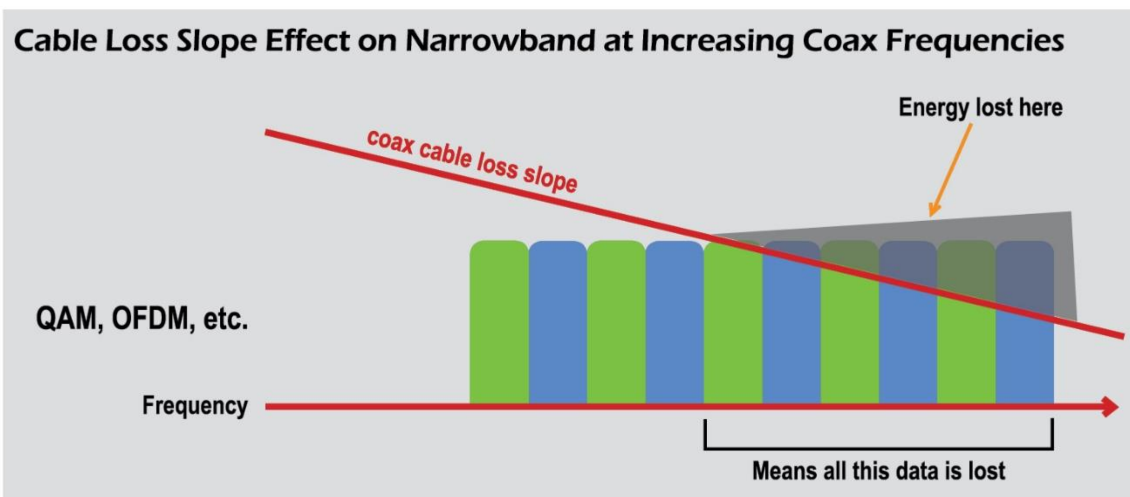
Below is an example of the spectral output by channel in a 1218 MHz DOCSIS 3.1 deployment and adjusting for both the increased SNR/MER in the legacy band, as well as aggregating the output of the BPSK modulated Intercept eHFC channel.

Effective Throughput for a 64 HHP FTTT Gen 1.5 Intercept eHFC implementation using a 10/1 xPON OLT per grouping and baseline DOCSIS 3.1 4096 QAM Data channel allocation.



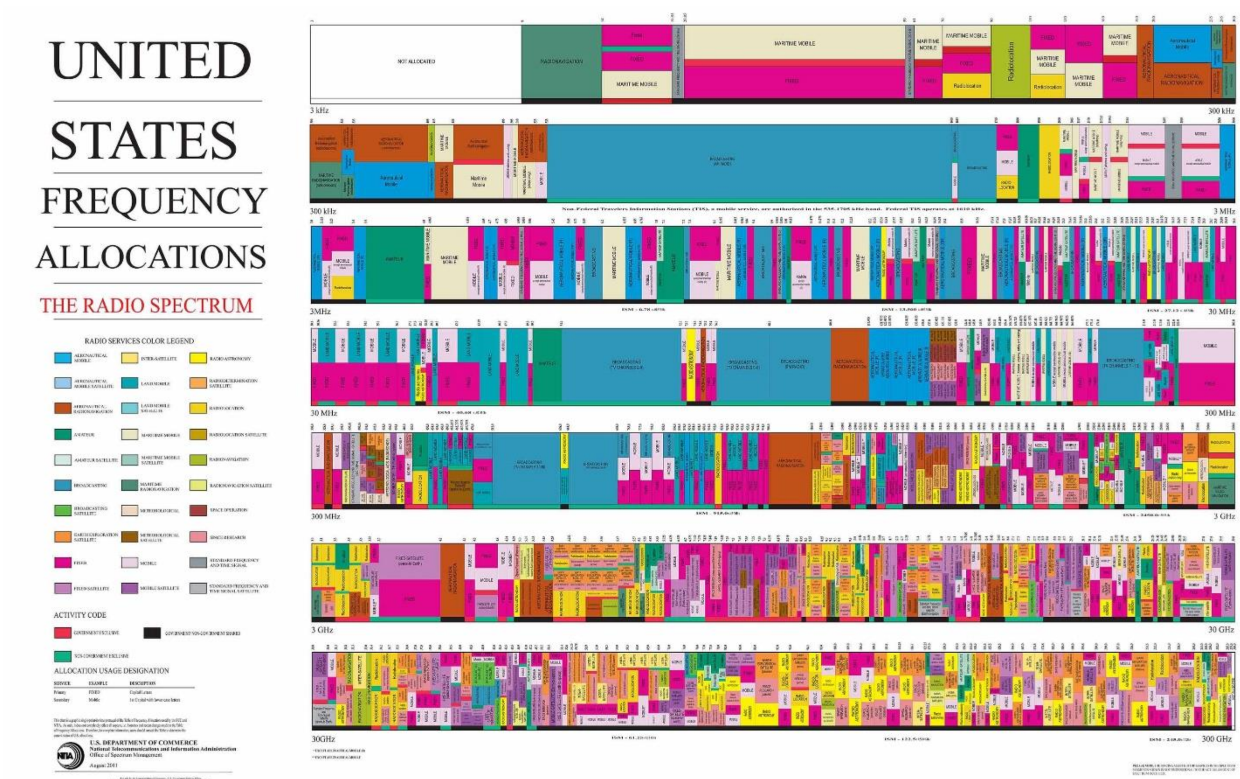


Intercept eHFC low energy, wide spectrum modulation and spectral output performance relative to tansmit power and SNR. **[SANT]**

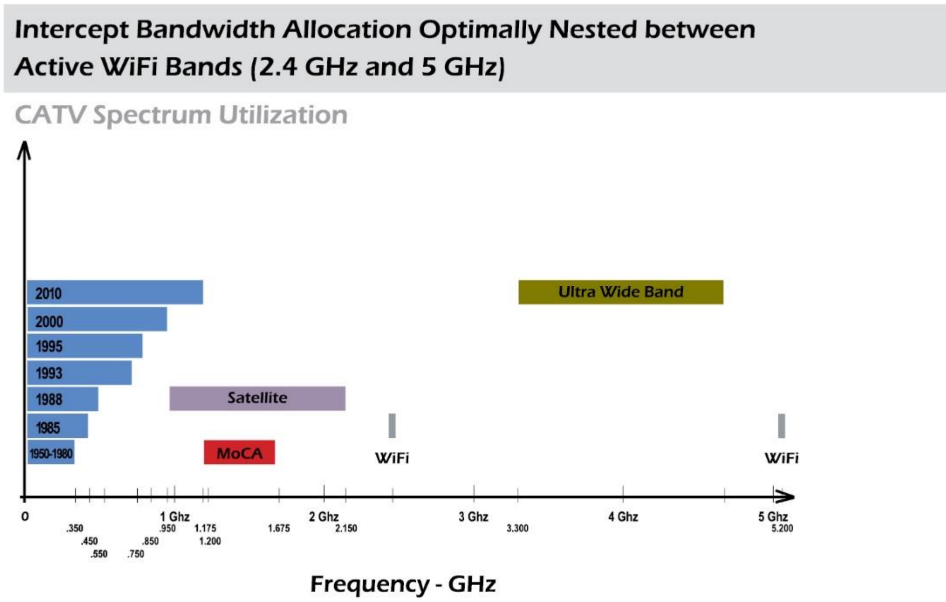


Cable Loss Slope Effect on Higher Order QAM and OFDM Modulation relative to Intercept PSK Low order, wide spectrum modulation.**[SANT]**

eHFC's Ultra Wide Band Channel allocation for both Gen 1.5 and Gen 2.0 are located between actively contemplated current and next generation Wi-Fi spectrum and licensed by the FCC for Wireless communications. The allocation is free of significant spectral emissions and spurious signals for other wired and wireless transmission modes in service today.

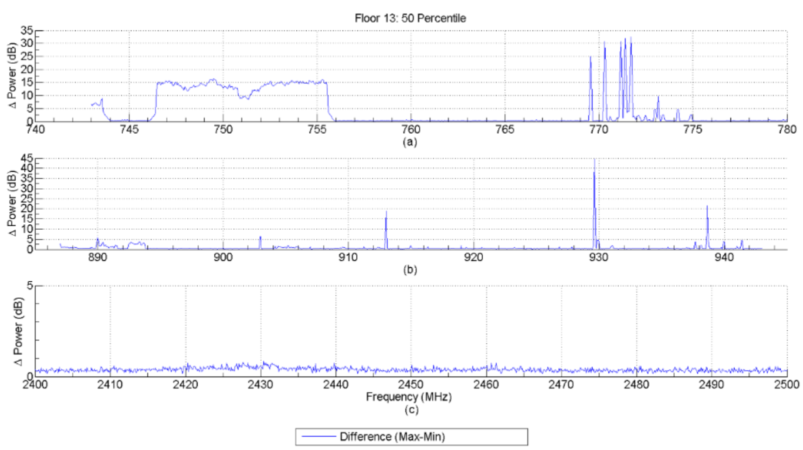


Current U.S.A. RF Spectrum Utilization [FCC]



[SANT]

Emissions and Ingress observations in relevant operating band.



High Frequency Spectrum test for Ingress and Emissions from NIST Technical Note 1885; Complexities of Testing Interference and Coexistence of Wireless Systems in Critical Infrastructure [NIST]

Note that in the above study, although a test plot was not published, the relative frequency band for eHFC single band operation between 3.3 and 4.7 GHz was noted as insignificant for emissions and ingress.

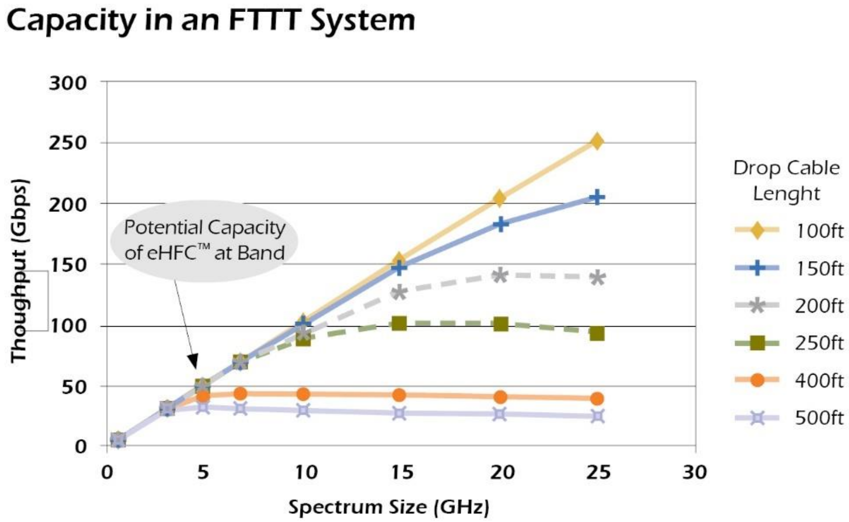
4. ***Theoretical limits of Near Passive Hybrid Architectures: Throughput capacity of FTTT and FTTLA: a comparison***
   a. ***Leveraging existing coaxial infrastructure capacity in eHFC implementations***

For future planning, the characteristics of Near Passive Architectures as well as PON provide cable service providers a platform that in theory can be upgraded without further intervention or disruption of the physical plant. The physical limitations of the cable media determine the extent to which future throughput can be supported. For PON architectures, the optical media provides a virtually limitless platform which can carry all future services, especially with the introduction of WDM which leverages the same fiber for multiple wavelengths.

For Node + 0/FTTLA architectures, the coaxial distribution segment is capable of significant throughput. However, this is limited by the RF performance of the passive devices in the cascade, which is currently 1218 MHz for current generation multi-taps and main line passives. Downstream of the passive devices, the length and specific media of the drop cable further limit the potential throughput of the network.

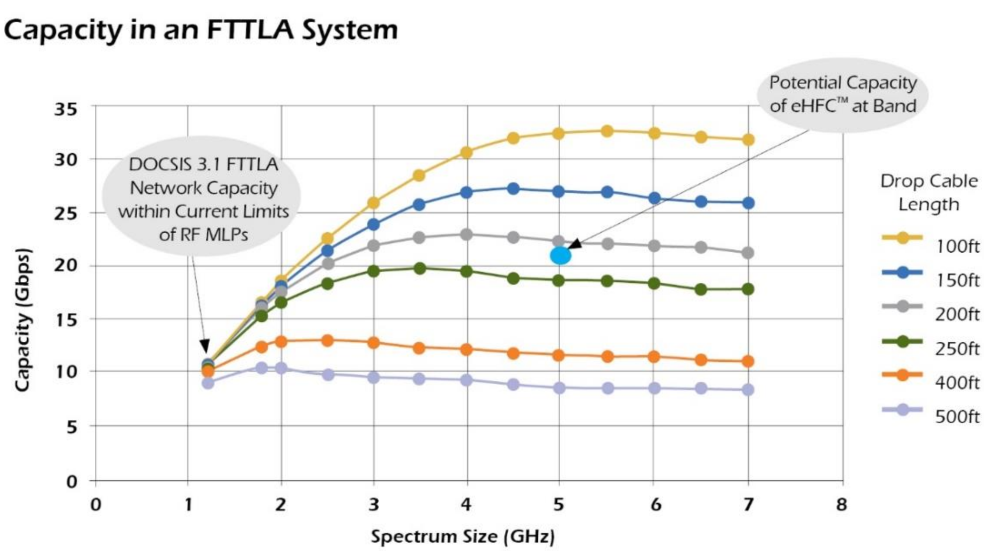
For FTTT architectures, the coaxial media for the drop segment only determine the theoretical capacity of the passive segment of the network. While drop design coaxial cable, RG6, produces significant losses over distance, these losses are limited by the typical span of the drop length, which in most cases is less than 300 feet from the multi-tap location to the customer premise. The advantage of FTTT implementations, as compared with FTTLA, is that while the losses over the coaxial media are greater, there are no losses or frequency limitations attributed to additional passives in a typical tap cascade which results in cumulative losses both related to the cable media, as well as the passive devices themselves, and, as in PON networks, no device upgrades would be required within the drop span in order to take advantage of next generation RF applications.

Throughput Capacity of Near Passive Architectures: FTTT and FTTLA



Throughput capacity of FTTT architectures – scaled by coaxial drop length and spectrum [ESDCLO]

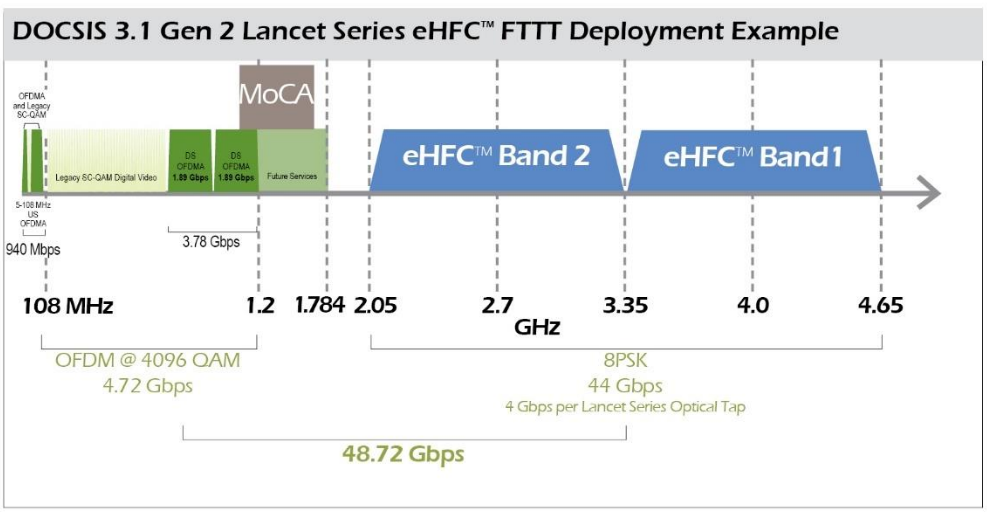
Up to 50 Gbps at between 200 ft. and 300 ft. drop length out to 5 GHz for Lancet eHFC Gen 2.0 implementation



Throughput capacity of Node + 0 architectures – scaled by coaxial drop length and spectrum [ESDCLO]*Current FTTLA Passives limit throughput capacity to 10 Gbps at 1218 MHz for QAM/OFDM modulation*

Note that for the FTTLA system, the theoretical limitations of the coaxial media are well beyond the capacity of currently available passive components and transmission platforms for DOCSIS implementation, leaving room for throughput growth well into the future without the need to migrate to optical media. However, limitations do exist within the active and passive component layer relative to frequency.

Whereas, for FTTT architectures, for Lancet Series eHFC implementation, the throughput capacity of the drop segment is leveraged for both spectrum and throughput, delivering well within the potential of the coaxial media measured at the operative UWB Frequency Band for Gen 1.5 and Gen 2 chipset designs out to 5 GHz, and well above the DOCSIS potential in FTTLA implementations of 10 Gbps. Below is a full-scale implementation frequency plan and spectral output for Gen 2.0 Intercept eHFC, illustrating the total potential output of an FTTT implementation for eHFC Gen 2.0 and Baseline DOCSIS 3.1.



Net Effective Throughput

FTTT eHFC Gen 2.0 Bonding Group for 64HHP FTTLA equivalent Service Group Size

Note that the above output is for the total bonding group and shared among all subscribers in the SG, and does not require or consider the total throughput as being transmitted over a single drop span. However, it is meant to validate a possible scenario where a future iteration of eHFC in FTTT could be supported by the cable media in order to satisfy growth demands and accommodate the throughput of as yet undeveloped technologies. Both models describe a scenario where a DOCSIS FTTLA implementation output potential could be exceeded by the FTTLA plant's RF capacity to withstand the total throughput potential of the modulation and frequencies available in the DOCSIS standard.

Current thought and investigation of Extended Spectrum DOCSIS largely considers maintaining QAM and OFDM formats for modulating channels above the current frequency range. However, it would not be unprecedented to have an evolution of the standard to support multiple modulation formats with a differentiated implementation based on the frequency range. In the evolution of DOCSIS 1.0 to 1.1, for example, PSK modulation was supported for upstream data communications while QAM was introduced for increased spectral output characteristics in the downstream. Furthermore, in the evolution of the standard from 3.0 to 3.1, OFDM was introduced while maintaining support of legacy QAM in the 6 MHz format for video and legacy services.

For considering Extended Spectrum evolution of DOCSIS 3.x, the high loss characteristics of frequency implementations above 1784 MHz would support an approach where: as the frequency is expanded above 1784 MHz, the modulation format accommodates superior performance relative to these high frequency noise and loss characteristics. PSK modulation for frequencies in the eHFC Band of 3.3 GHz and 4.7GHz largely solves this challenge, and the Ultra Wide Band channel format of eHFC produces a large block of bits, despite the low spectral efficiency and relative noise of the channel frequencies. Therefore, an evolution of DOCSIS wherein frequencies above 1784 MHz could be designated for PSK format modulation while the current 3.1 standard would apply to the 5-1784 MHz range as currently being implemented. This expansion of the standard could conceivably be accomplished with minimal complexity and allow cable service providers a pathway to plan for future services well into the next several decades, without being dependent on the emergence of new or as yet undeveloped technologies. The eHFC platform already provides a solution and chipset architecture based on this approach. Over time, as technologies evolve to support this approach, QAM and OFDM can be introduced to the standard, following the same evolutionary migration as it did in the 5-1784 MHz bands, increasing the supported QAM modulation orders as higher SNR/MER performance becomes more reliable and networks evolve towards more highly passive architectures such as FTTT. eHFC also has another distinct advantage over the current frequency implementation of QAM/OFDM – TDMA allows full upstream and downstream programmability, alleviating future growth demands of upstream data communications. The upstream is expensive to address in traditional approaches using extended return splits and diplex components in the RF network, and also difficult to predict, since upstream data usage trends have not followed the same steady growth trajectory as downstream growth trends of 50% CAGR [ESDCLO]. TDMA will allow Cable Service Providers to be more agile in addressing growth in upstream traffic demand without having to allocate specific capacity at the outset. The only change that would be required would be sufficient OLT capacity to service the eHFC platform's TDMA capabilities. In fact, the cost of symmetrical 10G/10G OLT, though not specifically investigated in this paper or considered in any of the evaluated use cases, will likely become much more affordable as the upstream demand trend takes shape over the next decade.

To fully capitalize on the near passive characteristics of Next Generation Architectures therefore, an FTTT deployment of eHFC in an FTTT architecture provides a longer-term transmission platform for future services and upgrades, as compared with FTTLA deployment architectures.

While not currently included in the DOCSIS standard, eHFC frequencies do meet the signal performance and stated objectives of Extended Spectrum evolution being widely discussed and agreed upon under the standard, and can already leverage many of the provisioning and operational features of D 3.1 and DPOE in a unified hybrid implementation.

5. **Extending the available operating frequency range of DOCSIS 3.1 in FTTT Architectures**

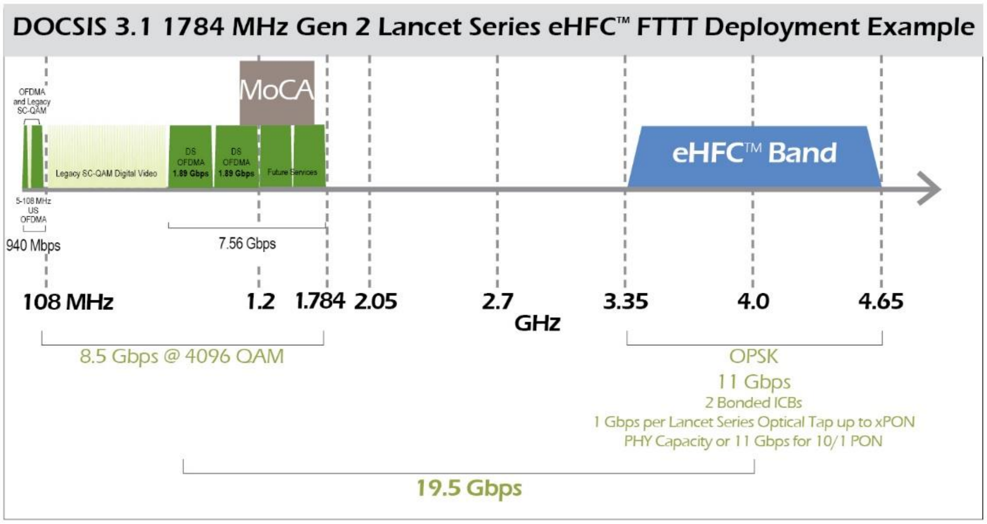
As mentioned above, at the time of the publication of this study, there were no commercially available passive RF devices capable of sustaining losses in the range between 1218 MHz and 1784 MHz for Node+0 or Node N applications, where a minimum cascade depth and coaxial cable spans would be required for implementation.

For DOCSIS 3.1 migration roadmap considerations, extending the frequency range entails the substitution of main line passives, fiber nodes, as well as in home devices which are not explicitly required to tune as high as 1784 MHz for data delivery services

DOCSIS 3.1 does however rely on the eventual expansion of frequency plans to include signal transmission up to 1784 MHz in order to achieve the stated potential of the standard of up to 10 Gbps DS and 2 Gbps US, without yet considering the possible implementation of Full Duplex DOCSIS. Note that the potential throughput of DOCSIS 3.1 assumes that the entire spectrum will be occupied by data channels, with no reservation of SC QAM spectrum for video and legacy services or native interactive platforms. In addition, it assumes that 4096 QAM is achievable in the respective architecture across the entire 5-1784 MHz band.

Due to the near passive nature of an FTTT implementation, the significant reduction of coaxial cable media in the signal path and unique design and optimized RF components in the Intercept Lancet Series eHFC optical tap, 1784 MHz transmissions are suitable for and consistent with the DOCSIS 3.1 expansion roadmap and standard. Likely in the near future chipset designers will resolve some of the challenges of 1784 MHz performance and deliver commercially viable chipsets capable of leveraging the D 3.1 platform's potential.

The below scenario considers this expansion of legacy DOCSIS 3.1 frequency plan accordingly and considers the possibility of QAM 4096 in the frequency range between 1218 MHz and 1784 MHz.



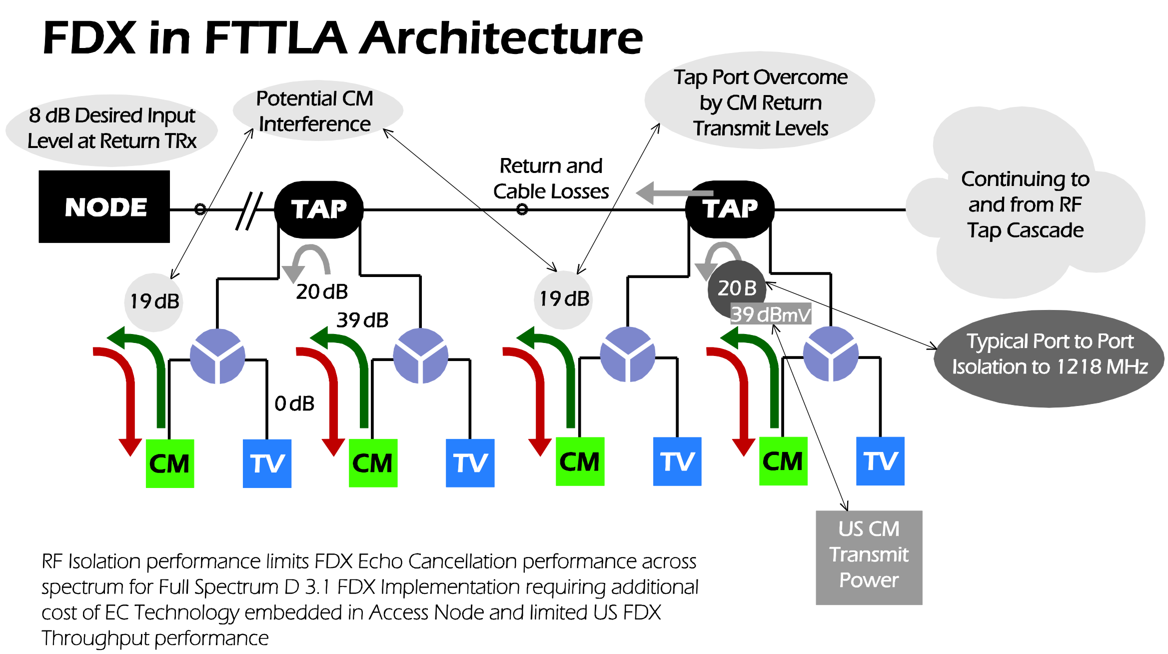
Net Effective Throughput

Frequency Plan of Expanded DOCSIS 3.1 OFDM Channel Bonding Group and eHFC xPON in 64HHP FTTT equivalent Service Group Size for Gen 1.5 eHFC implementation.

6. **Full Duplex DOCSIS 3.1 performance requirements in Node 0 and Intercept eHFC Lancet Series FTTT implementations – a comparison**

Full Duplex DOCSIS 3.1 or FDX is an expansion of the DOCSIS 3.1 standard which introduces both Frequency and Time Division Duplex technology in a unified standard, potentially extending the operative data rates of D 3.1 Full Spectrum implementation to a fully symmetrical 10 Gbps rate. Implementation of the technology is currently limited to Node+0 architectures. Full duplex DOCSIS 3.1 allows for simultaneous transmission and reception at the same frequency by utilizing Echo Cancellation (EC). The effectiveness of Echo Cancellation highly depends on the RF isolation between adjacent tap ports to segregate the transmitting modem on one tap port from interfering with the reception in the modem on the adjacent port.

As illustrated in the diagram below, higher isolation between tap ports will be required to limit interference between modems potentially operating over adjacent tap ports simultaneously. Since transmitting modems frequently have signals above +50dBmV, the modem(s) in the adjacent tap port(s) cannot properly utilize Echo Cancellation due to interference from the transmitting modem. The port to port isolation within the tap is not sufficient to fully prevent this interference. So the FDX 3.1 standard introduces the implementation of Interference Groups which groups modems together that do not interfere with each other. While EC functionality resolves the issue of interference with this approach, it doesn't fully enable FDX performance across the potential spectrum thereby reducing the possible US data rates. [FDX]

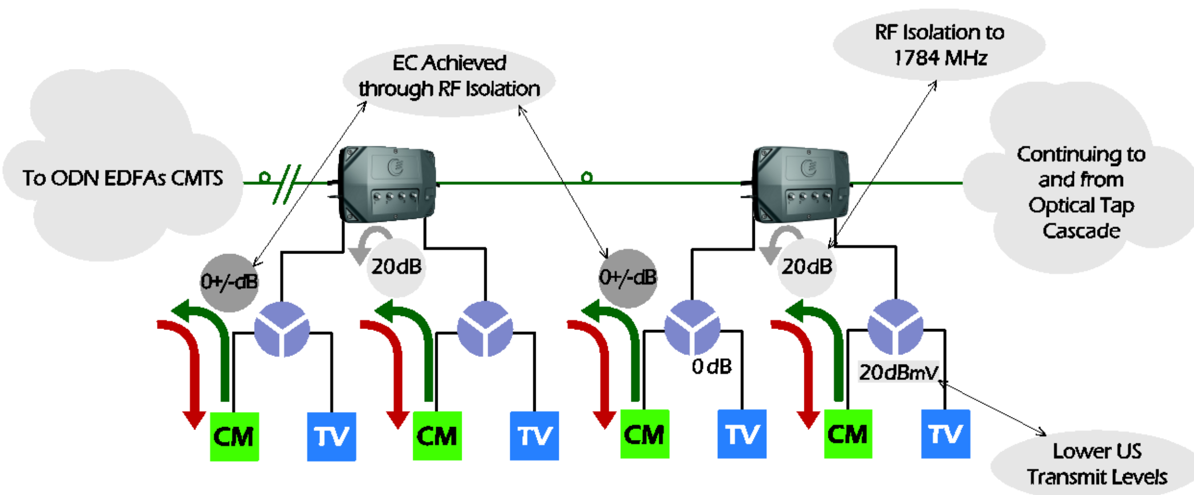


Above: FDX Isolation performance requirements in FTTLA/Node 0 implementations [FDX]

For this, and additional legacy channel allocation considerations (John T, Chapman, Hang Jin, 2016) the current first stage frequency plan for FDX consideration is between 108 MHz and 686 MHz, with a maximum US frequency allocation of 204 MHz, effectively limiting FDX performance to around 11 Gbps DS/1.5Gbps US for a 1218 MHz spectrum implementation of FDX D 3.1, and considered a Low Band implementation of the FDX standard.

Implementing FDX in an FTTT Architecture, however, could greatly improve FDX performance across a broader spectrum because required return transmit level thresholds would be lower than in equivalent Node + 0 scenarios. This is because the CM transmitter will only need to transmit at levels sufficient to reach the length of the drop cable to the Optical Tap location and resident return optical transmitter. There are no tap through losses or hardline cable losses to overcome as in a Node + 0 scenario. A +20dBmV return transmit level, for example, would be sufficient to reach the optical return transmitter at the Optical Tap location, so the port to port isolation requirements of the tap is greatly reduced and can possibly eliminate the potential interference between adjacent tap ports, even when transmitting simultaneously in the same frequency and time domains, across the entire FDX operating spectrum.

FDX in FTTT Architecture



Lower return CM transmit levels require lower isolation at the tap to prevent FDFX interference between CMs transmitting simultaneously in Time and Frequency Domains [FDX]

The resulting increased bandwidth potential now covers potential spectrum allocation across the entire DOCSIS 3.1 band, and achieves full spectrum symmetrical output estimated in FDX mode of 11G upstream and 10G downstream. This would be in addition to the xPON generated PHY of the eHFC Lancet technology, significantly increasing the aggregate upstream and downstream throughput potential of a Lancet eHFC FTTT deployment a compared with conventional Fiber Deep Node + 0 approaches and eventual FDX Implementation. This solution would also bring FDX within reach of Cable Service providers far sooner than envisioned currently and could reduce or eliminate the required added expense of Echo Cancellation equipped Fiber Nodes as a next stage investment when FDX technology is released commercially.

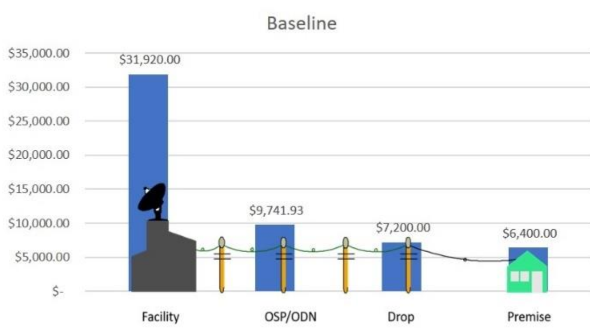
7. **Economic Evaluation of FTTLA Deployment Scenarios**

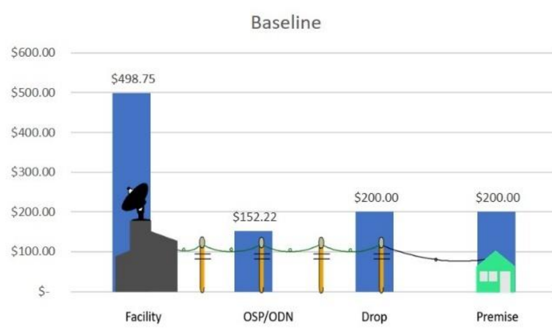
Baseline Use Case

Greenfield

DOCSIS 3.0
150 Mbps Downstream
20 Mbps Upstream
256 QAM

64 DS QAM Data Channels
11 US QAM Data Channels
5-85 MHz





Greenfield Summary

Total Cost per 64 HHP Node $55,262
Cost per Subscriber $1,727.00
Cost/Mbps/Subscriber $0.629
Cost/Mbps/active session at peak contention $1.26

Brownfield Scenario N/A

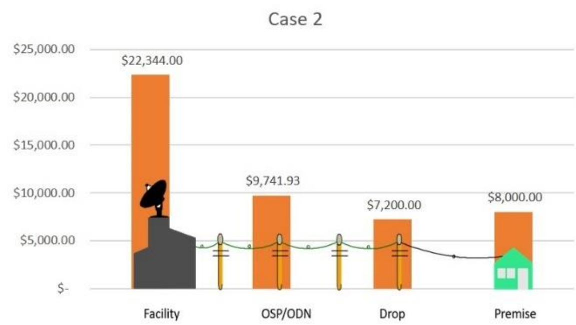
Use Case 2

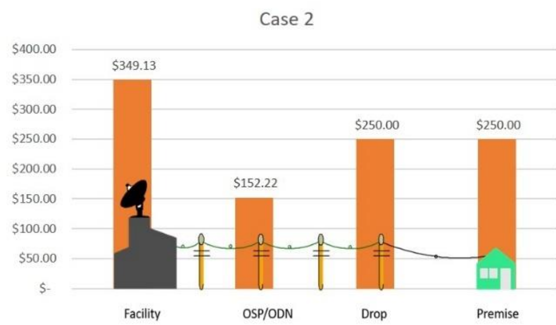
1.2 GHz DOCSIS 3.1, 2 DS OFDM and 1 US OFDM @ 1024 QAM Data Channel implementation Node 0

DOCSIS 3.1
200 Mbps Downstream
50 Mbps Upstream
1024 QAM

2 DS OFDM Data Channels
1 US OFDM Data Channels

Greenfield



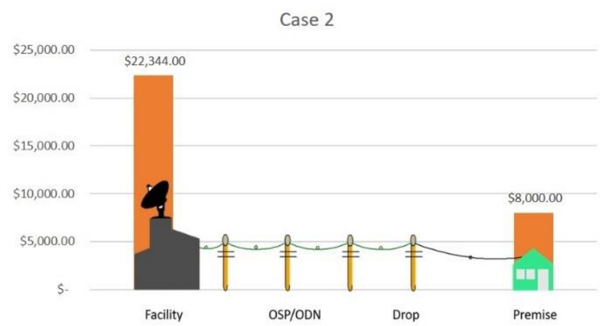


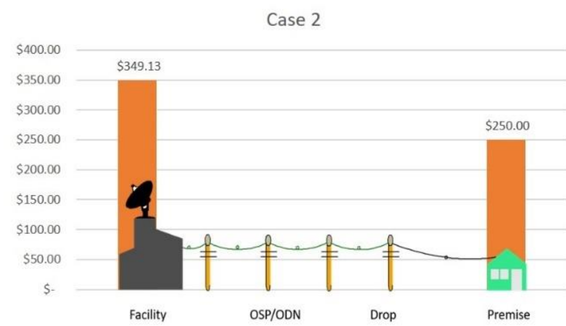
Greenfield Summary

Total Cost per 64 HHP Node $47,286
Cost per Subscriber $1,478
Cost/Mbps/Subscriber $0.375
Cost/Mbps/active session at peak contention $0.75

Brownfield Summary

Total Cost per 64 HHP Node $30,344.00
Cost per Subscriber $948.25
Cost/Mbps/Subscriber $0.241
Cost/Mbps/active session at peak contention $0.48
Cost per Incremental Mbps/Subscriber $0.79





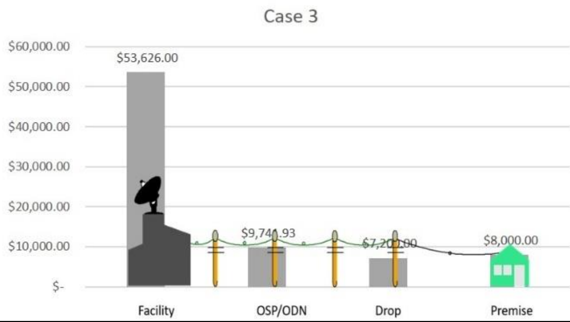
Use Case 3

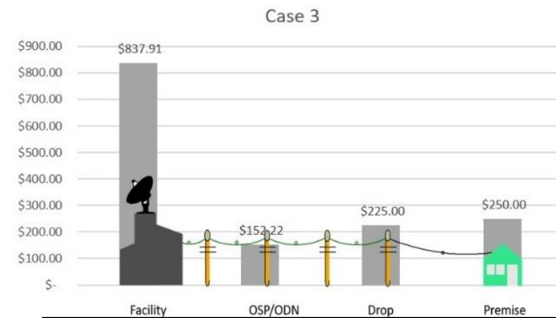
1.2 GHz DOCSIS 3.1, 5 DS OFDM and 2 US OFDM @ 1024 QAM Data Channel implementation Node 0

DOCSIS 3.1
500 Mbps Downstream
100 Mbps Upstream
1024 QAM

5 DS OFDM Data Channels
2 US OFDM Data Channels

Greenfield



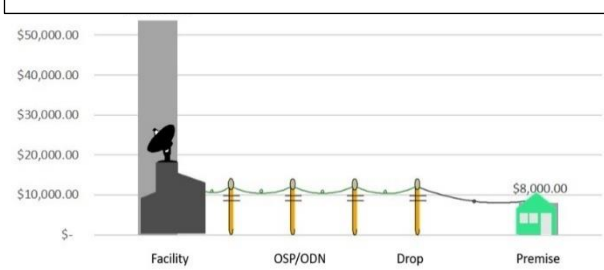


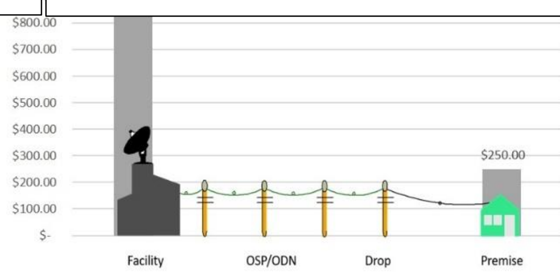
Greenfield Summary

Total Cost per 64 HHP Node $78,568.00
Cost per Subscriber $2,455
Cost/Mbps/Subscriber $0.259
Cost/Mbps/active session at peak contention $0.519

Brownfield Summary

Total Cost per 64 HHP Node $61,626
Cost per Subscriber $1,925.81
Cost/Mbps/Subscriber $0.203
Cost/Mbps/active session at peak contention $0.407
Cost per Incremental Mbps/Subscriber $0.29





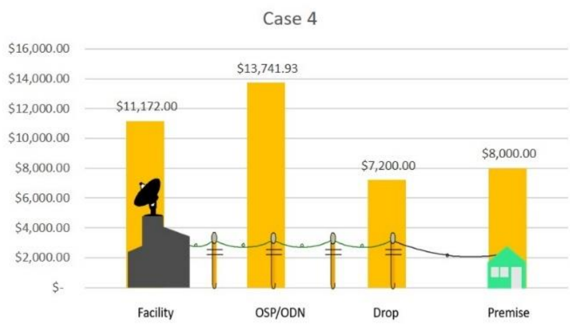
Use Case 4

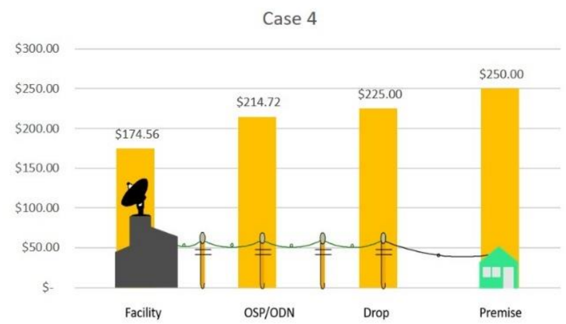
1.2 GHz DOCSIS 3.1 RPHY, 2 DS OFDM and 1 US OFDM @ 4096 QAM Data Channel implementation Node 0

DOCSIS 3.1 RPHY
250 Mbps Downstream
50 Mbps Upstream
4096 QAM

2 DS OFDM Data Channels
1 US OFDM Data Channels

Greenfield





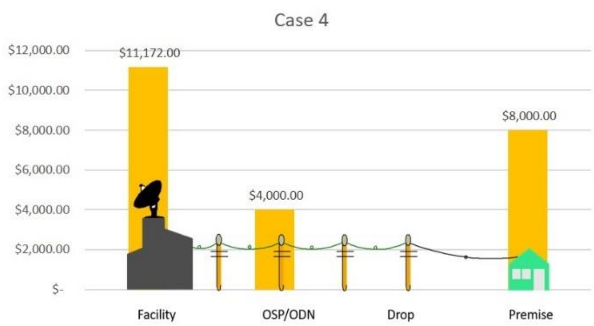
Greenfield Summary

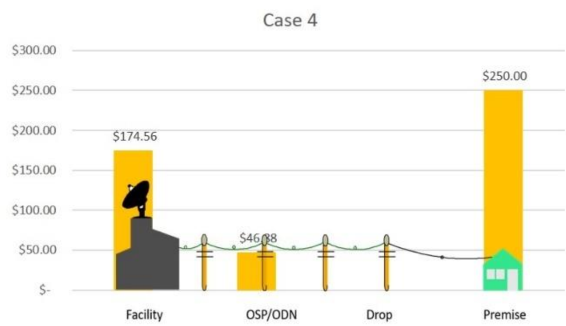
Total Cost per 64 HHP Node $40,114
Cost per Subscriber $1,253.57
Cost/Mbps/Subscriber $0.265
Cost/Mbps/active session at peak contention $0.531

Brownfield Summary

Total Cost per 64 HHP Node $23,172.00
Cost per Subscriber $724.12
Cost/Mbps/Subscriber $0.153
Cost/Mbps/active session at peak contention $0.306
Cost per Incremental Mbps/Subscriber $0.366

Brownfield Migration from Baseline Use Case





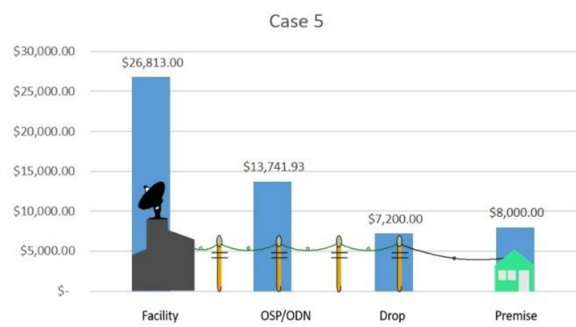
Use Case 5

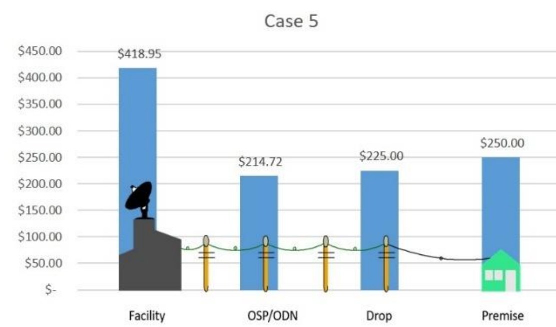
1.2 GHz DOCSIS 3.1 RPHY, 5 DS OFDM and 2 US OFDM @ 4096 QAM Data Channel implementation Node 0

DOCSIS 3.1 RPHY
600 Mbps Downstream
100 Mbps Upstream
4096 QAM

5 DS OFDM Data Channels
2 US OFDM Data Channels

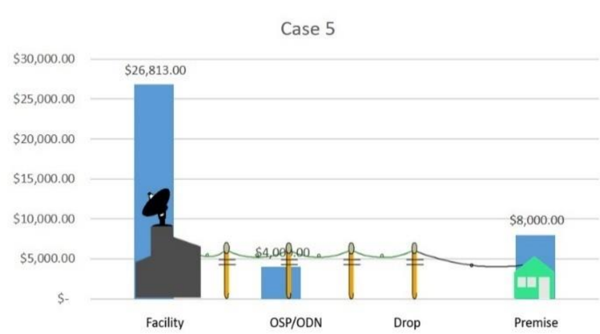
Greenfield

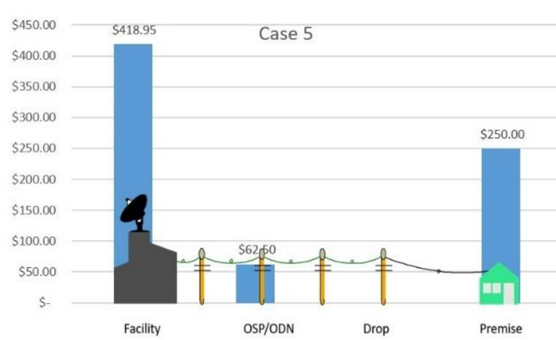




Greenfield Summary	**Brownfield Summary**
Total Cost per 64 HHP Node $55,756	**Total Cost per 64 HHP Node $38,813.00**
Cost per Subscriber $1,742	**Cost per Subscriber $1,212.91**
Cost/Mbps/Subscriber $0.153	**Cost/Mbps/Subscriber $0.107**
Cost/Mbps/active session at peak contention $0.306	**Cost/Mbps/active session at peak contention $0.214**
	Cost per Incremental Mbps/Subscriber $0.141

Brownfield Migration from Baseline Use Case





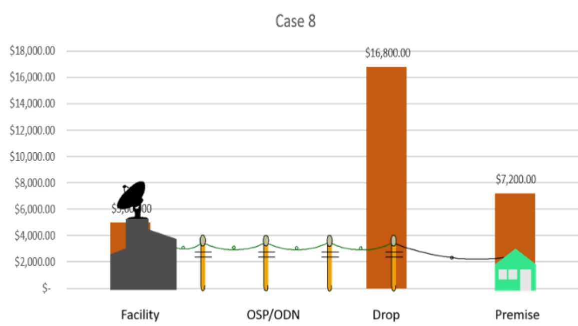
Use Case 8

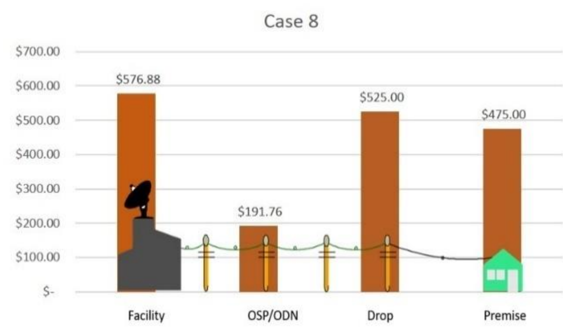
10G/1G FTTP PON Overlay of D 3.0

PON Overlay of D 3.0
600 Mbps Downstream
50 Mbps Upstream

10G/1G xPON

Brownfield





Brownfield Summary

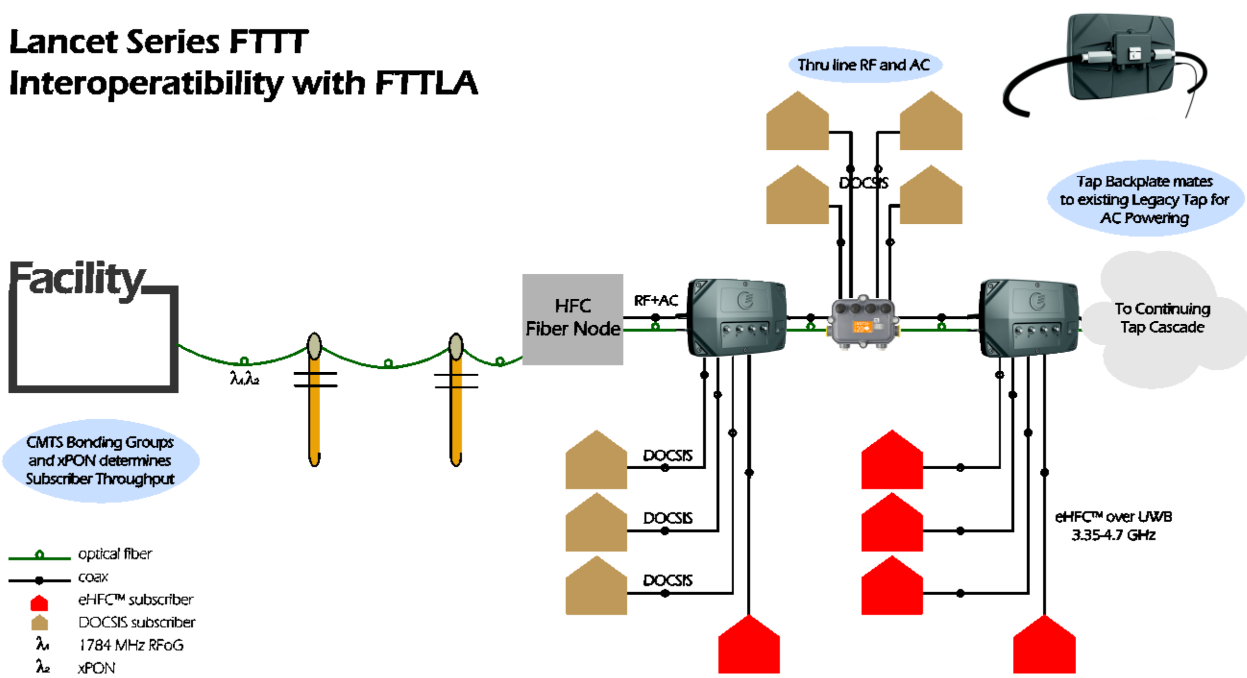
Total Cost per 64 HHP Node $29,000
Cost per Subscriber $906
Cost/Mbps/Subscriber $0.082
Cost/Mbps/active session at peak contention $0.164
Cost per Incremental Mbps/Subscriber $0.109

Greenfield Scenario N/A

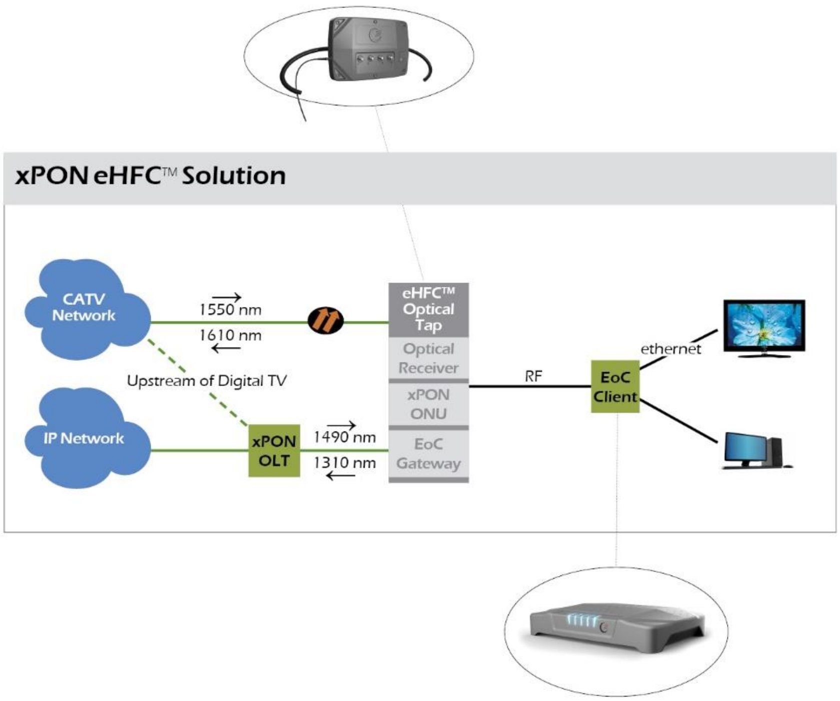
8. **Interoperability of DOCSIS FTTLA and Intercept Lancet Series eHFC FTTT Networks**

Intercept eHFC Lancet Series Optical Taps and the Intercept eHFC Platform are designed for interoperability and simplicity of implementation with existing DOCSIS and xPON infrastructure and network components. The Lancet eHFC Tap can be interlaced within a traditional FTTLA tap cascade, as diagramed below. This is achieved by providing RF and AC through-line performance in the electrical, RF and mechanical design. In addition to the mechanical features of the Lancet Tap, the eHFC platform leverages traditional and widely implemented PON standards for optical IP input at the Optical Tap along with the forward path analog optical transport of existing networks. Optionally, the legacy QAM transmission can be received from the distribution coaxial cable via the Tap faceplate interface, for minimum intrusion into the existing RF plant. The Intercept eHFC platform is both PON and DOCSIS agnostic, so any DOCSIS standard is transparent, as well as any optical IP input at the tap, including but not limited to GPON, EPON, GiGe, P2Pe

WDM is used to aggregate transmission over the optical media and an Intercept eHFC eMTA merges DOCSIS and eHFC data streams in an unified interface. Below is a diagram of FTTT and FTTLA interoperability from an architectural standpoint:



Physical Plant interoperability of Lancet eHFC Optical Taps in FTTLA/FTTN Networks

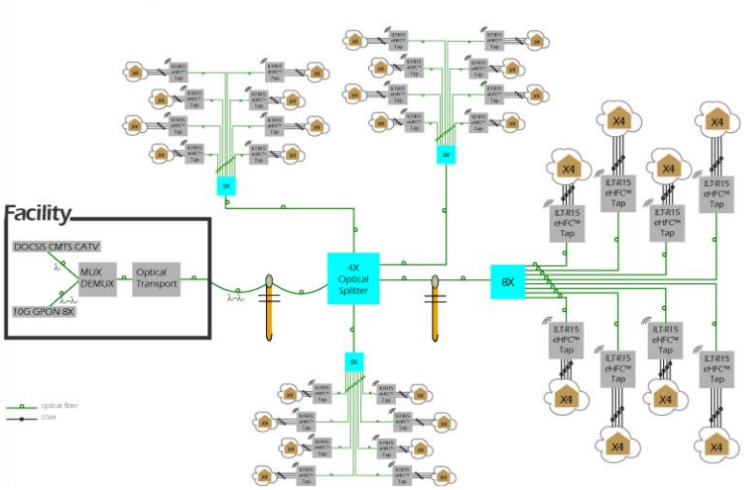


Signal Interoperability of Intercept eHFC and xPON in an FTTT FTTLA Hybrid deployment with Home Network components

For wide scale deployment of FTTT Architectures, there are no conventional Access Class Fiber Nodes in the OSP Network.

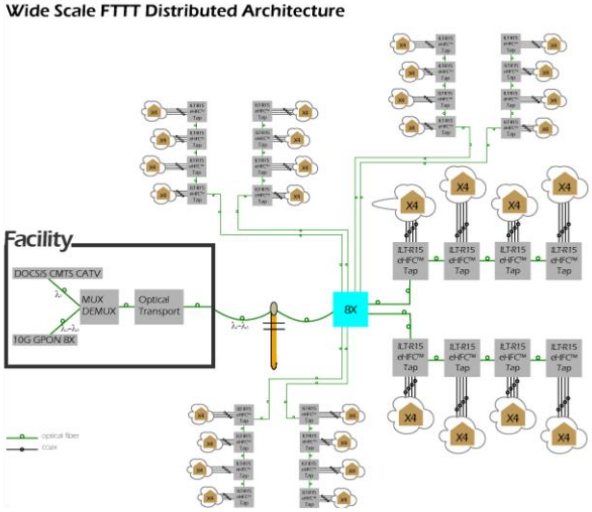
Wide Scale Deployment of Lancet Series eHFC FTTT

Lancet Series eHFC™
Wide Scale FTTT Split Architecture



Split Optical Architecture allows for dedicated optical capacity targeted to individual subscriber groups – requires more optical splices and available fiber media in the last leg. Provides superior redundancy of network infrastructure, provided Fiber strand is available and splice costs are factored.

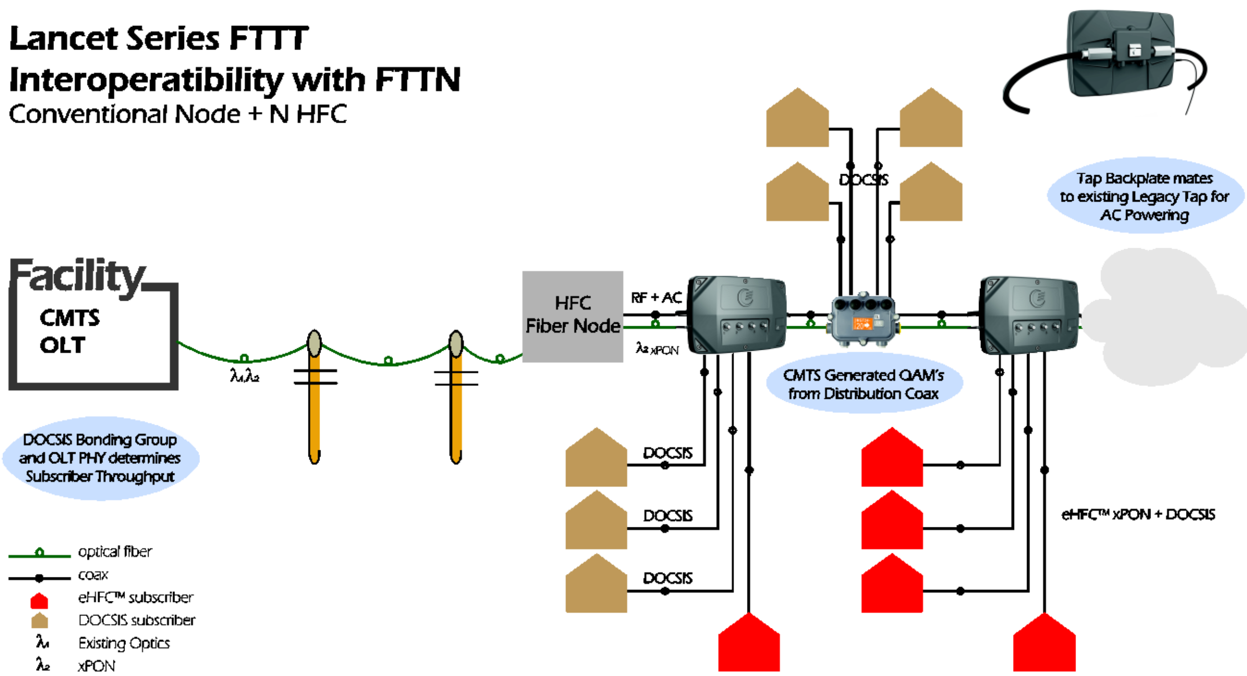
Lancet Series eHFC™
Wide Scale FTTT Distributed Architecture



Distributed Optical Architecture allows for dedicated optical capacity targeted to individual subscriber groups via WDM – requires up to 75% fewer optical splices and available fiber media in the last leg.

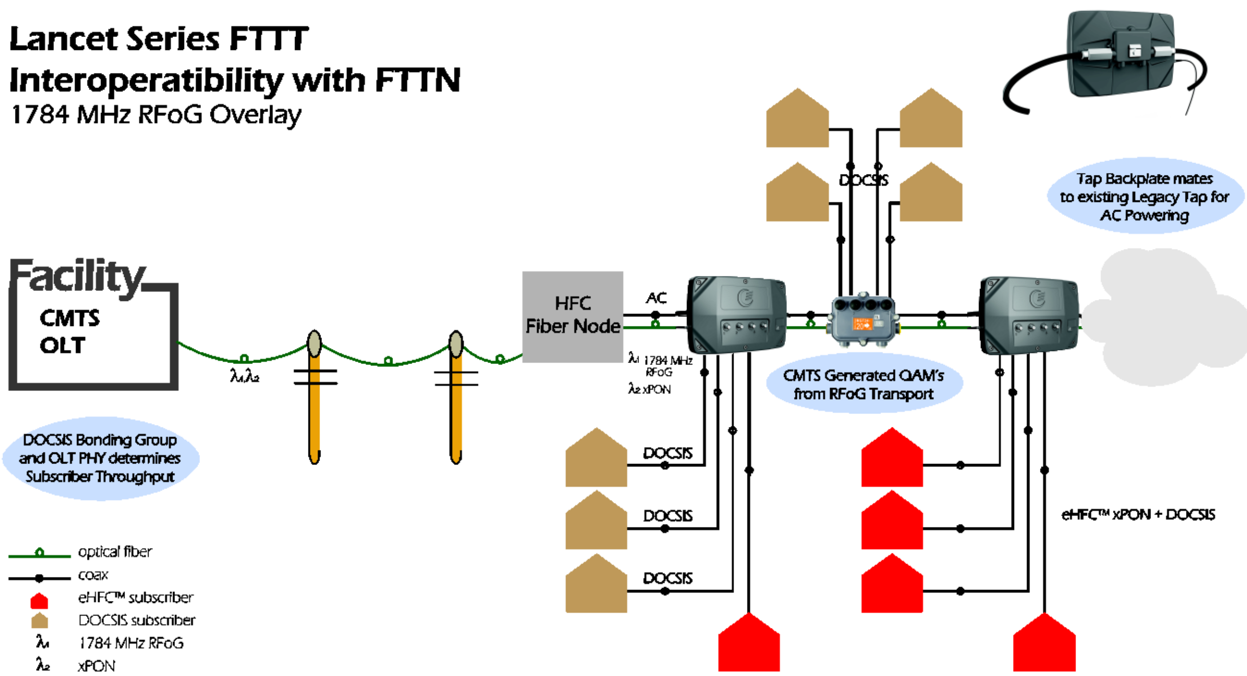
a. eHFC FTTT Implementations in Conventional FTTLA and FTTN Networks

For a traditional implementation in HFC FTTN Networks, the interoperability is very similar to the above, only here the CMTS generated QAMs can received from the Distribution coax or the RFoG lambda. While this scenario does not permit the advantages of extended frequency performance out to 1784 MHz, it does provide a pathway to aggregate the xPON PHY from the OLT over existing coax drop infrastructure and does not necessarily require migration to a FTTLA architecture, allowing Node N networks to provide increased data rates without further CMTS upgrades, expansions, Node Splits, or relying on PON Overlay approaches for selected high data demand subscribers within the SG.



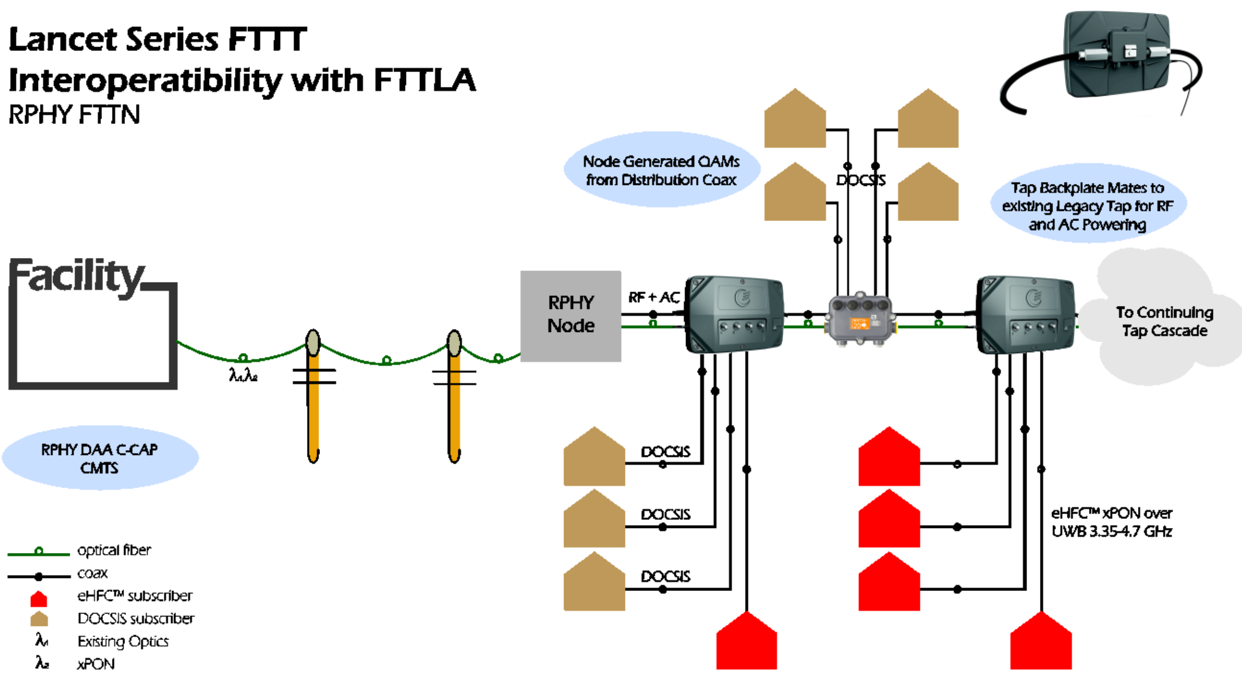
b. 1784 MHz RFoG Lancet eHFC implementation as an Overlay in FTTN Networks

With 1784 MHz capable D 3.1 CMTSs now available, an RFoG implementation of Lancet eHFC provides the possibility of loading data channels well beyond the limitations of DOCSIS 3.0, in addition to the benefits of higher QAM modulation orders and Forward Error Correction LDPC. Because currently available Access Node and conventional HFC multi tap designs are not suitable for transmissions above 1218 MHz, a scenario in which selected subscribers can be serviced via an extended frequency RFoG transport alongside or in parallel to an FTTLA architecture could enable extended frequency range performance to a high demand sub grouping as needed, while maintaining the remaining architecture intact In addition, providing a parallel RFoG transport over the same fiber media via WDM allows cable service providers the option to further leverage legacy D 3.0 CMTSs capacity as they transition to a DAA approach. In the scenario diagramed below, the eHFC platform leverages the RFoG transport for CMTS generated QAMs from the RFoG lambda, which are transmitted over the drop cable media as in traditional HFC networks.



c. **eHFC FTTT Implementations in RPHY FTTN and FTTLA Networks**

For RPHY FTTN Scenarios, the Lancet eHFC scenario is identical to the traditional FTTN HFC Scenario where the QAMs are passed through via the distribution coaxial cable, only here the QAMs are received from the RPD instead of the CMTS, a detail which is transparent and inconsequential to the eHFC implementation from an outside plant perspective. In this scenario however, the general economics, independent of the impacts of an investment in eHFC, could be important, as an RPHY deployment, while potentially improving efficiencies of the investment at the hub or headend, could be strained for smaller SGs in a FTTLA implementation due to the expected higher cost of the Access Node. Interlacing Lancet eHFC Optical Taps therefore could improve economic performance by enhancing throughput in larger SGs which would share a limited amount of RPHY generated QAMs from the RPD Access Node, while allowing for smaller SGs to be addressed as economically viable via RPHY in FTTLA scenarios where the Node generated QAMs can have maximal effect relative to SG size.



For Brownfield scenarios generally, and for scenarios where interlacing of Lancet Taps into an existing FTTLA or FTTN networks is involved, various pre-connectorized cable products are available that potentially could reduce the cost of running the additional fiber between Tap spans and from the Fiber Node to the first tap in a cascade, further improving the economics of either a Brownfield migration from the Baseline FTTLA scenario or for Opportunity Driven implementation in either FTTLA or Node N scenarios.

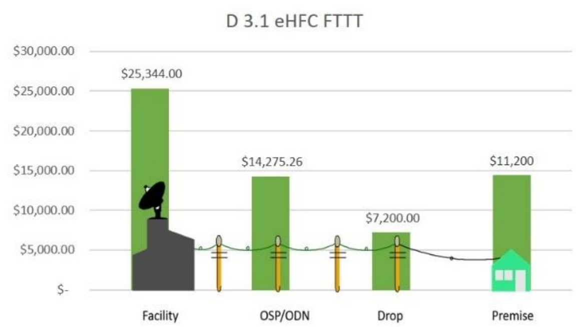
9. Economic Analysis of eHFC FTTT Wide Scale Deployments – Use Cases

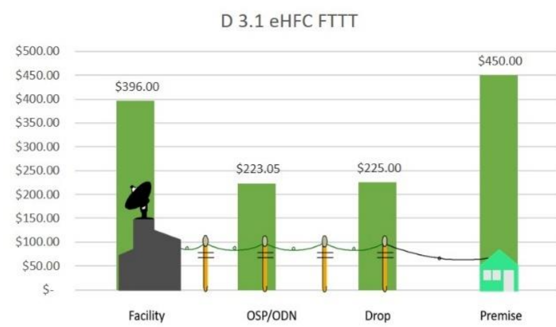
Use Case 6

1.2 GHz DOCSIS 3.1 FTTT eHFC Lancet Series, 2 DS OFDM and 1 US OFDM @ 4096 QAM Data Channel, 10G/1G xPON OLT implementation

Lancet eHFC FTTT
900 Mbps Downstream
150 Mbps Upstream
4096 QAM

2 DS OFDM Data Channels
1 US OFDM Data Channels





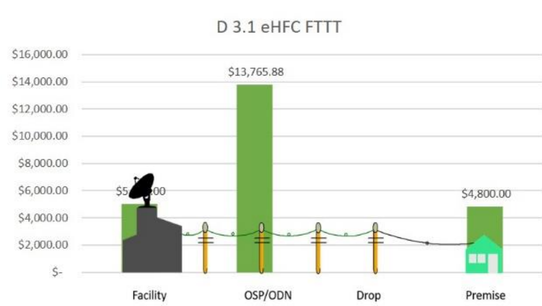
Greenfield Summary

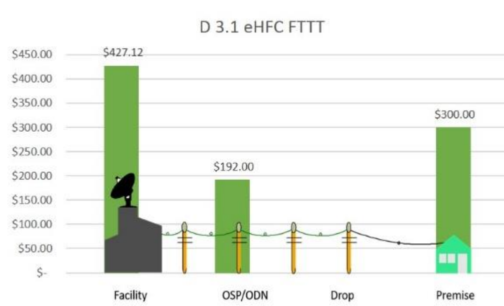
Total Cost per 64 HHP Node $61,219
Cost per Subscriber $1,913
Cost/Mbps/Subscriber $0.1216
Cost/Mbps/active session at peak contention $0.243

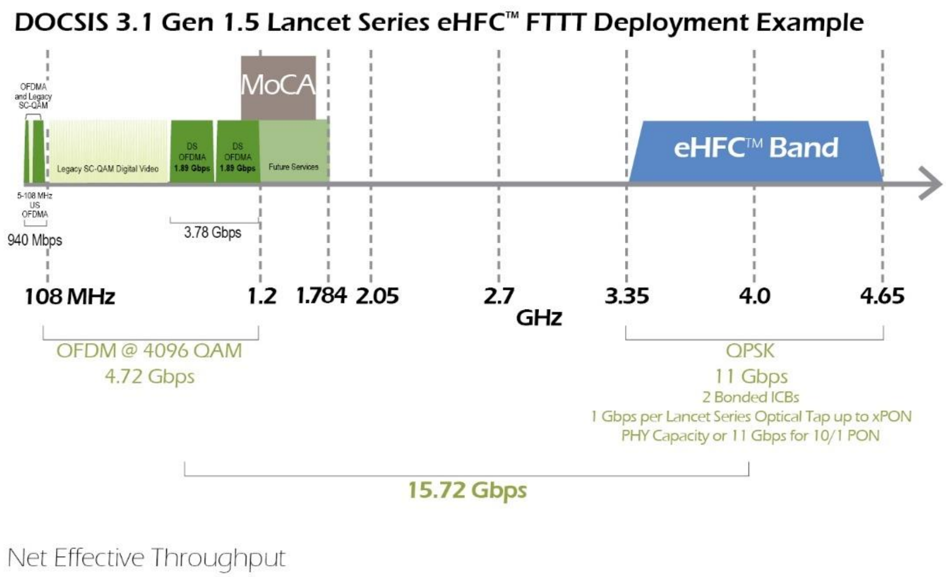
Brownfield Summary

Total Cost per 64 HHP Node $46,277
Cost per Subscriber $1,446
Cost/Mbps/Subscriber $0.092
Cost/Mbps/active session at peak contention $0.184
Cost per Incremental Mbps/Subscriber $0.111

Brownfield Migration from Baseline Use Case







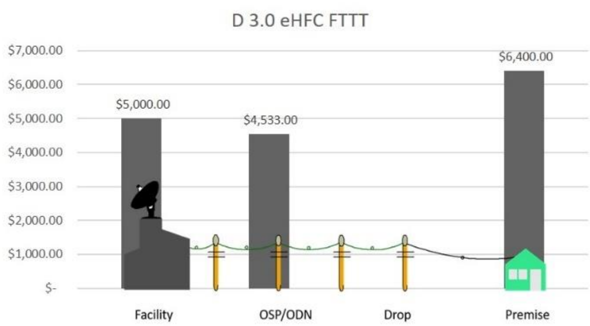
Use Case 6 eHFC Lancet Series FTTT implementation frequency plan using a 10G/1G xPON OLT for an equivalent 64 HHP deployment scenario

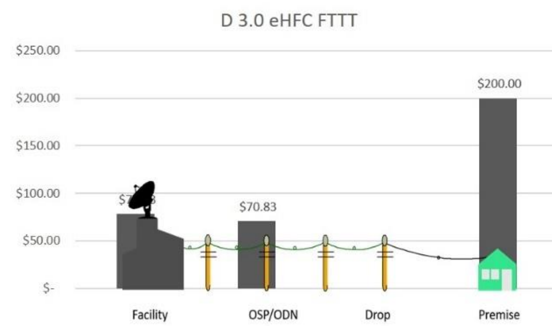
Use Case 9

eHFC Lancet FTTT 10G/1G xPON Brownfield upgrade to DOCSIS 3.0 Implementation, 64 DS QAMs, 11 US QAMs

Lancet eHFC FTTT DOCSIS 3.0 Brownfield
800 Mbps Downstream
100 Mbps Upstream
256/64 QAM

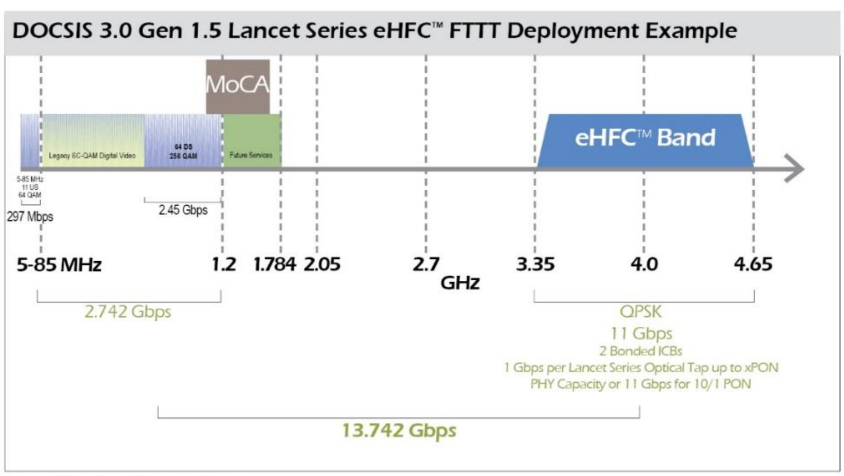
10G/1G xPON OLT
64 DS QAM Data Channels
11 US QAM Data Channels





Brownfield Summary

Total Cost per 64 HHP Node $15,933
Cost per Subscriber $498
Cost/Mbps/Subscriber $0.036
Cost/Mbps/active session at peak contention $0.072
Cost per Incremental Mbps/Subscriber $0.045



Net Effective Throughput

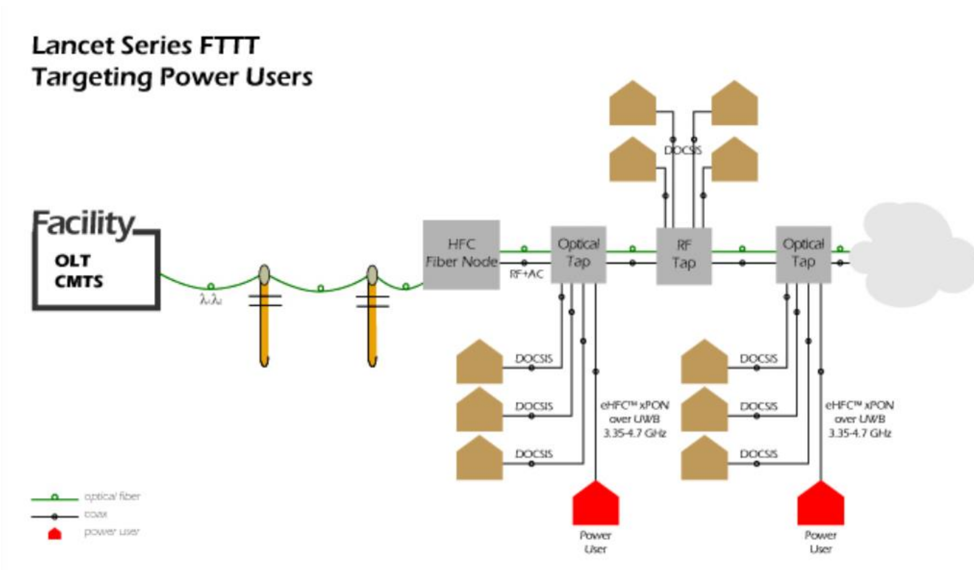
Use Case 9 Frequency Plan

10. **Opportunity driven Intercept eHFC Lancet Series Optical Tap FTTT services**

An alternative to full scale implementation of the above Brownfield migration from the Baseline DOCSIS 3.0 is an incremental opportunity driven implementation from the Baseline, targeting 40% Maximum Tier Take Rates for eHFC grouped subscribers.

The following Use Cases follow current implementation models for xPON overlay approaches wherein a small percentage of subscribers are identified and segmented by their data usage behavior and related market demand. In the current approach, a fiber drop is installed to the customer premise and segregated to the PON network, alleviating data traffic for the remaining DOCSIS subscribers in the Service Group, while providing PON level data rates to the targeted subscriber. While the percentage of these high demand, or Power Users, varies considerably between service groups and general demographics of the wider service area or market, a baseline case of 40% of subscribers, or a net subscriber penetration of 20% is utilized here for consideration. The below implementation considers a hybrid implementation of Lancet Taps and conventional RF Taps within the same SG. Power User installations are enabled via a Lancet Tap, and considered at 20% net penetration of total HHP in the SG, and accounting for 80% of data traffic on the network, while remaining DOCSIS subscribers are calculated at 80% net of HHP in the SG and responsible for 20% of data traffic on the network.

Use Case 7



Only High demand HSD Subscribers Receive FTTT implementation network components

The resulting economics, as well as QoE and data rates at peak contention for each group is evaluated below.

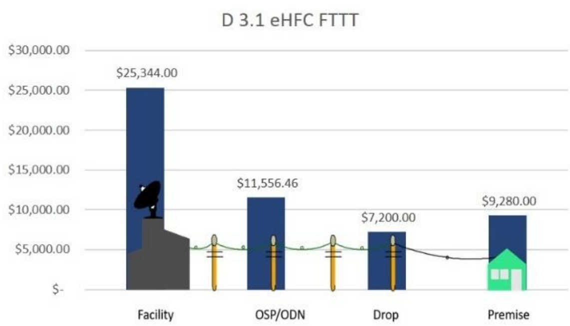
Use Case 7

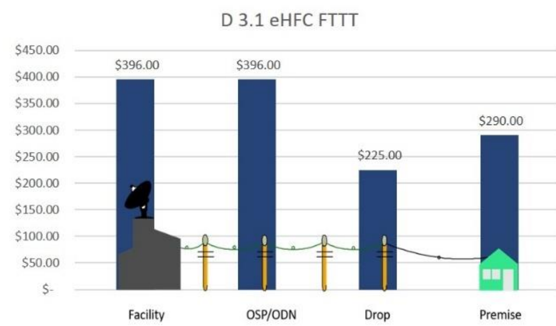
Lancet eHFC FTTT

eHFC User Grouping
1000 Mbps Downstream
100 Mbps Upstream

DOCSIS 3.1 Grouping
650 Mbps Downstream
100 Mbps Upstream

2 DS OFDM Data Channels
1 US OFDM Data Channels
4096 QAM





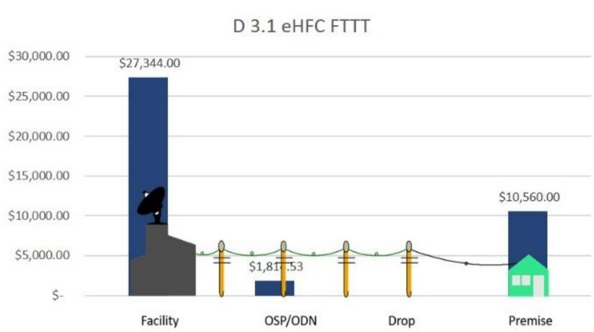
Greenfield Summary

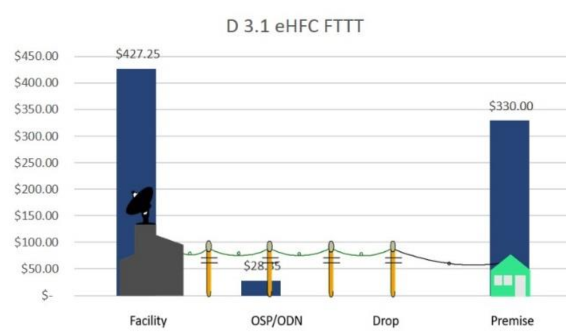
Total Cost per 64 HHP Node $53,380
Cost per Subscriber $1,668
Cost/Mbps/Subscriber $0.106
Cost/Mbps/active session at peak contention $0.212

Brownfield Summary

Total Cost per 64 HHP Node $39,718
Cost per Subscriber $1,241
Cost/Mbps/Subscriber $0.079
Cost/Mbps/active session at peak contention $0.158
Cost per Incremental Mbps/Subscriber $0.095

Brownfield Migration from Baseline Use Case





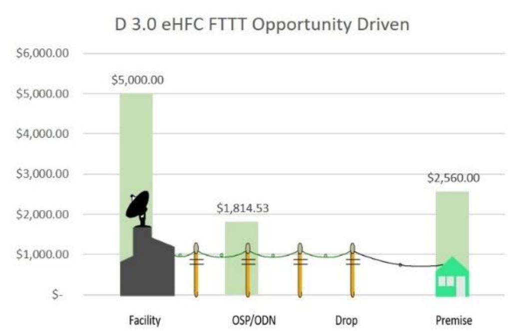
For the following scenario, without any additional investment as compared to the previous scenario, a Max Tier of 1Gbps DS and 100 Mbps US can be delivered to 40% of subscribers and support above Billboard rates at a contention rate of 80% for this subgroup, while also improving the experienced data rates for the remaining low contention behavior DOCSIS grouping. This scenario also provides the most economical incremental migration path to full scale eHFC and Gigabit services as a base Tier which can be supported at full contention for all subscribers in the Service Group.

Use Case 9A

Lancet eHFC FTTT DOCSIS 3.0 Brownfield
1 Gbps Downstream
100 Mbps Upstream
10G/1G xPON OLT

DOCSIS 3.0 Grouping
650 Mbps Downstream
100 Mbps Upstream

64 DS QAM Data Channels
11 US QAM Data Channels

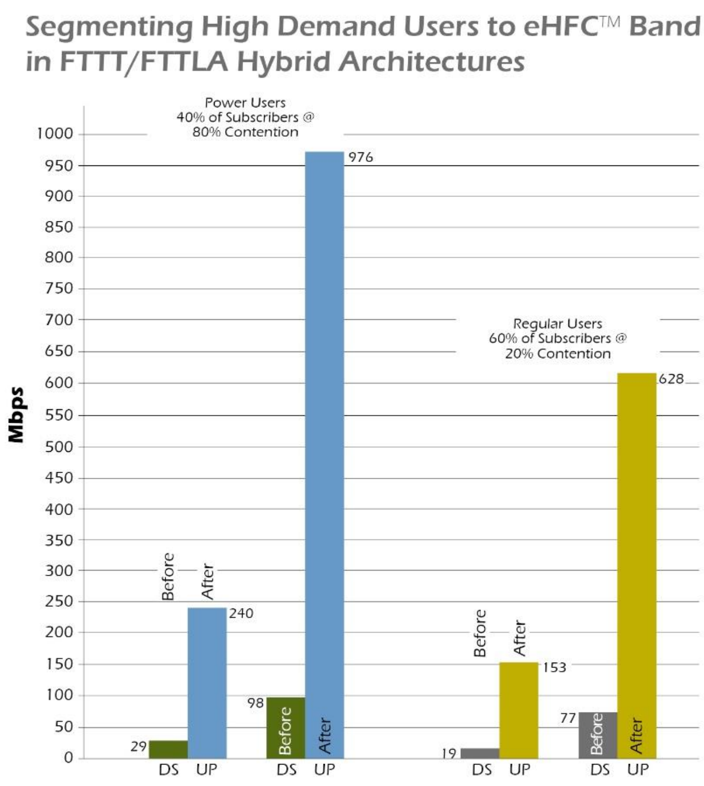


Brownfield Summary

Total Cost per 64 HHP Node $9,375
Cost per Subscriber $293
Cost/Mbps/Subscriber $0.021
Cost/Mbps/active session at peak contention $0.042
Cost per Incremental Mbps/Subscriber $0.027

In addition, eHFC provides TDMA capability so that high demand users can also be individually serviced with varying Upstream data rate profiles, up to 1Gbps symmetrical, depending on the capacity and symmetry of the OLT in the implementation. The scenario described here considers a 10G/1G OLT for evaluation. However, the Intercept eHFC platform is capable of full symmetry, provided there is Upstream PON capacity available. For a dedicated 1G/1G OLT for example, or alternatively, a 5G/1G OLT dedicated via WDM to each Lancet Tap, full Upstream, and Downstream Symmetrical Gigabit services can be achieved in a Gen 2.0 chipset implementation. For Gen 1.5 Chipset designs, and programmed via TDMA for full symmetry, the eHFC only grouping of Power Users in this scenario can be capable of a maximum of 500 Mbps DS/500 Mbps US, or any proportional distribution of the aggregate 1 Gbps total net effective rate per Lancet Tap. For Use Case 9A as evaluated, a Billboard Max Tier of 1 Gbps Downstream and 100 Mbps Upstream is considered, and can be supported for a penetration rate of 40% of this Max Tier and support a simultaneous contention rate of 80% among this grouping with QoE within 3% of the Billboard rate, or 976 Mbps actual versus 1 Gbps Billboard. A 10G/10G is not evaluated in this paper due to the high cost of currently available OLTs in the market.

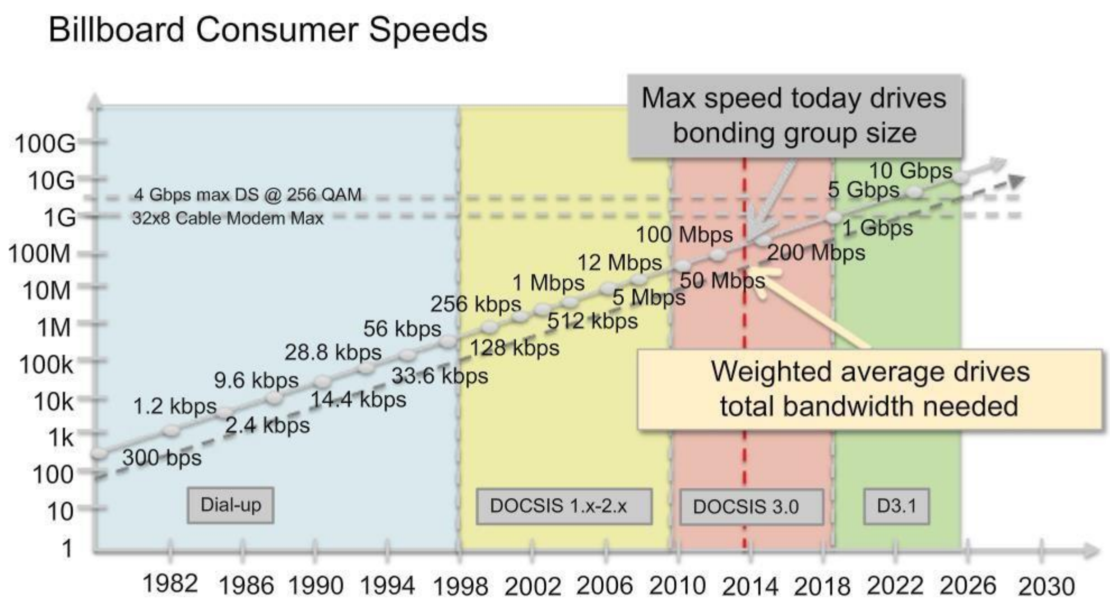
Data rates based on this model are evaluated below and depict rates before and after segmentation of Tiers based on the above described deployment model.



11. *Capacity planning Considerations for increasing take rates for next generation HSD service Tiers*

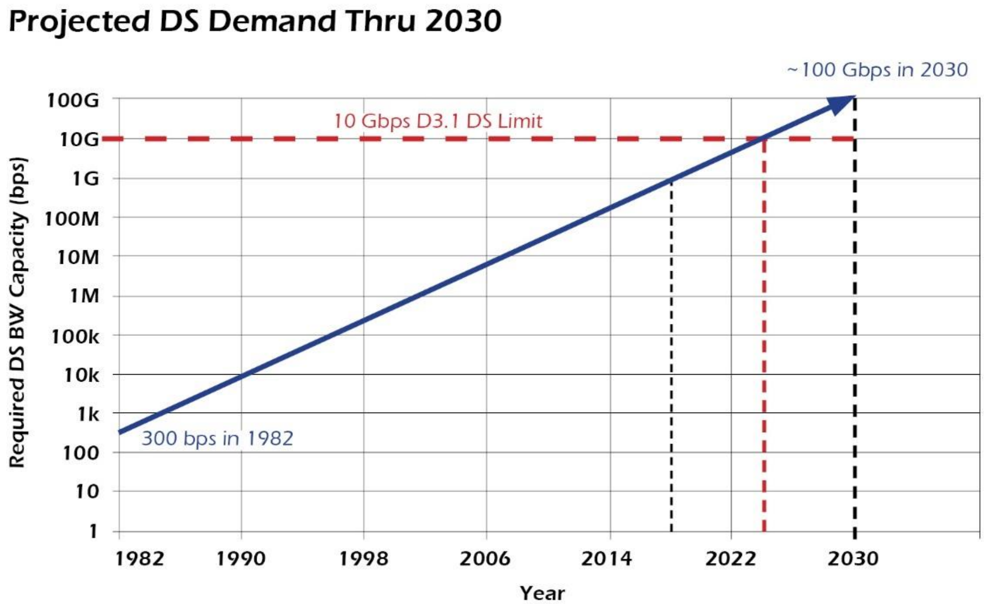
Capacity Planning models currently being considered for implementation generally follow the below formula for determining bonded data channel groupings, where the Max service tier determines the bonding group size.

C >= # subs * bps average + K (QoE coefficient) * Max Tier



[SD]

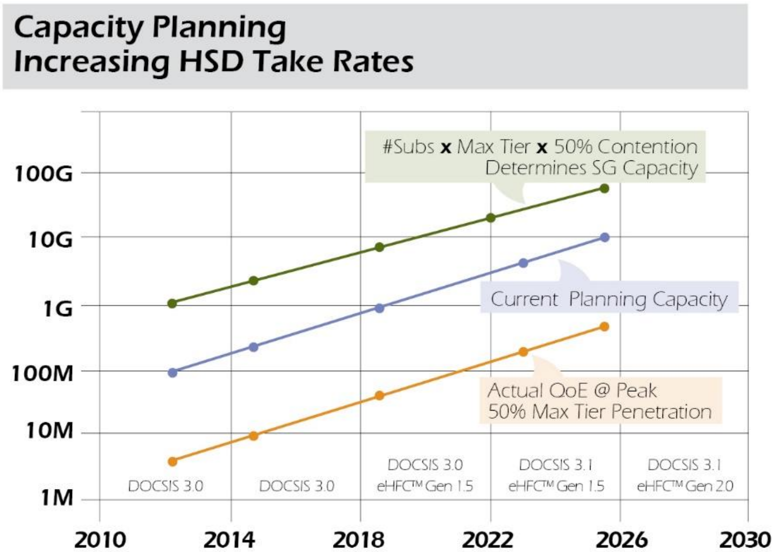
However, for large scale deployment of High Speed Data Services, and more importantly, to achieve Billboard speeds for more than a very small percentage of subscribers at the Max Service Tier considering peak contention, the above algorithm only accounts for achieving actual QoE at the Billboard Tier for a single subscriber at contention, with a variable QoE coefficient over and above demand for a single subscriber in the grouping. In fact, future demand models envision a convergence of the Max Tier demand with the weighted averages. Put differently, at some point, all subscribes will demand and use the Max Tier bit rates if the trend continues its current trajectory. If current throughput demands continue, as depicted below from a study conducted by Arris and cited in the relevant study, demand will outpace the throughput potential of DOCSIS 3.1 by 2030. Note that while the below projection considers a SG size of 100 HHP, our models consider smaller SGs (64 HHP) based on real world FTTLA averages, and would result in higher throughput per subscriber as well as increased longevity of the network However, it is still the case that in order to deliver wide scale Gbps services, D 3.1 alone will not be sufficient to keep up with demand at current growth rates.



[ESDCLO]

There is also an important economic dynamic that should be considered when evaluating take rates of Max Tier Services. While take rates for Gigabit speed services are currently very low, we should not assume that this will always be the case without factoring in a data subscriber's value judgement of the service relative to cost. While it is a standard practice that the initial offerings of Gigabit services might be artificially priced to induce demand and achieve some scale, this economic subsidy doesn't fully achieve a widely accepted economic model for most subscribers, which in turn will have a negative effect on take rates. So, reducing the cost of Gigabit services over time will also affect the take rate for the next generation of Max Tier, and should therefore be considered in any long-term capacity planning model. For the targeted deployment scenarios evaluated in this paper, these considerations and projections are considered, and apply a take rate target of 40% as an initial capacity basis, and eventually a 100% rate for the Max Tier, as current trendlines indicate will be necessary after 2020. [ESDCLO]

In order to achieve QoE equal to Billboard rates, therefore, a planning model that considers the number of subscribers contending for service at peak, given a service's Max Tier speed, as detailed below, is adequate for increasing take rates relative to Max Service Tiers.



The above planning model validates the implementation of FTTT Near Passive Networks and modulation schemes capable of delivering sufficient throughput to deliver credible Billboard rates across a wide universe of subscribers over the next several decades.

12. Conserving SC QAM spectrum for Native Content and Services – subsidization of OTT Content competitors and ARPU Ad and Interactive Service Revenue Considerations for Cable Service Providers

In addition to the increased spectral output of the total bonding group size and xPON PHY for eHFC implementations, the RF data channel allocation of Gen 1.5 and gen 2.0 technology also conserves legacy spectrum for use as legacy Video or Interactive Services. If one considers the data channel allocation as a subsidy to OTT content competitors in current approaches – due to the fact that that there is no current distinction in frequency plans between data capacity used for OTT streaming on multiple devices, and data spectrum being utilized for native content and video, e.g. Video or other Content which has been either produced for specific use over a Cable Service Provider's user interface, has been optimized for access via the Cable Service Provider's Channel Guide or customized search application software, or otherwise related to specific advertising or viewership revenue which is only monetized if viewed or accessed via the native guide or interactive platform.

Consider for example the difference in revenue generation between a native content VOD stream and content which is viewed Over The Top via any of the streaming applications available through a subscription service and unrelated to the Cable Service Provider.

In the case of the VOD stream, revenue is directly linked to the bandwidth dedicated to the streaming session. This is also true of any other type of data related service, whether it is an online gaming application, interactive service, etc.

In the case of the OTT stream, no revenue is generated from the data usage other than a flat fee for advertised data rate and the access fee sold by the Service Provider.

US Digital Video Viewers and Penetration, 2014-2020

	2014	2015	2016	2017	2018	2019	2020
Digital video viewers (millions)	196.1	205.8	213.2	219.3	224.5	228.5	232.1
—% change	5.3%	5.0%	3.6%	2.8%	2.4%	1.8%	1.5%
—% of internet users	77.5%	79.2%	80.3%	81.0%	81.8%	82.5%	83.1%
—% of population	61.5%	64.1%	65.8%	67.1%	68.2%	68.9%	69.4%

Note: internet users of any age who watch digital video content via any device at least once per month
Source: eMarketer, Feb 2016

204343 www.eMarketer.com

Internet User growth outpaces Digital Video Viewer Growth. Proper data capacity alignment of resources would differentiate OTT data usage from Native Video.

Put simply, the superior resource allocation approach would target the costliest investments in data capacity to enable those services with the highest revenue or Return on Investment potential based on verifiable fee for service models.

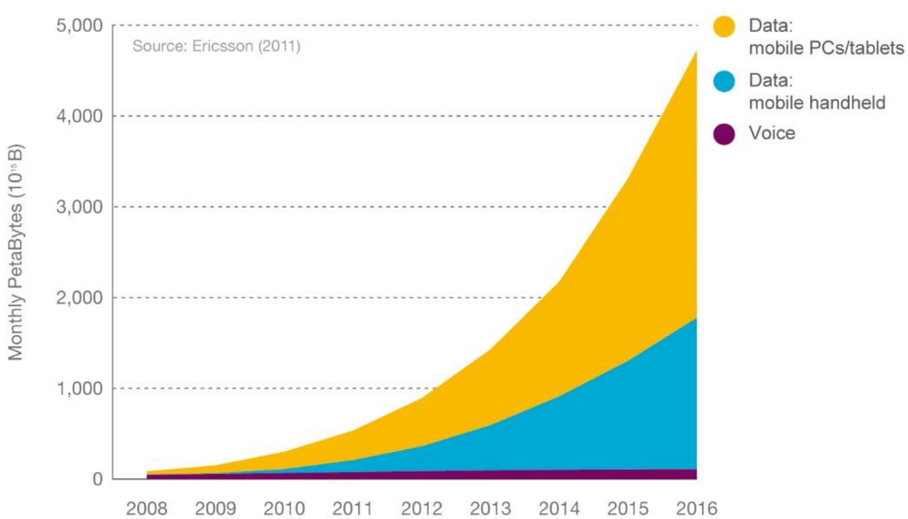
Because eHFC data channel allocation utilizes UWB channels that are Out of Band relative to CMTS generated data and Video QAMs, the more logical resource allocation would be to dedicate the lowest cost PHY to those services which do not correlate revenue to data usage.

Because DOCSIS components do not tune to the UWB eHFC frequencies above 1784 MHz, natural segmentation and data channel resource allocation occurs in any eHFC implementation.

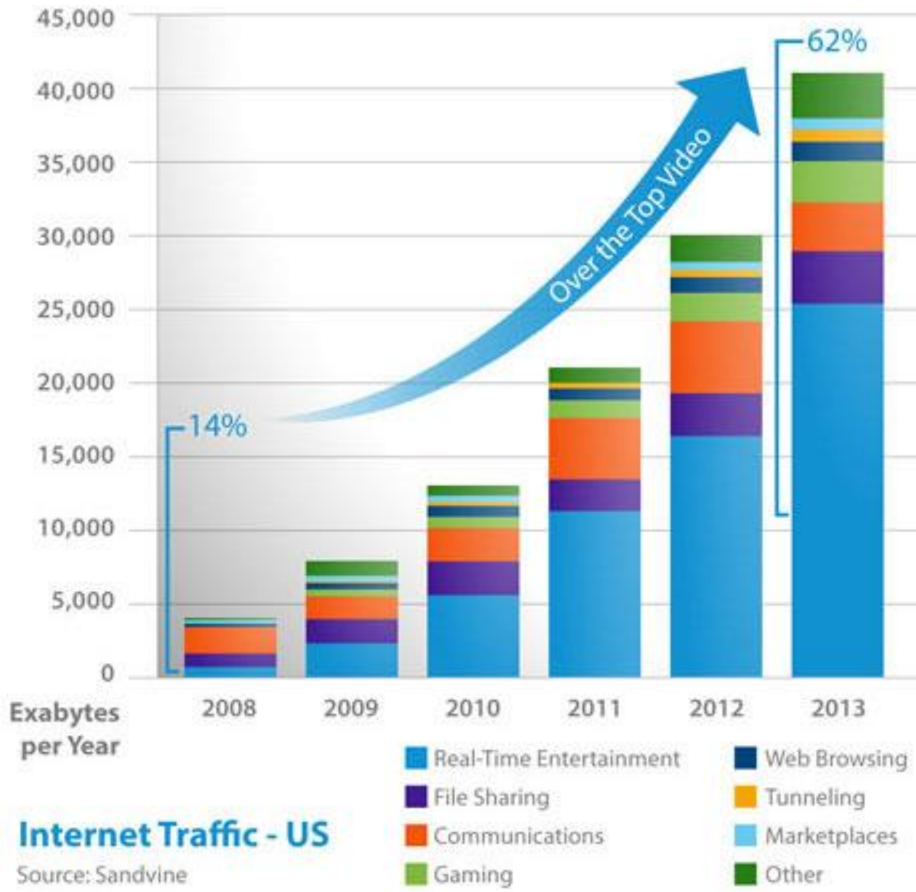
Put more simply, leveraging out of band frequency for OTT services would be the best allocation of network resources from an economic perspective. In an eHFC implementation, the OTT “subsidy” receives the proper resource allocation based on cost and value of resources relative to Return on Investment in data capacity.

As Cable Service Providers branch out into interactive services and optimize their data resources cost effectively, this segmentation of resources will become more important.

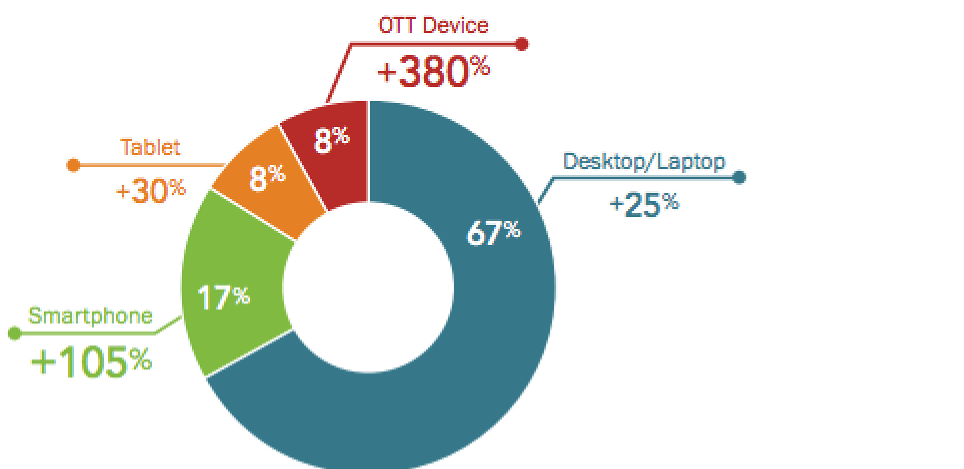
Given the trend in OTT usage as detailed below, this distinction and differentiation in the allocation of data capacity as an economic resource should be considered in any next generation architecture and frequency plan strategy.



High Growth Rate of alternative viewing platforms.



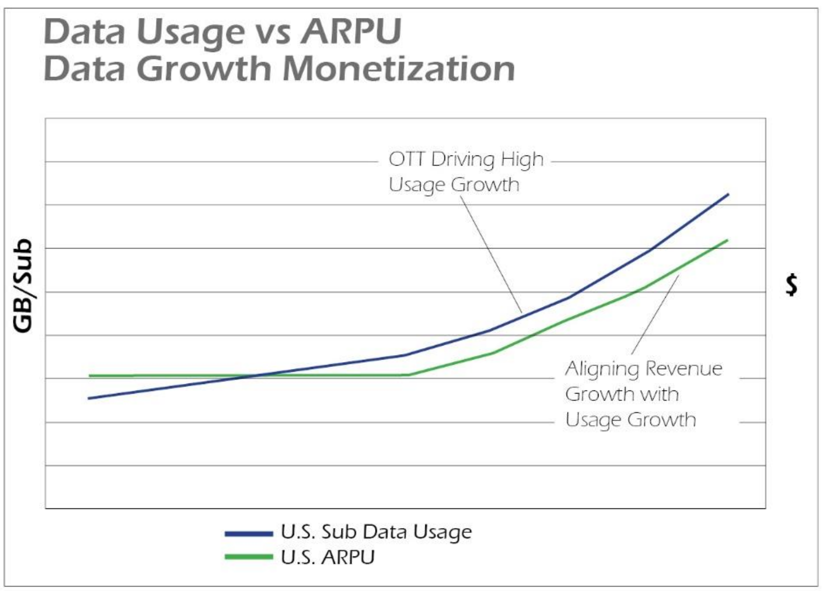
OTT usage projections should align with data capacity as a resource allocation.



Source: eMarketer (2011)

For more information on this dynamic, please refer to analysis of consumer viewership behavior for native content, i.e. content which is only available via a Cable Service Provider's Customized User Interface, offered by so called "recommendation engines" that are resident in Cable Set Top Boxes or Cloud based Interactive User Guides, or accessible via optimized "Walled Gardens" wherein only revenue generating content is served and accessible via the User Interface, increasing revenue and improving ROI for the CMTS and QAM investment. In published or otherwise publicly available data, an increase of 30% or more has been reported for video content viewership and related advertising revenue for content views which are "served" by the recommendation engine via the native User Interface or Guide. [PARKS]

As a general rule, data usage should track ARPU closely as shown below. Unless specifically segmented, current data channel planning and usage profiles do not correlate with ARPU at least as it relates to content viewership and fees. This basic principle should be considered in any future architecture and frequency plan implementation.



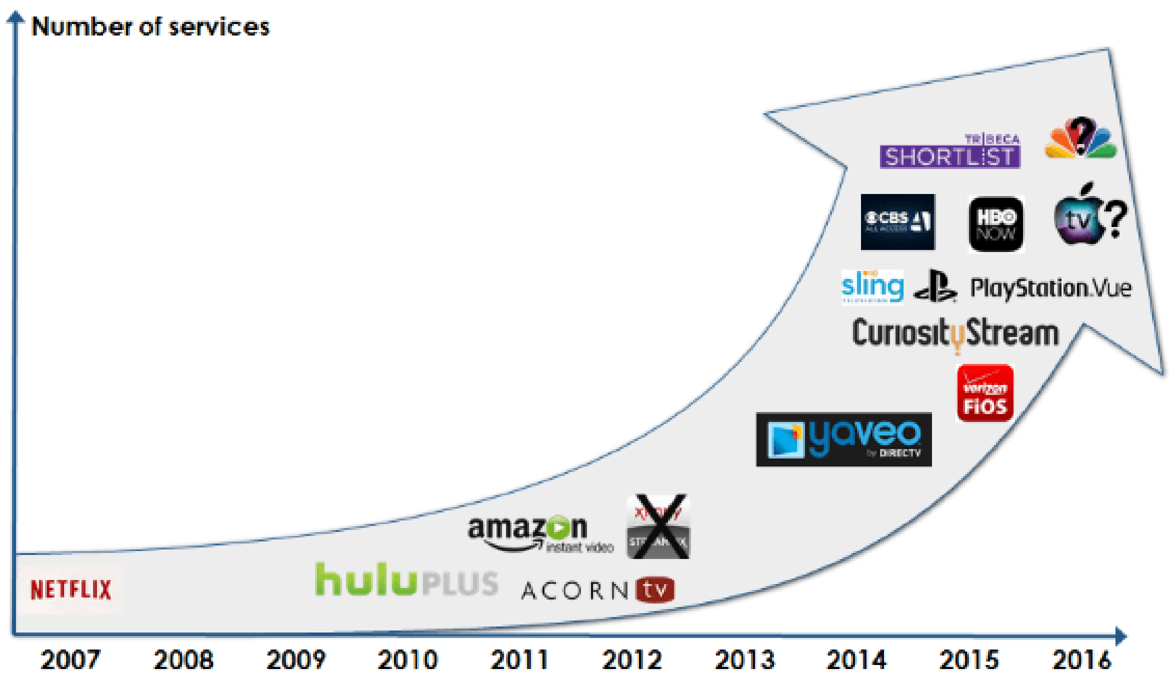
Source: Open Vault (2011)

Aligning ARPU with Data usage requires a differentiated resource allocation, segmenting OTT non-revenue generating usage to Carrier class services

Given these economic fundamentals, the proper basis for evaluating incremental throughput as an investment in data capacity as a revenue generating resource, and considering that OTT usage does not correlate with ARPU, the proper cost per incremental bit rate should be as near $0 as possible.

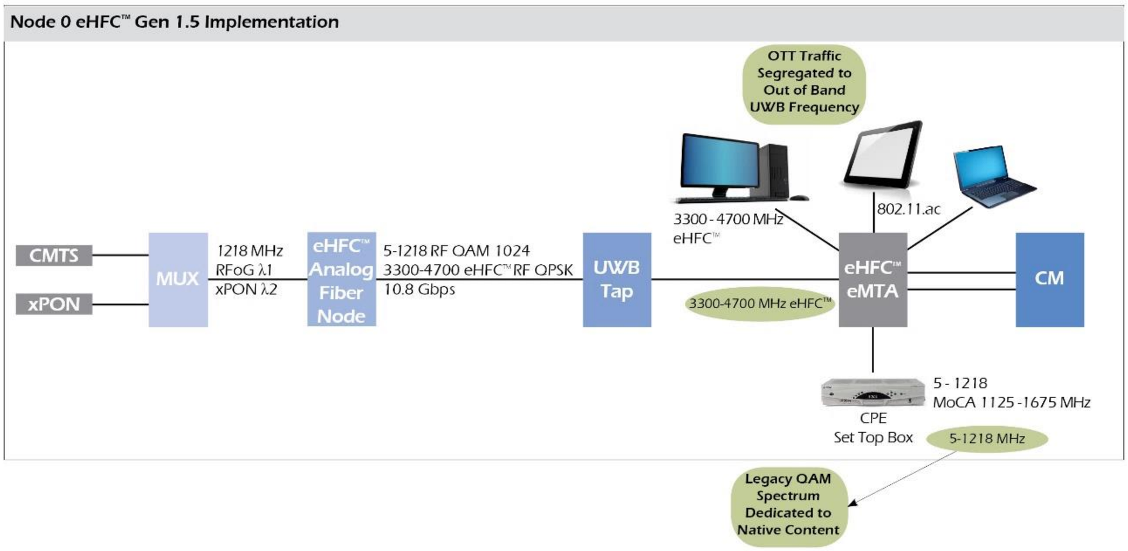
While it is often said that “data is data”, considering this distinction, all data is not the same, and its capacity allocation should be driven by its highest yield of potential revenue relative to both its relative cost per bit rate as well as the devices and services within the network which are optimized for monetizing the data.

Because eHFC implementation provides a very high return on throughput relative to the investment in network infrastructure, a cost of $.027 per incremental Mbps per Subscriber relative to the baseline DOCSIS 3.0 implementation is achieved for the most economical Brownfield migration model. Considering the current market environment wherein data rate value cannot be fully realized based on actual demand, nevertheless, data consumers still insist on highly competitive and high performing networks, an eHFC implementation can be validated in a variety of circumstances.

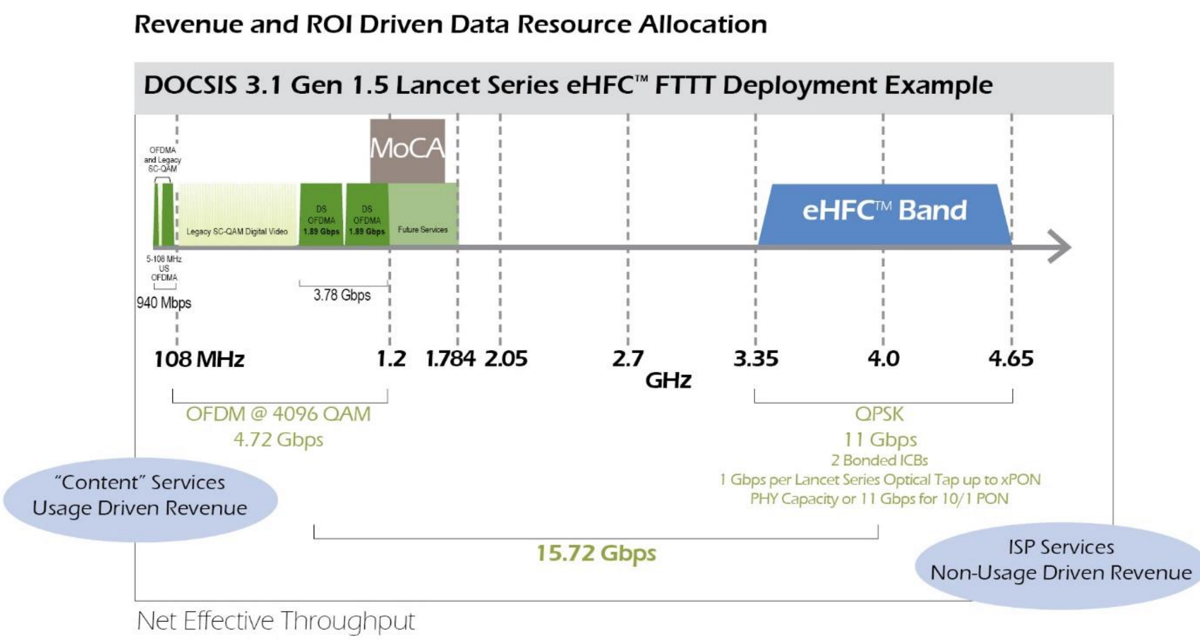


Source: Ooyala (2012)

OTT market competitors driving data pressure for "Carrier" services.



eHFC UWB Spectrum data service segregation



Revenue and ROI driven Resource allocation. *$.027 per Incremental Mbps per Subscriber PHY investment reserved for non-specific revenue generating Carrier/ISP type services. QAM capacity reserved for native revenue generating content accessible exclusively through monetized UIs, search engines and interactive Cable Service Provider platform.*

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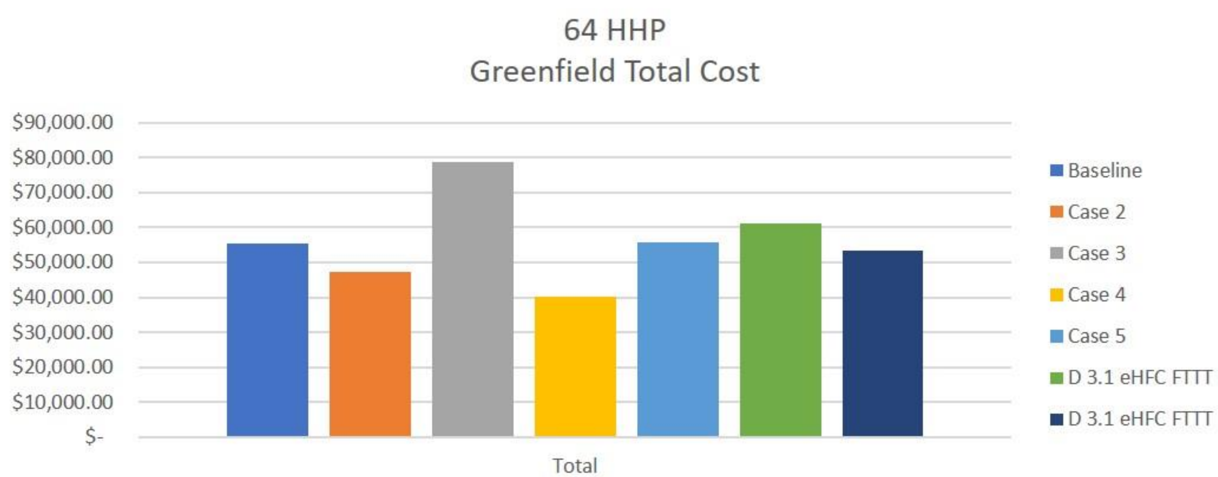
13. Summary

Following is a cost comparison Summary for all evaluated Use Cases, including Brownfield migration options:

Lancet FTTT eHFC implementations are representd in Use Cases 6,7, 9 & 9A. Brownfield migration implmentatuions have been added for compartison and consider starting from the baseline FTTLA imnplementation scenario.

Greenfield					
Total for 64HHP deployment or equivalent SG by Network Segment					
	Facility	OSP/ODN	Drop	Premise	
Baseline	$ 31,920.00	$ 9,741.93	$ 7,200.00	$ 6,400.00	$ 55,261.93
Case 2	$ 22,344.00	$ 9,741.93	$ 7,200.00	$ 8,000.00	$ 47,285.93
Case 3	$ 53,626.00	$ 9,741.93	$ 7,200.00	$ 8,000.00	$ 78,567.93
Case 4	$ 11,172.00	$ 13,741.93	$ 7,200.00	$ 8,000.00	$ 40,113.93
Case 5	$ 26,813.00	$ 13,741.93	$ 7,200.00	$ 8,000.00	$ 55,754.93
D 3.1 eHFC FTTT	$ 25,344.00	$ 14,275.26	$ 7,200.00	$ 14,400.00	$ 61,219.26
D 3.1 eHFC FTTT Oportunity Driven	$ 25,344.00	$ 11,556.46	$ 7,200.00	$ 9,280.00	$ 53,380.46
D 3.0 eHFC FTTT	$ 5,000.00	$ 4,533.33	$ -	$ 6,400.00	N/A
D 3.0 eHFC FTTT Opportunity Driven	$ 5,000.00	$ 1,814.53	$ -	$ 2,560.00	N/A



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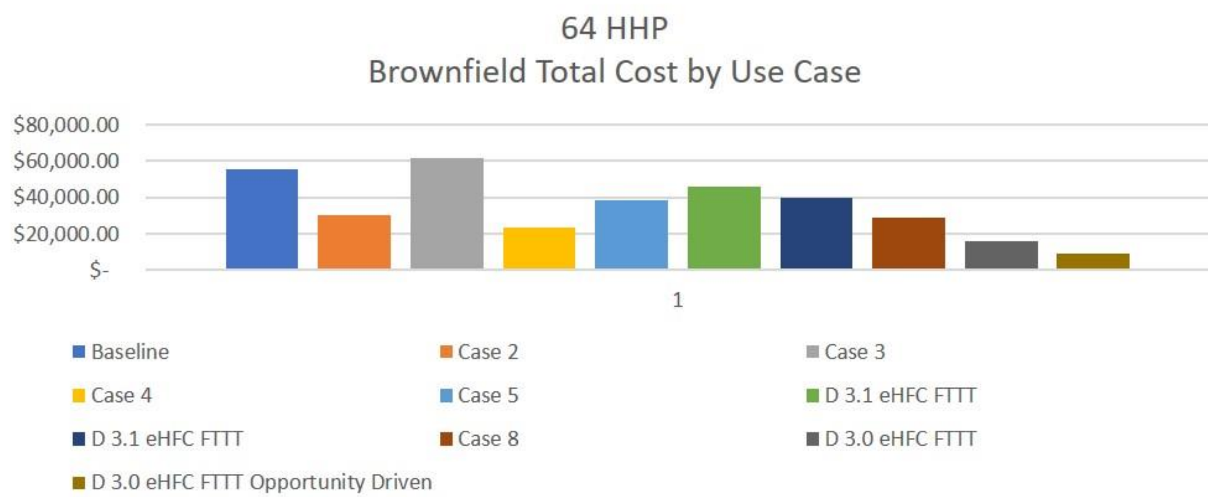
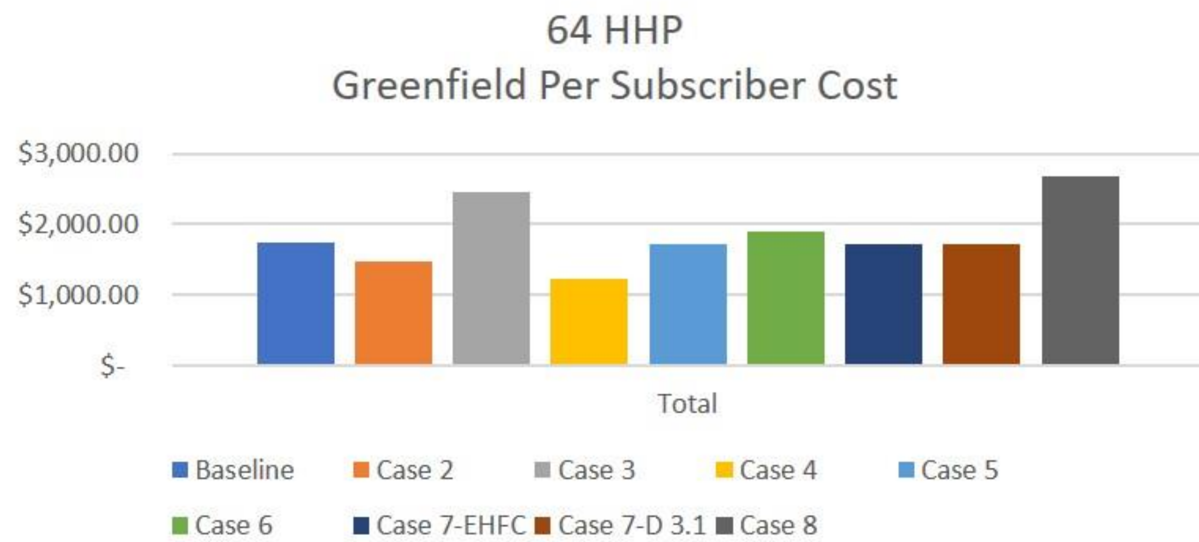
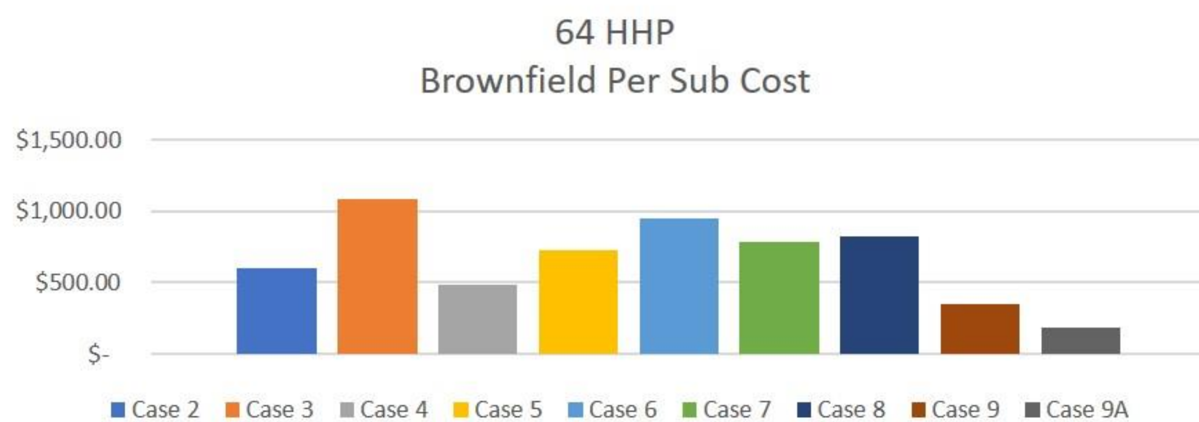
Brownfield					
Total for 64HHP deployment or equivalent SG by Network Segment					
	Facility	OSP/ODN	Drop	Premise	Total
Baseline	$ 31,920.00	$ 9,741.93	$ 7,200.00	$ 6,400.00	$ 55,261.93
Case 2	$ 22,344.00			$ 8,000.00	$ 30,344.00
Case 3	$ 53,626.00			$ 8,000.00	$ 61,626.00
Case 4	$ 11,172.00	$ 4,000.00		$ 8,000.00	$ 23,172.00
Case 5	$ 26,813.00	$ 4,000.00		$ 8,000.00	$ 38,813.00
D 3.1 eHFC FTTT	$ 27,344.00	$ 4,533.00		$ 14,400.00	$ 46,277.00
D 3.1 eHFC FTTT Oportunity Driven	$ 27,344.00	$ 1,814.53		$ 10,560.00	$ 39,718.53
Case 8	$ 5,000.00	$ -	$ 16,800.00	$ 7,200.00	$ 29,000.00
D 3.0 eHFC FTTT	$ 5,000.00	$ 4,533.00		$ 6,400.00	$ 15,933.00
D 3.0 eHFC FTTT Opportunity Driven	$ 5,000.00	$ 1,814.53		$ 2,560.00	$ 9,374.53







A comparison based on cost and relative throughput gains of the investment suggest the Lancet eHFC FTTT implementation are the lowest cost per bit rate options among all scenarios evaluated, with the lowest cost implementation being a Brownfield migration to Lancet Series eHFC from the baseline DOCSIS 3.0 FTTLA scenario.The eHFC FTTT implementations also resulted in the largest total PHY per aggregate xPON and DOCSIS bonding group, providing the most longevity of the network relative to future demand.

The Summary adds more realistic and economically accurate cost considerations for Brownfield upgrades of existing infrastructure.

The relative advantages of cost versus throughput are more pronounced for these Brownfield scenarios due to the eHFC platform's ability to leverage current coaxial and DOCSIS components and infrastructure. While this result is more accurate from an economic perspective alone, it does not consider the various other factors involved in upgrading the DOCSIS standard, coaxial infrastructure and RF components which are not considered in the evaluation.

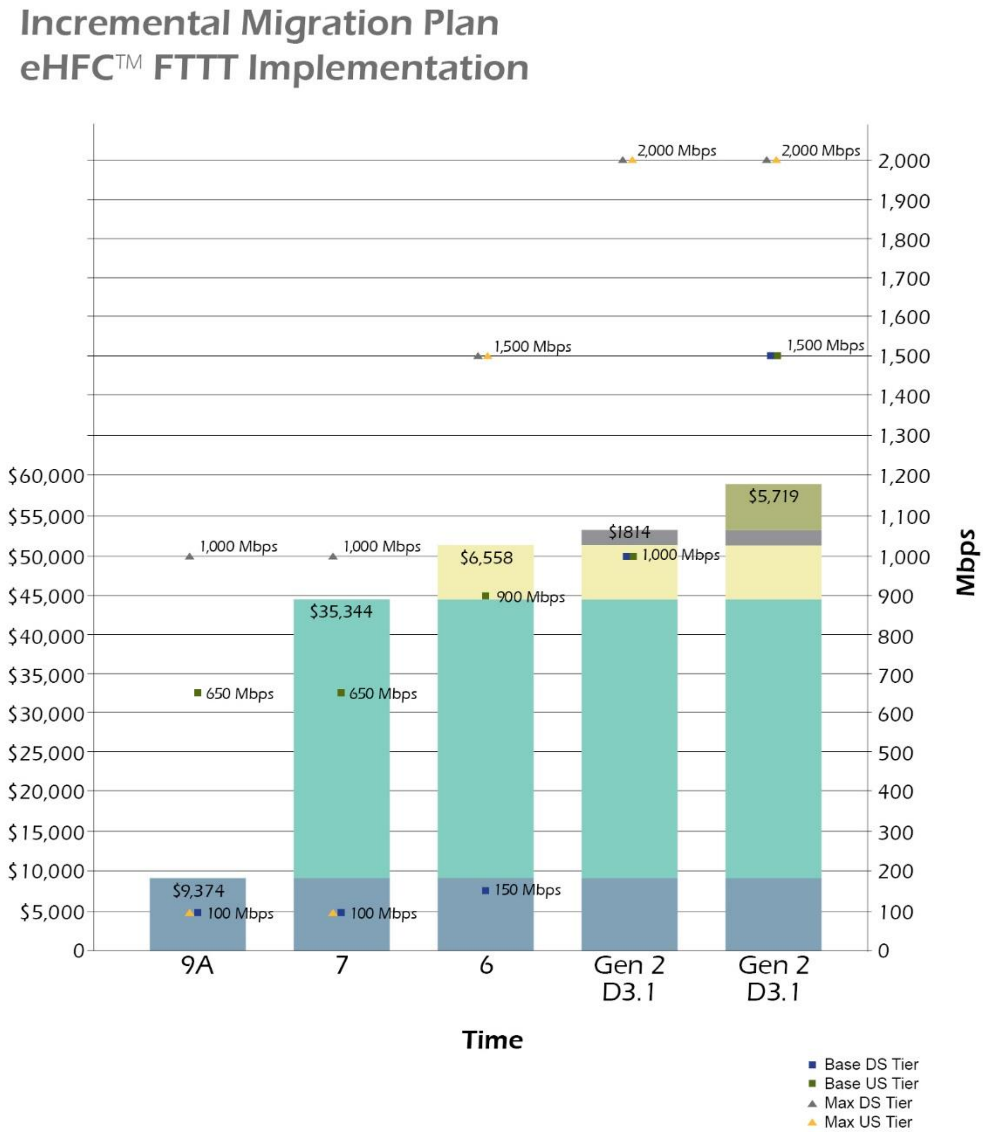
For all scenarios, however, the Brownfield migrations also more accurately reflect the investment required in new equipment which is not fully backwards compatible. For DOCSIS 3.1 migration scenarios, it is important to consider that while CMTS upgrades are required, the standard is backwards compatible with D 3.0 and a cable service provider will likely maintain data subscribers on the 3.0 standard while migrating all future expenditures to D 3.1 either on an as needed basis, or uniformly as part of a long term migration strategy that includes operating both the D 3.0 and 3.1 standard in parallel. These approaches will vary widely by demograhic or market areas. This consideration as well as many other implementation scenarios will affect the initial investment and may be important, but it should not affect the basic results of the Use Case evaluation as far as relative cost versus incremental throughput.

Evaluated strictly on a cost per bit rate basis as well as the ability to leverage existing RF and DOCSIS infrastructure, the summary and comparison suggest the following migration and implementation roadmap, with the following additional considerations not explicitly evident in a purely economic evaluation based on lowest to highest cost per incremental bit rate. For example, while the DOCSIS 3.0 Brownfield migration to eHFC FTTT might be the lowest initial cost, it would not provide the future efficiencies available in a DOCSIS 3.1 implementation. In such a scenario any advantages of leveraging the higher order QAM modulation of the D 3.1 standard would not be possible. As such, the migration plan below considers first migrating to the eHFC FTTT platform with a D 3.0 CMTS Brownfield scenario channel bonding frequency plan, and targeting only a portion of existing subscribers for the revised HSD Max Tier at a take rate of 40%. The subsequent migration plan considers an upgrade to the D 3.1 standard but keeping the achieved penetration rate of 40% and targeted eHFC implementation described in Use Case 7. The subsequent migration considers a 100% penetration of eHFC D 3.1 Data services for the entire SG, as well as future evolution to the eHFC Gen 2 platform, eventually enabling delivery of symmetrical multi Gigabt services to all subscribers in the SG at a contention rate of 50%, by adding OLT capacity over time and as needed to leverage the full potential 4 Gbps TDMA performance of the eHFC Gen 2 band as well as higher order DOCSIS modulation. Beyond this stage, more data capacity would be acheivable either by adding additional OLT capacity or by extending the D 3.1 Frequency plan and QAM Bonding Group size.

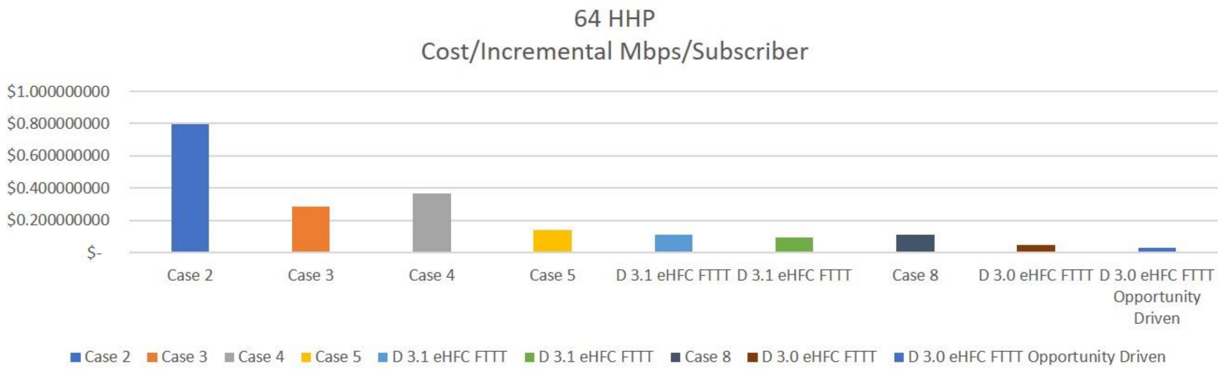
Incremental Migratiuon Path Progression Over Time:

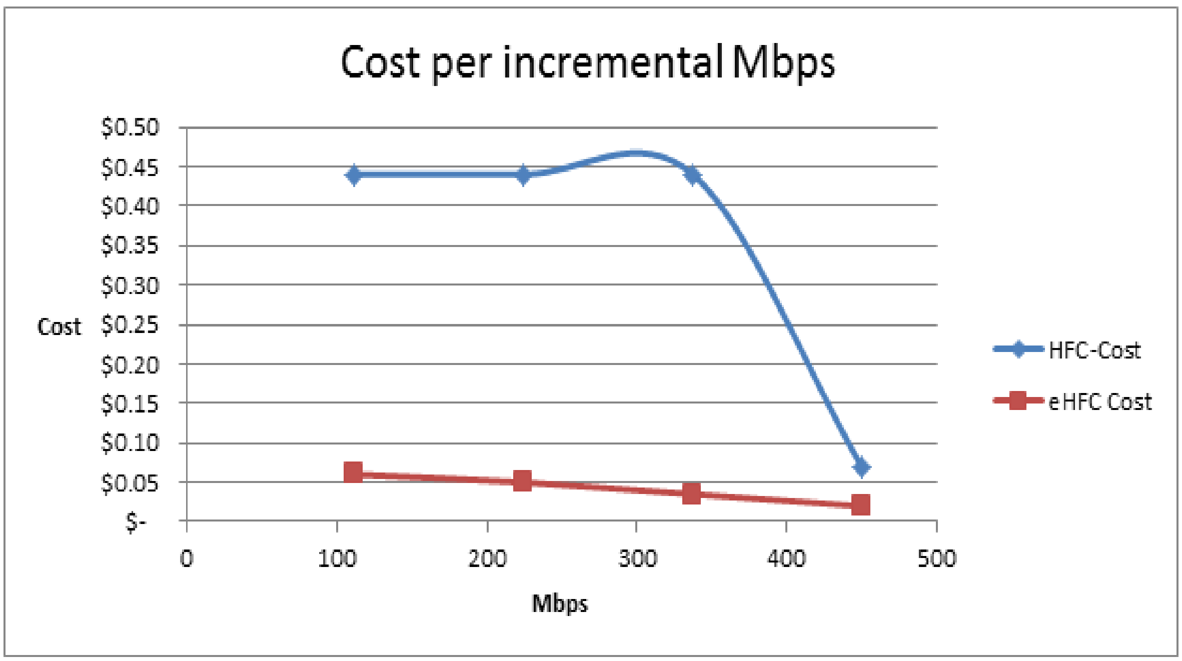
Baseline FTTLA –

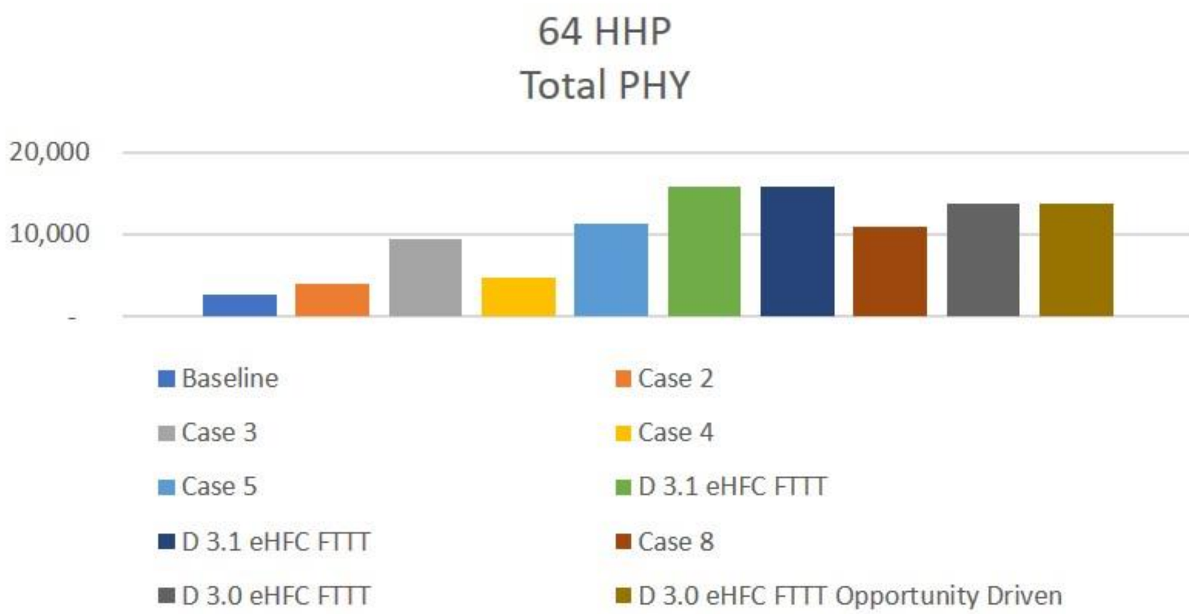
- *- Case 9A Opportunity Driven eHFC implementation with DOCSIS 3.0 baseline bonding group*
  - *- Case 7 DOCSIS 3.1 implementation of Opportunity Driven eHFC FTTT*
    - *– Case 6 Full Scale Deployment of eHFC FTTT with Baseline DOCSIS 3.1 Bonding Group*
      - *– Opportunity Driven Migration to eHFC Gen 2 implementation of Baseline DOCSIS 3.1 Bonding Group*
        - *– Full Scale Deployment of eHFC Gen 2 implementation of Baseline DOCSIS 3.1 Bonding group*
          - *Scale xPON OLT for Symmetrical Gbps Service Delivery to all Subscribers*
            - *– Future spectrum allocation via DOCSIS 3.1 plan expansion*



Imcremental Migration Plan – achieving 100% penetration of Symmetrical Gigabit HSD Services over Time


64 HHP
Cost/Incremental Mbps/Subscriber
$1.000000000
$0.800000000
$0.600000000
$0.400000000
$0.200000000
$-
Case 2
Case 3
Case 4
Case 5
D 3.1 eHFC FTTT
D 3.1 eHFC FTTT
Case 8
D 3.0 eHFC FTTT
D 3.0 eHFC FTTT Opportunity Driven
Case 2 Case 3 Case 4 Case 5 D 3.1 eHFC FTTT D 3.1 eHFC FTTT Case 8 D 3.0 eHFC FTTT D 3.0 eHFC FTTT Opportunity Driven


Cost per incremental Mbps
$0.50
$0.45
$0.40
$0.35
$0.30
Cost
$0.25
$0.20
$0.15
$0.10
$0.05
$-
0
100
200
300
400
500
Mbps
HFC-Cost
eHFC Cost



64 HHP
Total PHY
20,000
10,000
-
Baseline
Case 2
Case 3
Case 4
Case 5
D 3.1 eHFC FTTT
D 3.1 eHFC FTTT
Case 8
D 3.0 eHFC FTTT
D 3.0 eHFC FTTT Opportunity Driven

14. *Conclusion:*

Today's technology landscape provides many options for Cable Service Providers to choose from as they determine the most viable path forward. As Cable Service Providers evaluate these various options, an "All of the Above" strategy wherein differentiated approaches can be brought to bear on differentiated applications and unique challenges is the most versatile, viable and likely approach to solving these challenges. A Lancet Series FTTT as part of the general mix of solutions is only one of these various options.

As a general long term approach for expanding the capacity of RF transmission networks and legacy coaxial infrastructure via DOCSIS, Lancet Series eHFC Optical Taps, implemented either as a unified approach to service large service areas or as a more surgical approach to solving challenges of FTTLA Network reach and aggregate throughput relative to cost of deployment, provides a pathway for Cable Service Providers to envision and realize output from high frequency wide band spectrum previously unavailable. As the physical plant and cable media are relied on to support increased throughput, lower order modulation schemes such as PSK provide a solution to realizing the potential of the physical plant while alleviating SNR requirements. Simply expanding the DOCSIS frequency range without modifying the modulation order or data channel spectrum will result in diminishing returns or prohibitive costs of subscriber activation in the very near future due to the sophistication of the technology required to get more and more out of a limited frequency range. Near passive architectures such as FTTT and FTTLA should both be considered in the context of their respective deployment criteria, including but not necessarily limited to:

- System reach, Service Group densities and topography
- Current and future throughput needs relative to economics and subscriber demographics
- Network architecture and transmission platform's adaptability to future solutions
- Opex and Capex performance relative to potential revenue streams and ROI
- The cost of incremental bit rate performance relative to market value of services and data intensive applications, services and content

The inherent cost benefits of xPON in the facility and ODN relative to DOCSIS deployment, as well as the out of band characteristics of eHFC, can be compelling in many deployment scenarios, but should be weighed relative to interoperability with other platforms being considered in this varied landscape of technology and architectural options.

It will be important also to more accurately plan for expected demand in a market environment that does not value data speeds commensurately with the incremental cost of delivering HSD as a core service which is widely available. In other words, while consumers demand higher speeds, they are not always, or rarely, willing to pay for those services on a relative basis as compared with data speeds which are widely available and serviceable via today's architectures.

The more flexible the system architecture, the more gradual the approach that can be taken as demand becomes validated in the coming years. Ideally, then, an architecture which is capable of sustaining the higher throughput requirements of the next several decades would be an appropriate investment over time. However, the high cost of connecting every subscriber to the network ideally could be more measured as opportunity and the market at large becomes receptive. A hybrid xPON/DOCSIS FTTT/FTTN architecture, such as the eHFC lancet Tap enables, could be an ideal avenue for achieving these goals. In the coming years, as demand for throughput increases, FTTT architectures will become more viable due to their highly passive nature and ability to carry the throughput future services will demand. However, Cable Service providers can migrate to that eventuality gradually while leveraging existing HFC architectures and DOCSIS infrastructure as they grow.

This is an important consideration as one evaluates the likelihood of consumer behaviors changing as current data intensive applications become more mainstream, or new applications become available and drive demand in an economically meaningful way.

As the content landscape becomes more unified, absorbing a larger number of competitors vying for data capacity, it will also become important to differentiate data delivery methods based on service type such as Interactive, VOD and a variety of other services which are available to Cable Service providers as they explore the possibilities of data services whose **revenue scales with usage such as *content, as opposed to ISP or flat rate revenue streams.***

Of course, a simple conclusion would be to implement solutions which cost no more than the markets value the services they provide. Achieving a minimal cost for incremental bit rate performance is an important metric, and perhaps the most important measure, but not the only one in determining the appropriate solution for a given application.

Future network planning criteria should consider all of these factors in determining the best differentiated approach to migration towards the future of Hybrid Networks.

15. Explanation of terms/Glossary

CMTS – Cable Modem Termination System

ODN – Optical Distribution Network, used to describe the Access Network in PON Architectures

OSP – Outside Plant Network, used to describe the Access Network portion in HFC Architectures

HFC – Hybrid Fiber Coaxial

Node Zero – An HFC Network architecture which has only a single active per service group, and 0 active devices downstream of the central access fiber node

Fiber Deep – An HFC Architecture where the optical cable construction reaches deep into the network and nearer the subscriber premise.

Near Passive Architecture – Architectures which have a very limited or minimal number of active components downstream of the Optical Access Node, such as Node 0 and Fiber Deep, but more than PON Networks

xPON, any and all Passive Optical IP Network Protocols, a generic term for expressing a PON network, without specifying the specific transport methodology or standard, including but not limited to IEEE EPON and ITU GPON, Peer to Peer Ethernet (P2P) and GigE (Gigabit Ethernet)

GPON – ITU PON Optical IP Network Transport Standard

EPON – IEEE PON Optical IP Network Transport Standard

DOCSIS – Data Over Cable System Interface Standard

DOCSIS 3.1 – Introduced in 2014, The latest standard introduced included several enhancements, including OFDM and QAM Modulation orders above 256 QAM.

DOCSIS 3.0 – DOCSIS standard which introduced Channel bonding, capable of up to 256 QAM,

FTTLA – Fiber To The Last Active

FTTLP – Fiber To The Last Passive

FTTT – Fiber To The Tap

FTTP – Fiber To The Premise

Node N – An HFC Architecture requiring N number of active components downstream of the central access fiber node. N signifies the number of active components in a given implementation which are located downstream of the Central Access Node.

WDM – Wave Division Multiplexing

CWDM – Coarse Wave Division Multiplexing

DWDM – Dense Wave Division Multiplexing

Remote PHY – Technology Architecture where QAM Channels are generated at the Access Node and not within the Central Facility or Headend. A portion of the Physical Layer resides in the Access Network and not in the Central Facility as with legacy approaches.

RPHY – Remote PHY

Full Duplex DOCSIS 3.1 – Standard enhancement which introduces Full Duplex (Time and Frequency Domain) allowing a maximum theoretical data rate of 10 Gbps Upstream and 10 Gbps Downstream, applicable only in Node 0 architectures.

FDX – Full Duplex DOCSIS 3.1

OFDM – Orthogonal Frequency Division Multiplexing.

SNR – Signal to Noise Ratio

MER – Modulation Error Ratio

BER – Bit Error Rate or Ratio

QAM – Quadrature Amplitude Modulation

Contention – The number of Data subscriber simultaneously engaging in data transfers on a given network, expressed as a percentage of the total number of subscribers vying for data capacity simultaneously.

Penetration – The number of cable subscribers as a percentage of the total number of Homes Passed or potentially serviced by the data network

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16. References and Suggested Reading:

[ESDCLO] Tom Cloonan “USING DOCSIS TO MEET THE LARGER BW DEMAND OF THE 2020 DECADE AND BEYOND “ - “Extended Spectrum DOCSIS” 2016

[EM] Michael Emmendorfer “An Economic Analysis of Brownfield Migration CTTH vs FTTH”, 2016

[FDX] John Chapman “Full Duplex DOCSIS”, Cisco

[SANT] John Santhoff, “Ultra Wide-Band - C Wave”

[DCL] Dave Sinclair “DOCSIS What’s Next” SCTE

“US LESSONS LEARNED: OTT, DATA USAGE GROWTH & MENETIZATION RESULTS” Open Vault, 2016

John Barrett, “Segmentation: VOD & OTT Usage”, Consumer Analytics 2015

Alex Vukovic, “Performance Characterization of PON Technologies”, 2007

[FCC] “United States Frequency Allocations”, Measuring Broadband America

Galen Koepke, “NIST Technical Note 1885 “, NIST

[SD]SCTE San Diego D 3.1

[CLORPHY] – Tom Cloonan, “Moving On Up: Remote PHY..”, 2016

[SCTE] “SCTE Standard 235 2017”, Operational Practice for the Coexistence of DOCSIS 3.1 Signals and MoCA Signals in the Home Environment, 2017

John Ulm, “Future Directions for Fiber Deep HFC Deployments”, Arris, 2010

[RCRG] FTTLA Implementation modeling by Rich Gregory and Robert Crowe, Antronix, Inc.

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