NEXT GENERATION - GIGABIT COAXIAL ACCESS NETWORK

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Abstract

The media and telecommunications industry is entering a decade of rapid change. The change will be driven from consumers and competition. The consumers of the next decade will likely be those whom have a desire to have any content made available anytime, anywhere and to any device. The programmers and telecommunication providers are planning how to meet this challenge. Consumers are not just recipients of content they have increasingly become creators and/or distributors of content. We have seen in the last decade the use of peer-to-peer (P2P) and the sudden increase of YouTube and social networking, this has driven how telecommunication providers, like cable operators have become not only content distributors to the home but also increasing "from" the home. A key challenge the cable industry may face in the future is the transition from a largely broadcast service delivery network to a rapidly growing unicast delivery network. This paper is a forward looking study which will examine alternative architectures for the cable industry to address new competitive threats posed by fiber to the premise (FTTP) providers. The paper will examine the business and bandwidth drivers of the coming decade and predict the transition of the cable delivery network to accommodate the future of more unicast video and data services. As the cable industry examines next generation access architectures such as RFoG and EPON for new build residential and commercial deployments, this paper will focus entirely on leveraging their most valuable network asset, the existing coaxial network to the home. This study examines strategies to meet the demands utilizing IP based network technology to and "from" the home. This Next Generation – Gigabit Coaxial Access Network may eventually be capable of delivering multi-gigabit IP services to the home while defining architectures to enable 1 Gbps from the home, all while leveraging the coaxial network to the home.

INTRODUCTION

The study of the Next Generation – Gigabit Coaxial Access Network or simply Gigabit Coax Network (GCN) is an attempt to examine the drivers and possibilities of the coming decade and how the cable network may evolve to support a multi-gigabit IP network to the home while defining architectures to enable 1 Gbps from the home, all while leveraging the coaxial network to the home. The paper is an initial assessment meant to inform members of the cable technical community of some of the network migration drivers and options. This paper is also intended to spark research and debate within the industry surrounding requirements and possible solutions. The paper will document the transition drivers and trends as well as predictions of how the cable delivery network may evolve to support higher IP based services to and from the home with an emphasis to consider an architecture which may support 1 Gbps symmetrical services. The cable industry seems to be entering a period of unprecedented transition. This transition will have two key threads, 1) the transition to a unicast service delivery platform (service personalization) and 2) the increased spectrum and bandwidth allocation for IP as the delivery technology. The future is always difficult to predict and especially in the area of technology. The demands of the end consumers and the value of the service will also remain a challenge to forecast. We can examine trends from the past which may help shape and guide our predictions of the future; this paper will examine these business drivers. The cable network is incredibly flexible allowing the operators to select migration paths to expand capacity where and when needed, the current approaches are reviewed in this document. The paper examines a key area called upstream augmentation which will serve as the building block for the cable network to expand capacity in the upstream.

BUSINESS DRIVERS

It may be hard to imagine another time in cable's history where the competitive landscape was so fierce. The competition has expanded from DBS providers to Telecos offering triple play services to recently competitive threats from Over The Top (OTT) providers such as Hulu and Netflix. It is important to understand some of the key business drivers which we may face in the future as these will serve as guide for network planning. These drivers as stated above will come from consumers and competitive threats. It remains uncertain which path the MSO may take to meet the consumer's insatiable demand for unicast and personalization of video content or to the degree they will address the competitive threats. We know that the usage of the high speed data network and the allocation of spectrum to support this service will continue to increase. The future delivery of video services may evolve as operators examine the viability of using IP based network technology for the distribution of their video services to consumers. We need to examine these business drivers listed below and others to guide the strategy and planning for the future of the cable network. The cable network end to end is well positioned to meet the demands of the future and leveraging the existing coax to support the transition to greater IP based bandwidth to and from the home is a compelling advantage the cable industry has over alternative technologies.

Internet Bandwidth Trends

As illustrated in the figures below the consumption curve may have began with email, web browsing and newspaper like illustration on user PCs. This evolved to a magazine experience and use of short video clips. Perhaps midway through the decade the network was used for digital music distribution, gaming and P2P. We may have ended the decade with what may become the biggest drivers of internet growth, OTT providers of video and social networking. This next era will see an increase in the usage of full movie downloads from the internet to the home; this will increase the downstream bandwidth as was as upstream bandwidth. Figures 1 and 2 provide illustrations of the Internet bandwidth trends.

In addition to consumption rising as illustrated in the figures above, a key contributor to overall bandwidth drivers is the maximum service tier offered to consumers. The figure below shows a 25 year history of the max bandwidth offered or available to consumers. This figure also attempts to predict the max service tier we may see in the future if the growth trend aligns with the preceding 25 years. The maximum service tier plays a significant role in the application developed. It would be fair to assume that some of the most recent application such as over the top video was a result of increase in the higher data speeds offered to consumers.[1]

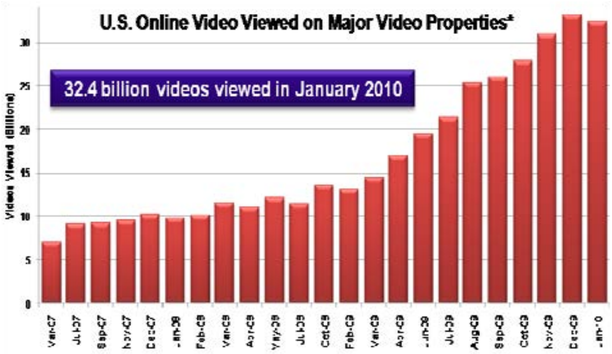


Figure 1— On-line Monthly Video Viewing

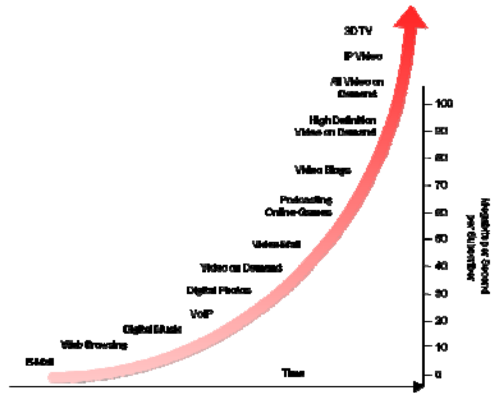


Figure 2—Megabits per Second per Subscriber

Sources: comScore and Internal ARRIS Research

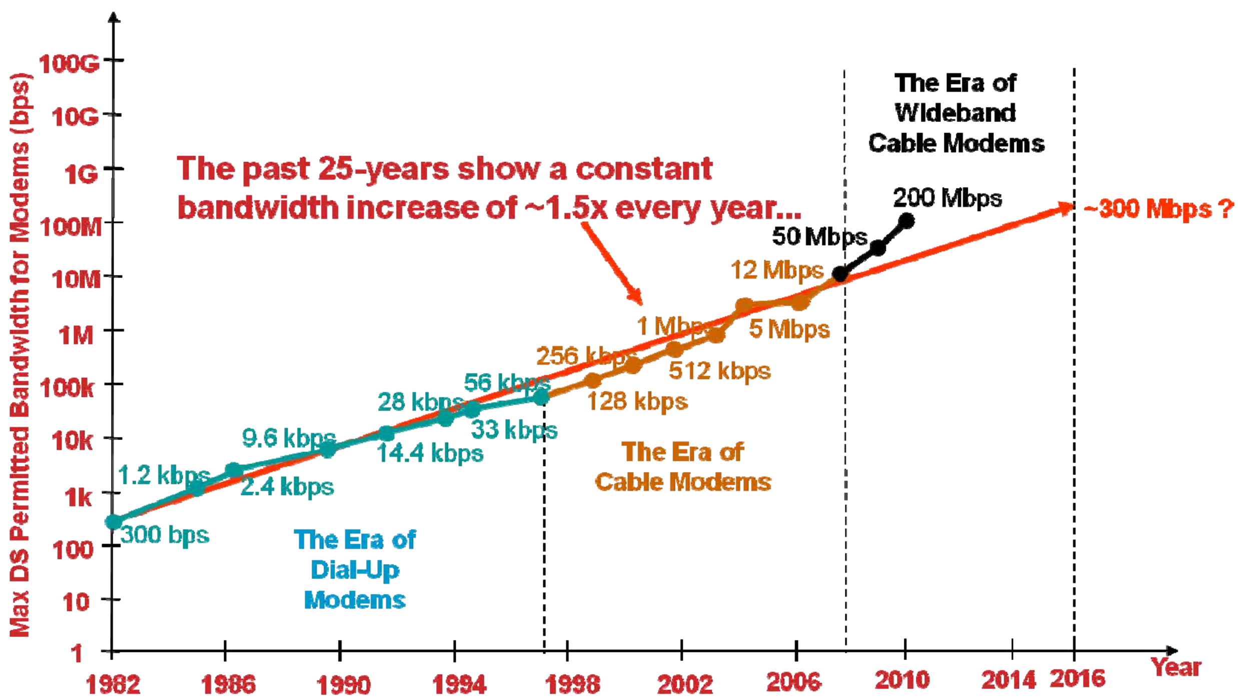


Figure 3—Trends & Predictions of Maximum Offered Modem Bandwidths

Downstream Spectrum

The expansion of downstream spectrum over the last 60 years provides cable a high capacity network to the home. The figure below is an illustration of cable's investment in expanding the downstream network capabilities to meet the service demands of the consumer, where today some systems may have as much as 6 Gbps (assuming a 1 GHz system) of forward capacity. This investment will help the MSO transition from a largely broadcast provider to a high bit rate unicast provider to the home.

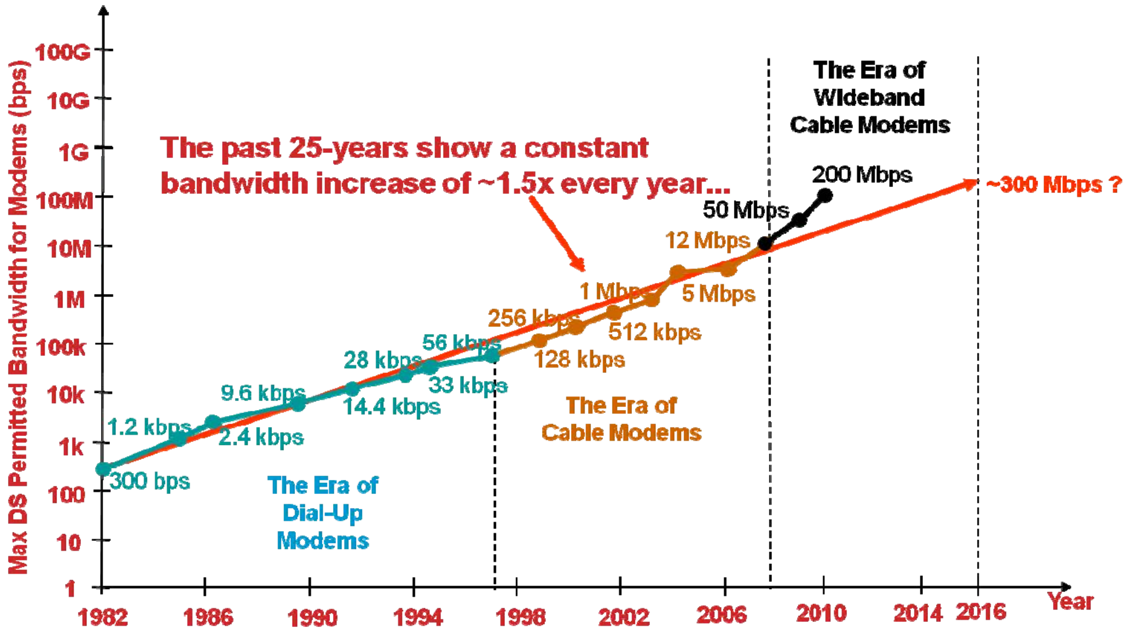


Figure 4—Cable Network Downstream Spectrum Expansion

Downstream Bandwidth Predictions "A Network in Transition"

The amount of spectrum allocated for services will evolve from an entirely broadcast allocation providing analog TV and digital TV distribution network to a more unicast network supporting services like high speed date, telephone, and video on demand. To efficiently offer these unicast services MSOs use a technique called narrowcast whereby the same spectrum allocation may be reused throughout a system because the distribution of these signals is targeted to a predefined service area. The use of narrowcast services allows the MSO to reuse spectrum in a given market. The figures below illustrate the spectrum allocation in the year 2010 and an estimate for year 2015 for the broadcast and narrowcast/unicast services and the number of 6 MHz channels which may be allocated. These figures clearly illustrate the transition the MSOs may make to support the need for greater and greater narrowcast/unicast service. In perhaps as many as five years the MSO transformation may moved from a largely broadcast content distributor to largely a unicast content distributor. The transition of the downstream bandwidth enables the MSO to offer consumers far more personalized services.

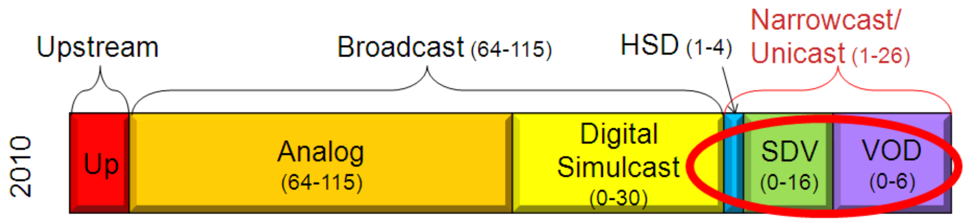


Figure 5

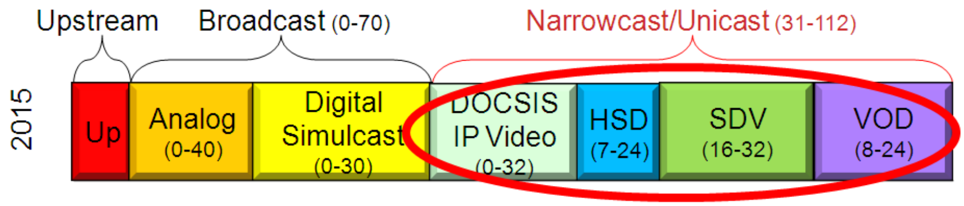


Figure 6—Downstream Bandwidth Predictions

Figure 7 illustrates the spectrum allocation projected in 2010 and 2015 for the combined HSD and DOCSIS IP Video services in the form of megabits per second (mbps). The graph captures the low and high estimates for each year. The high-end allocation of spectrum and bandwidth suggests that cable may allocate over 2 Gbps of downstream capacity for IP based services and technology in the coming decade.

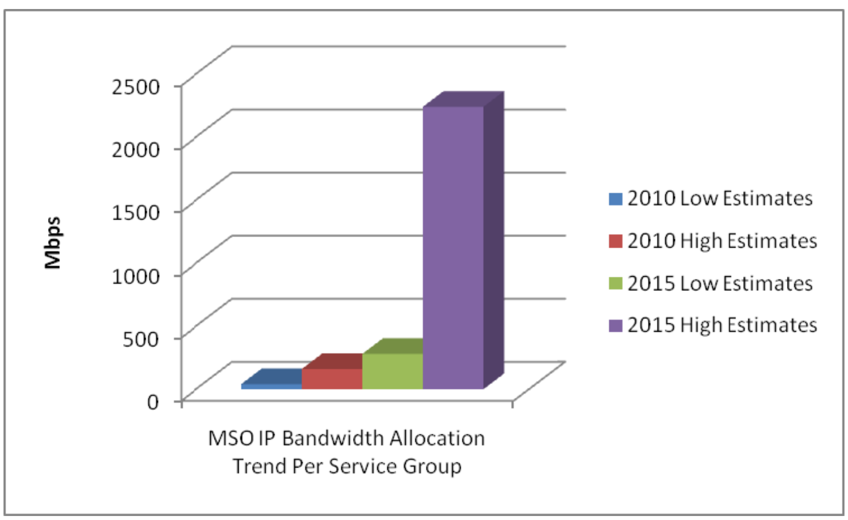


Figure 7—IP Based Bandwidth Supporting HSD and DOCSIS IP Video Predictions

The diagram below suggests the greatest network transition in the MSOs history from a broadcast content delivery network to the home to nearly an entire unicast content delivery network. This transition which began many years ago with the introduction of HSD and VoD services enables the cable operator to continue to expand their service offering incrementally and through targeted capital investment where and when needed. The consumer's ability to obtain any content, anytime, from anywhere and to any device will be fulfilled during this transition. MSOs are well positioned to enable these future services and capabilities. This figure captures the possibilities an MSO may consider for the next decade and the allocation of their

spectrum for more and more unicast services.

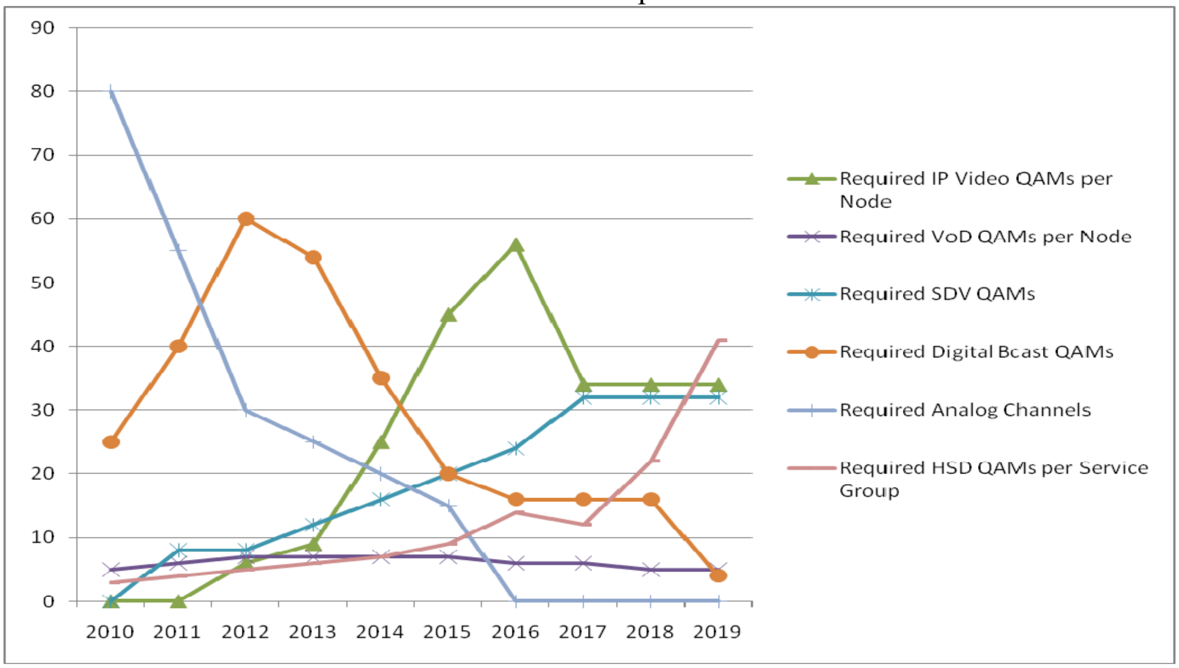


Figure 8—A Network in Transition

Upstream Spectrum

The upstream may also see a transition in the coming decade to accommodate the increase in consumer network usage and the transition of the downstream to more IP/DOCSIS channels. As seen in figure 4 the downstream spectrum allocation has increased steadily over the last 60 years. The upstream, however, has largely been untouched. This is primarily because the current 5-42 MHz spectrum allocation (U.S.) remains lightly loaded and has much as 150 Mbps of capacity.

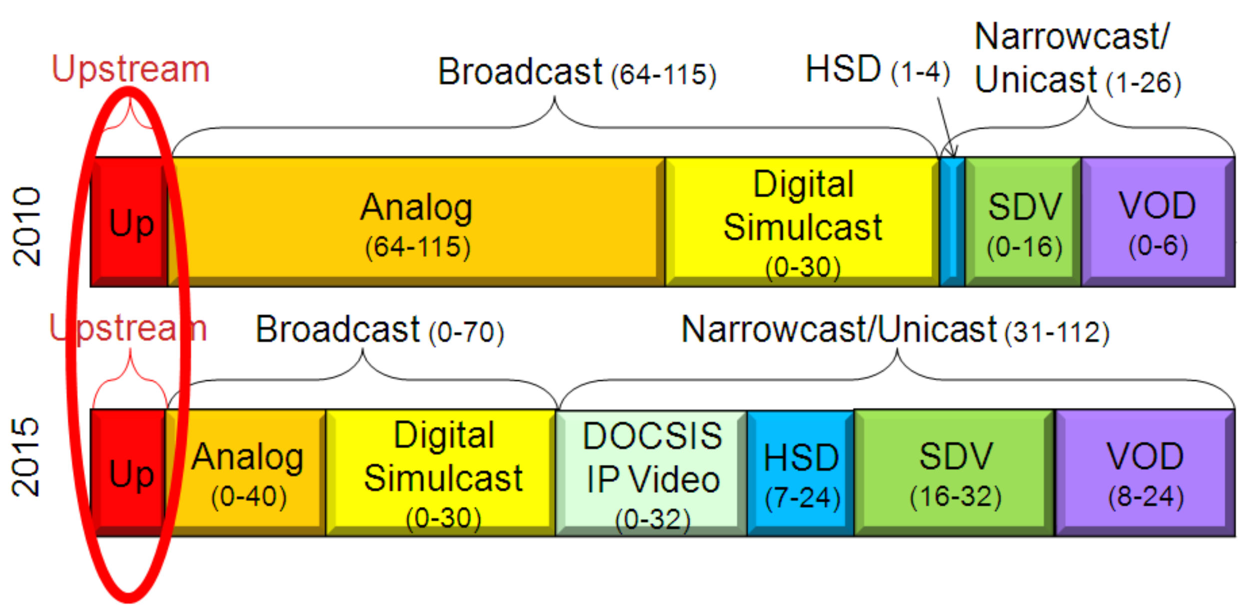


Figure 9—Upstream Spectrum Allocation Remains Unchanged

Upstream Bandwidth Predictions

In the beginning of this section we examined the Internet growth trends and the downstream bandwidth predictions to include the expansion of more IP/DOCSIS bandwidth in the coming decade and the growth of the max service tier offered. The downstream bandwidth usage has risen over time and the upstream continues to increase as well. The upstream traffic load may be represented by a value of about 25% of the downstream HSD traffic load during busy hour. The upstream may grow in percentage terms faster than the downstream in this coming decade as a result of consumer adoption of user generated content such as YouTube, Social Networking, P2P, and Video conferencing. The increased consumption of upstream traffic will also be attributed to an increase in downstream bandwidth allocated to IP/DOCSIS. The reasoning behind the increase in the upstream as a result in the increase in downstream traffic is derived by the transmission technology used, Transmission Control Protocol (TCP) and the acknowledgment packets which are transmitted upstream to the content distribution server. As the downstream expands the increase in the upstream traffic load will increase perhaps as much as 50% CAGR for the next decade. In the figure below the upstream traffic load is examined assuming an expanded downstream traffic allocation for HSD and IPTV and the continued expansion of upstream bandwidth as a result of consumer and application behavior.

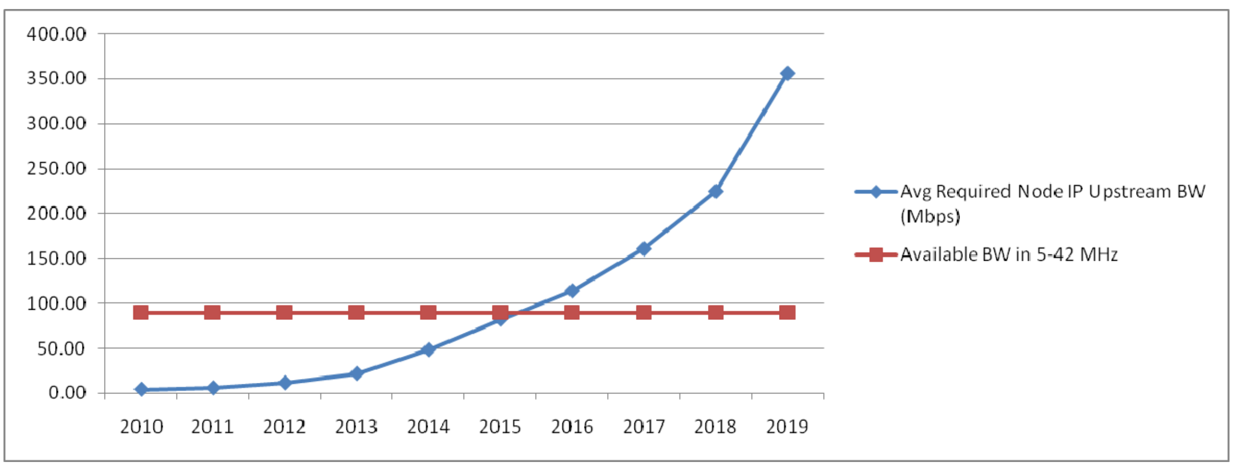


Figure 10—Upstream Bandwidth Predictions

The diagram above assumes a 500 HHP node and the allocation of upstream capacity is 90 mbps. In this diagram the upstream for the node may be exhausted by the year 2015, however, the HFC is remarkably nimble and through targeted investment additional capacity may be made available as described in the diagram below. The use of node segmentation allows the MSO to partition a node and perhaps only the nodes affected to increase capacity by decreasing the HHP served in the upstream. The diagram also suggests that upstream augmentation may be needed if an upstream service offering exceeds the available throughput of the upstream. The diagram below suggests that investment in upstream capacity in not needed for some time but will likely occur as part of routine traffic planning throughout the decade.

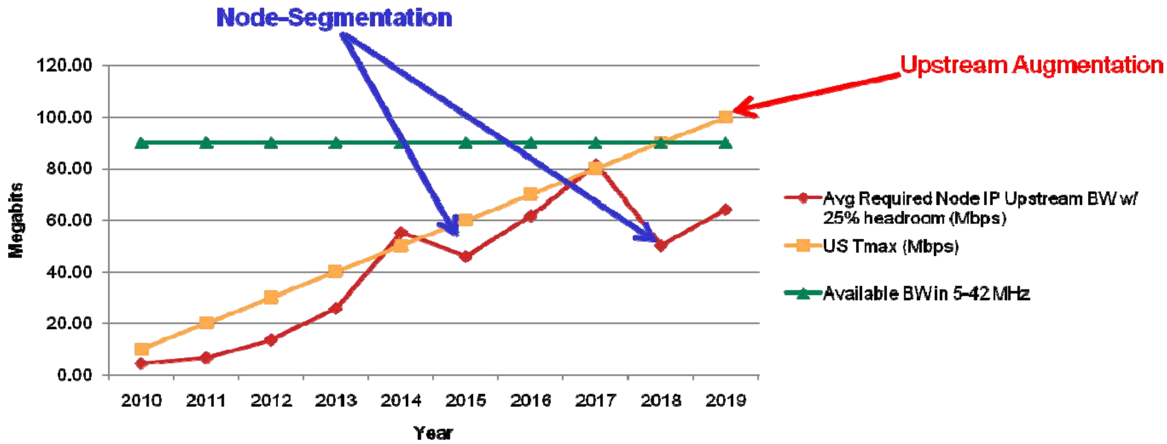


Figure 11—Upstream Prediction Addressed using Node Segmentation and Upstream Augmentation

Competitive Threats

In the beginning of this section we cited some key business drivers for the transition of the network may be driven by competition. The diagram below illustrates the various network technologies available or which may emerge in the coming decade that will compete against cable. In this diagram the technologies maximum bandwidth to and from the home are examined. This illustrates that when compared to alternative technologies cable's massive bandwidth to the home is a key differentiator. Cable has the ability as illustrated in the sections above to allocate more and more of the spectrum bandwidth to IP based technologies which will enable continued evolution of the service offerings as well as take advantage of the efficiencies found with IP network technology.

The upstream bandwidth allocation is very competitive with alternative technologies with the exception of GPON. This paper will examine migration strategies for the upstream to compete with the capacity found using PON technology.

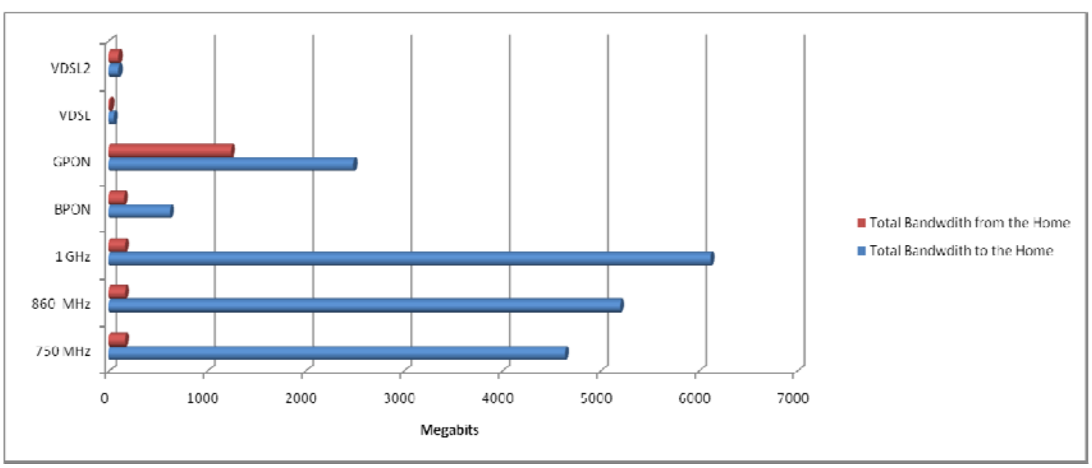


Figure 12—Comparison of Maximum Bandwidth Available To and From the Home

Business Driver Summaries

There are many factors cable operators are considering as they begin planning the network evolution over the next decade. The changes in technology and service expectations of the consumer coupled with competitive threats will redefine the cable network. The following sections will begin to address how cable will respond to these business drivers and document some of the migration options to remain competitive.

CABLE'S CAPACITY EXPANSION METHODS

The modern cable network is incredibly flexible allowing the MSO to make targeted investments where and when needed to either incrementally or in some cases substantially increase network capacity depending on the capacity expansion method selected. The use of capacity expansion methods may be applied across an entire network footprint or with laser beam focus to address capacity challenges. The table below is an attempt to capture the various methods available to increase or improve capacity of the network. The diagram brings together methods and techniques used by various disciplines within the MSO, such as outside/inside plant, IP/Data, SDV, and Video Processing. The techniques will allow the MSO to transform their network from broadcast to unicast and from analog/digital to IP.

Today, in fact MSOs may use techniques to increase capacity without touching the outside plant; this is dramatically different than the approaches that were used for decades. The technique referred to as Bandwidth Reclamation and Efficiencies, as illustrated in the top of figure 13 is becoming the primary method to address system wide capacity challenges. In most cases this technique may be implemented with equipment in the headend and home, thus not requiring conditioning of the outside plant or headend optics. A technique recently put into practice by some cable operators is partial or even full analog reclamation, this enables the operator to transition the channels currently transmitted in analog and to transmit them only in digital format allowing greater bandwidth efficiencies by requiring the use of a digital terminal adapter (DTA) alongside televisions that may have only had analog services. Another technique for Bandwidth Reclamation and Efficiencies is the use of Switch Digital Video (SDV). The use of SDV allows the cable operator to transmit in the network only the video streams that are being viewed by consumers. This allows the operator to increase the number of channels offered to consumers, in fact the actual channels offered to the consumers may exceed the throughput capabilities of the network but through careful traffic engineering and capacity planning this approach is an excellent way of adding additional capacity to the network. This technique is a form of over subscription and has been in practice for decades by the telecommunication industry. The items captured in Bandwidth Reclamation and Efficiencies are the modern methods to expand capacity. In many respects the Bandwidth Expansion "upgrade" approach as illustrated in figure 4 whereby the entire network was upgrade to increase capacity may be seldom used in the future. If used this may be part of a joint plan to increase the spectrum allocation of the return path.

In the future, the use of IP for video delivery will provide even greater bandwidth efficiencies IP used for digital video transmission and will also provide functionality similar to the techniques used in SDV. Another key advantage is that IP allows for the use of variable bitrate (VBR) encoding increasing the capacity of the network [2].

Figure 13—Cable's Capacity Expansion Methods

Summaries of Capacity Expansion Methods

Cable operator's selection priority of the capacity expansion methods has and will continue to vary. The MSOs will eventually use all or near all of the Capacity Expansion Methods in the table above.

Downstream Capacity Expansion

- DTA's & SDV will provide long term downstream plant capacity expansion
- Reduced Service Group Size enabling fewer customers to share bandwidth
- Node Segmentation and Node Splits will continue to be used in a targeted basis
- Possible downstream bandwidth expansion along with upstream augmentation

Upstream Capacity Expansion

- Use of highest order modulation and Channel Bonding to increase throughput [3]
- Progressively smaller upstream service groups
- Ongoing node splits / segmentation
- These incremental steps should last for a majority of the decade
- Upstream Augmentation expands upstream spectrum and bandwidth such as conversion to mid-split, high-split, or tri-split (as described in detail in the section below)

UPSTREAM AUGMENTATION ANALYSIS

The application of Upstream Augmentation is not likely to occur in the near future. The current spectrum allocation should be sufficient considering the bandwidth predictions as cited earlier in this paper. This paper is again a forward looking study meant to increase awareness of the upstream augmentation options. The hybrid fiber coax (HFC) network has a lot of legs left in both the downstream and upstream direction. This paper considers a future architecture capable of delivering multi-gigabit IP services to the home and perhaps 1 Gbps from the home, all while leveraging the coaxial network to the home. This is referred to as the Next Generation – Gigabit Coaxial Access Network or simply Gigabit Coaxial Network (GCN). Some cable operators are already planning for an expansion of IP based traffic in the downstream and this may reach multi-gigabit speeds within this decade. The cable network has the ability to transition all of the capacity to IP if desired.

<u>Overview</u>

The use of upstream augmentation will have many trade-offs for network planners to consider. This diagram captures the upstream and downstream allocation of bandwidth predicted by 2015. This diagram is meant to illustrate the placement of the upstream spectrum given three (3) Upstream Augmentation Options:

- Mid-Split
- High-Split
- Tri-Split

This use of Mid-Split or High-Split consumes existing downstream capacity. The use of High-Split may compress the year 2015 channel allocation forecast assuming a 750 Mhz system. The use of Tri-Split allows the existing forward capacity to remain as well as the forecasted utilization because additional upstream spectrum is allocated above the current downstream spectrum. The following sections examine all three approaches as well as others.

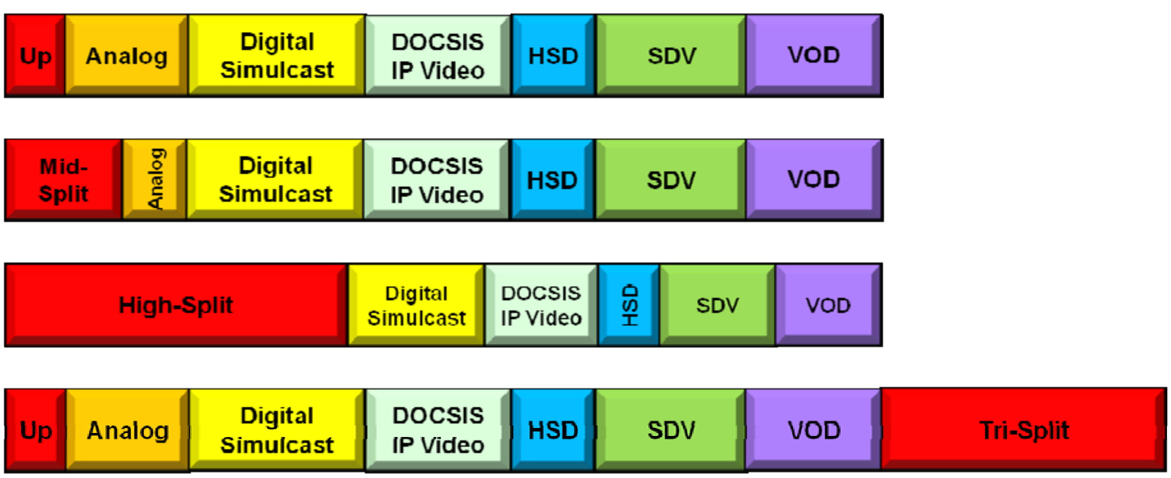


Figure 14—Upstream Augmentation Comparison

Mid-split 5-85 MHz Analysis

The Mid-Split Architecture is defined as 5-85 MHz with the downstream starting at approximately 105-108 MHz; this may also be referred to as the 85/105 split. The mid-split has been discussed for many years; in fact the DOCSIS 3.0 [4] [5] specifications included support for mid-split. The inside and outside plant network element may have support for mid-split however this depends on the year of the deployment, manufacturer used, and type of network element. The mid-split architecture essentially doubles the current upstream spectrum allocation. The tables below capture some the advantages and disadvantages when considering Mid-Split

Mid-Split Advantages	
Area	**Comment**
Bandwidth	Upstream moves to nearly 315 Mbps +
Spectrum Upstream Allocation	5-85 Upstream
Headend Optical Transmitter	Existing Equipment should support
Headend Optical Receivers	Existing analog receivers should support up 200 MHz
Nodes (Optical Side)	DFB 200 MHz Tx should support
Node (RF Side)	Best Case: replace the Diplexer filters with a pluggable filter swap
Amplifiers	Best Case: If pluggable replace the Diplexer filters
Passives	Mid-split leverages existing Passives
DOCSIS 3.0 CMTS and CM/EMTAs	Recent DOCSIS 3.0 products (CMTS and EMTAs) are built to use mid-split spectrum this maybe leveraged for full High-Split

Table 1—Mid-Split Advantages

Mid-Split Disadvantages	
Area	**Comment**
Bandwidth	Does not support PON like speeds and perhaps limited to 315 Mbps + (not 1 Gbps) We will assume: 10-85 MHz is useable 2 MHz set aside for Legacy STBs 2 MHz set aside for Legacy Status Monitoring 3.2 MHz for Legacy DOCSIS Traffic Leaves about 67.8 MHz of usable capacity for DOCSIS 3.0 or Ten 6.4 channels at 30 mbps and One 3.2 channel at 15 mbps Usable DOCSIS bandwidth perhaps 315 Mbps +
Spectrum Guard band (between US/DS)	Guard band 85-105 or 85-108 (about 20 MHz)
Impact to Exiting Forward Capacity	Reduced by about 50 MHz
Spectrum Interference Concerns	Assume 10-85 MHz is useable
Headend Optical Receivers	Digital Receivers would have to be replaced
Nodes (Optical Side)	FP 200 MHz Tx will need to be replaced 42 MHz Digital Return will have to be replaced
Node (RF Side)	Worst Case: Replace the housing because there is no pluggable filter or amp that fits into existing housing
Amplifiers	Worst Case: Replace the housing because there is no pluggable filter or amp that fits into existing housing
House Amplifiers	Mid-split will require change of a home amp
OOB Set-Top Box Communications	Some STBs may be hard coded within the mid-split range (75.5 and 104.25 MHz)

Table 2—Mid-Split Disadvantages

High-split 5-200 MHz Analysis

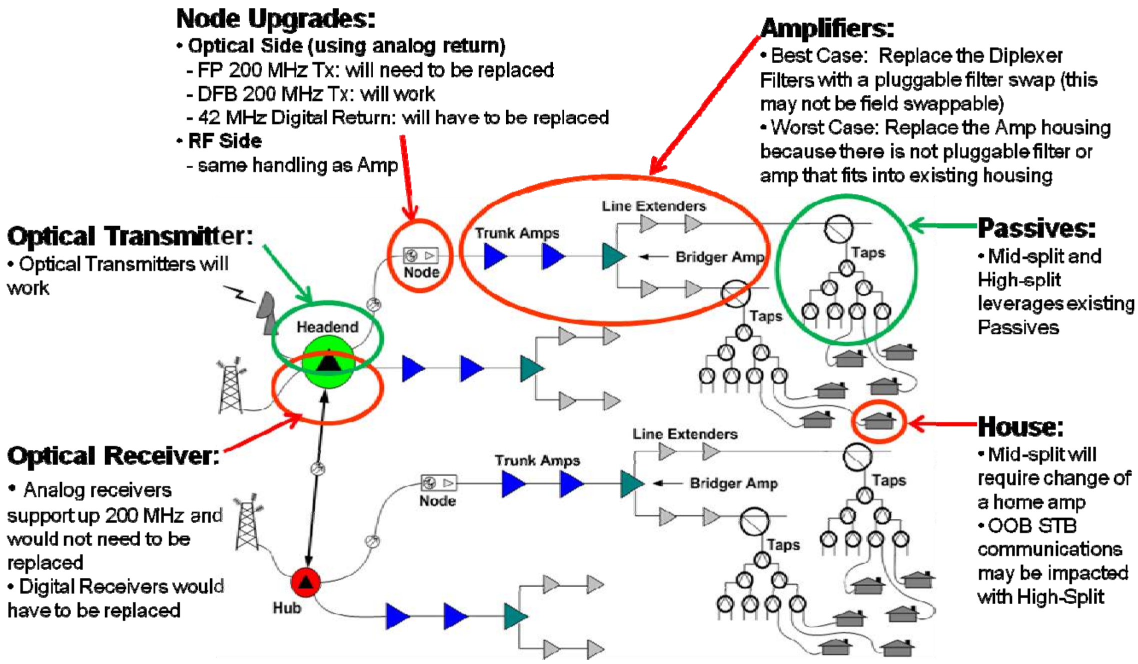
The High-Split Architecture is defined as 5-200 MHz with the downstream starting at approximately 250-258 MHz; this may also be referred to as the 200/250 split. The High-split is being considered because full or partial analog reclamation is underway or planned by cable operators. This will allow a smoother transition when considering consumption of existing analog spectrum. As with mid-split DOCSIS 3.0 specifications systems may be used, however to take advantage of the full spectrum additional development is required. The tables below capture some advantages and disadvantages when considering High- Split.

Area	**Comment**
Bandwidth	Upstream moves to nearly 855 Mbps + with existing DOCSIS technology
Spectrum Upstream Allocation	5-200 Upstream
Headend Optical Transmitter	Existing Equipment should support
Headend Optical Receivers	Existing analog receivers should support up 200 MHz
Nodes (Optical Side)	DFB 200 MHz Tx should support
Node (RF Side)	Best Case: If pluggable is supported replace the Diplexer filters with a pluggable filter swap
Amplifiers	Best Case: If pluggable replace the Diplexer filters
Passives	High-split leverages existing Passives
DOCSIS 3.0 CMTS and CM/EMTAs	Recent DOCSIS 3.0 products (CMTS and EMTAs) are built to use portion of High-split spectrum

Table 3—High-Split Advantages

High-Split Disadvantages	
Area	**Comment**
Bandwidth	• Does not support PON like speeds and perhaps limited to 855 Mbps + (not 1 Gbps) We will assume: 10-200 MHz is useable 2 MHz set aside for Legacy STBs 2 MHz set aside for Legacy Status Monitoring 3.2 MHz for Legacy DOCSIS Traffic Leaves about 182.8 MHz of usable capacity for DOCSIS 3.0 or (28 Channel of 6.4 channels at 30 mbps) and One channel at 3.2 channel at 15 mbps) Usable DOCSIS bandwidth perhaps 855 Mbps Assumes no other interference • 1 Gbps Speeds maybe achieved with changes to DOCSIS 3.0 thus new industry investment in new PHY encoding, MAC/PHY layer technology and legacy investment may be stranded.
Spectrum Guard band (between US/DS)	Guard band 200-258 (58 MHz)
Impact to Exiting Forward Capacity	Reduced by about 200 MHz
Spectrum Interference Concerns	FM Radio Band, DTV and Aeronautical frequencies - avoidances of these bands reduces the overall spectrum bandwidth available for data services
Headend Optical Receivers	Digital Receivers would have to be replaced
Nodes (Optical Side)	• FP 200 MHz Tx will need to be replaced • 42 MHz Digital Return will have to be replaced
Node (RF Side)	Worst Case: Replace the housing because there is no pluggable filter or amp that fits into existing housing
Amplifiers	Worst Case: Replace the housing because there is no pluggable filter or amp that fits into existing housing
House Amplifiers	High-split will require change of a home amp
OOB Set-Top Box Communications	• Some STBs may be hard coded within the mid-split range (75.5 and 104.25 MHz) • ANSI/SCTE 55-2 2008 [6] and ANSI/SCTE 55-1 2009 [7] defines 70 MHz – 130 MHz as usable.

Table 4—High-Split Disadvantages



Red Circle Areas: represent investment or possible investment
Green Circle Areas: represent no investment required

Figure 15—Anatomy of the Mid-Split and High-Split Architecture

<u>Tri-split 1.3 – 1.8 GHz Analysis</u>

The Tri-Split Architecture may be defined as 1.3 – 1.8 GHz this may also be referred to as spectrum overlay. The Tri-split may be considered because this avoids consuming existing downstream in terms of Capacity, Services, OOB STB management and the entire DS architecture does not have to change. As with mid-split and high-split DOCSIS 3.0 specifications systems may be used, however to take advantage of the full spectrum additional development is required. Tri-split is a touch it once architecture in that this clearly competes against PON. The tables below capture some the advantages and disadvantages when considering Tri-Split.

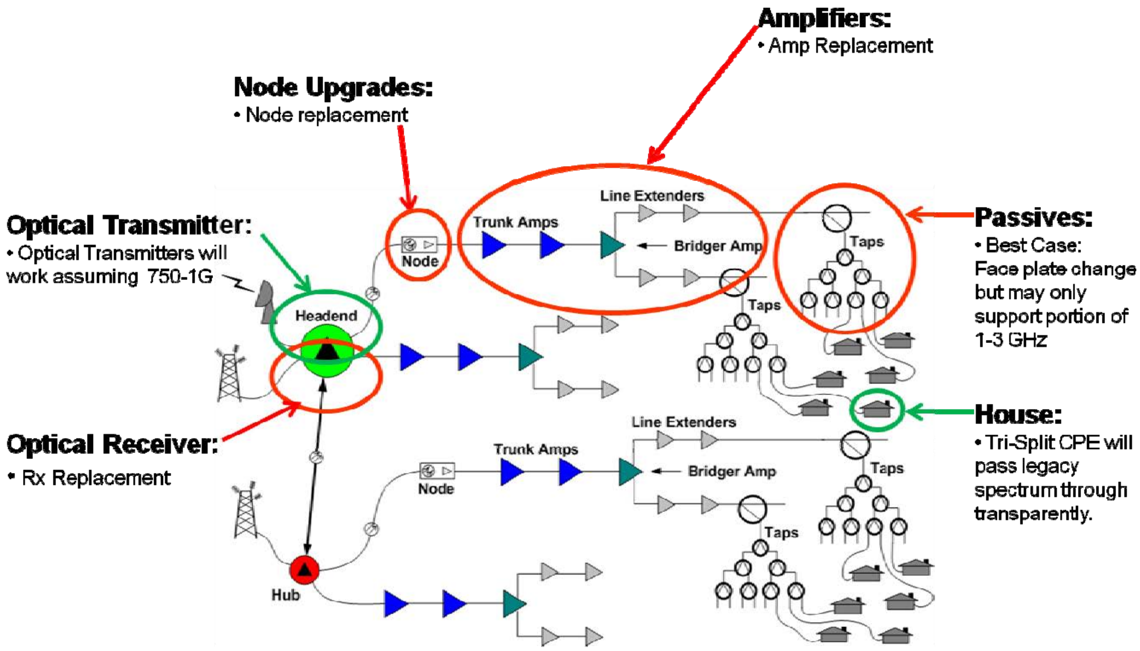
Tri-Split Advantages	
Area	**Comment**
Bandwidth	• 1 – 2 Gigabits with existing DOCSIS technology • 1 Gbps Speeds maybe assumed if we account for MoCA bandwidth which may leak into plant. • Clearly competes against PON in terms of bandwidth over HFC
Spectrum Upstream Allocation	1.3 GHz - 1.8 GHz Upstream In the Tri-Split there is no ceiling (Upstream does

	push up against the Downstream)
Impact to Exiting Forward Capacity	No Change to the Downstream in terms of: Capacity, Services, and the entire DS Architecture does not need to change.
Headend Optical Transmitter	Existing Equipment should support legacy downstream
Passive	Face Plate Change Possible
House Amplifier	Possibly Leveraged for existing spectrum
OOB Set-Top Box Communications	Not Affected
DOCSIS 3.0 CMTS and CM/EMTAs	Recent DOCSIS 3.0 products (CMTS and EMTAs) are built to use mid-split spectrum this maybe leveraged for full Tri-Split

Table 5—Tri-Split Advantages

Tri-Split Disadvantages	
Area	**Comment**
Bandwidth	-
Spectrum Guard band (between DS and new upstream)	Guard band 300 MHz
Spectrum Interference Concerns	MoCA 1.0 ratified in 2007 may operate in 850-1,500 MHz range MoCA 1.1 ratified in 2008 may operate in a 50 MHz band in the range the 850-1,550 MHz range [8]
Headend Optical Receivers	Replace
Node	Replace
Amplifiers	Replace
Home	High Frequency usage results in high power level required from the CM

Table 6—Tri-Split Disadvantages



Red Circle Areas: represent investment or possible investment
Green Circle Areas: represent no investment required

Figure 16—Anatomy of the Tri-Split Architecture

<u>Quad-Split Analysis</u>

The term Quad-Split may be applied to additional forward capacity in the 1 – 3 GHz range. This new downstream spectrum if used would likely be placed on top of the upstream allocation which may occupy 1.3 – 1.8 GHz.

<u>Fiber to the Last Active (FTTLAx)</u>

The term Fiber to the Last Active (FTTLA) refers to extending fiber from the node or overlashing from the headend or hub to each active on the plant. This network transition may be used in conjunction with Mid-Split, High-Split, or Tri-Split technologies. This architecture may be considered if a non DOCSIS MAC/PHY layer technology is used and may not support transmission through actives or only through few actives due to performance and distance limitations. It is unlikely that this approach would be considered because of the massive fiber builds, optical network transition to WDM for fiber conservation, and an increased number of actives in the plant if addition new MAC/PHY or media conversion elements are added.

<u>Summaries of Upstream Augmentation</u>

The use of Upstream Augmentation is not anticipated in the near future because of the massive upstream bandwidth the cable industry has in place today. The use of upstream augmentation is another example that the existing coaxial network to the home may evolve to support the demands of the consumer. These approaches cited above extend the useful life of the existing HFC investment.

<u>EXAMINING THE MAC AND PHY LAYER TECHNOLOGIES</u>

As described in the previous section the underling physical layer spectrum options have been examined and it is planned that the MAC/PHY layer options described in this section may function in any spectrum allocation.

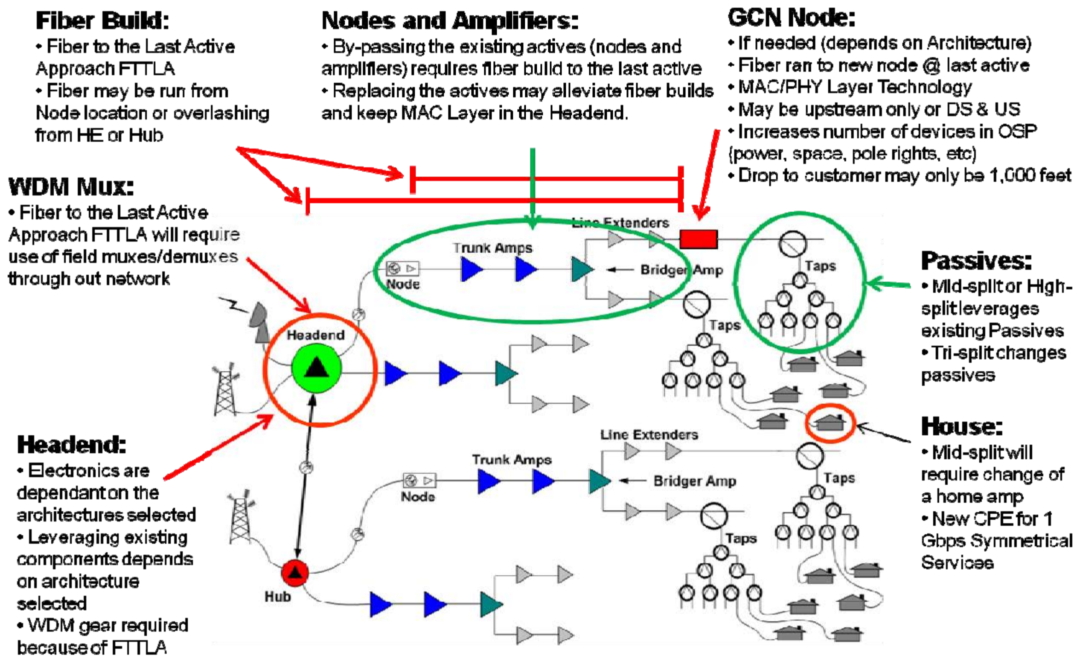
Alternative MAC and PHY

An emerging class of the technology called Ethernet over Coax (EoC) may become a competitive technology to DOCSIS. The use of EoC may be applied to the new spectrum allocation as described in the previous section. The term EoC may reference current standards such as MoCA, HPNA 3.1, G.hn, and perhaps others that may emerge. These technologies were typically used in premise distribution networks and some may find applications in the access network. Some EoC technologies may however have some significant drawbacks when used as an access layer technology such as distance limitations and number of end customers supported in a given MAC/broadcast domain. In addition, consideration of MAC layer limitations in terms of QoS required in a shared media access layer technology to assure QoS for each customer and service type at a scaling level required for the coaxial access network should be considered. The scaling of the MAC layer domain may be a significant consideration. In the cable access network this is a key factor as cable may have 1,000 of customers sharing a MAC domain and as bandwidth increases number of customers served in a MAC domain may rise for economies of scale. The number of unique end points served in a given MAC domain, such as 32, 64, or even 256 subscribers may not be sufficient in a cable access network application.

The use of new PHY layer technology may be desired to increase the bits per second per hertz. This may include the use of orthogonal frequency division multiplexing (OFDM) or similar approaches.

A key architecture consideration about some EoC based technologies is that the distance limitation from the beginning of the coaxial drop to the customer premise may need to be 1,000 feet or less. This is a critical consideration because a drop of not greater than 1,000 feet of coax may require an outside plant infrastructure using Fiber to the Last Active (FTTLA). This may result in a significant cost premium when considering DOCSIS architectures which may travel up to 100 miles or 160 km. These are all key selection criteria when considering alternative MAC and PHY layer technology in access layer deployment architecture.

The architecture illustration considers a fiber to the last active (FTTLA) and the selection of Mid-split, High-split, or Tri-Split. This architecture assumes a drop distance of no greater than 1,000 feet and that no existing actives are leveraged. This architecture places a device called a Gigabit Coaxial Network Node at the last active location and throughout the entire network (note this would not be required if DOCSIS was used).



Red Circle Areas: represent investment or possible investment
Green Circle Areas: represent no investment required

Figure 17—Possible Architecture Using FTTLA and Non-DOCSIS MAC/PHY

<u>Traditional MAC and PHY</u>

The use of DOCSIS MAC and PHY layer technology may be considered for the Gigabit Coaxial Network. The use of existing DOCSIS 3.0 standards may be leveraged as this would already be occupying spectrum and bandwidth. If the existing DOCSIS standards were considered this would allow for large bonding groups to be leveraged as these may terminate on existing or current DOCSIS 3.0 upstream cards. Conversely if an alternative MAC layer technology is used the spectrum DOCSIS occupies may affect the possible throughput of the solutions. There may also be the presence of significant number of existing DOCSIS 3.0 channels occupying downstream capacity and this too may be leveraged for the Gigabit Coax Network. DOCSIS was designed for cable access network distribution and leveraging DOCSIS for the next generation coaxial access network may be considered as this would continue to place the electronics for MAC/PHY processing in the Headend and CPE, thus avoiding placing these active components in the OSP. In addition, the distance capabilities of DOCSIS will continue to allow MAC/PHY processing at the current distances thus not requiring a GCN Node in the OSP plant, this is a significant difference as the current active counts in the OSP would not increase. Moreover leveraging DOCSIS and either Mid-Split, High-Split, or Tri-Split approaches would not requires additional fibers or wavelengths to be deployed.

DOCSIS could evolve adopting new PHY layer encoding technologies like OFDM to improve performance [9] and also improvements to the MAC could be adopted which may strengthen the position to use DOCSIS to support Multi-Gigabit or Gigabit IP Services to compete with PON.

COST ANALYSIS FOR UPSTREAM AUGMENTATION

The following assumptions were used to compile a comparison of Mid-Split conversion, Tri-Split, and EPON overlay:

- 30% of the infrastructure is underground with limited or no conduit access.
- Homes passed density averages 100 homes/mile.
- Expected symmetrical service take rate is 15% of homes passed.
- Enhanced HSD service group size target is 1024 homes passed.

The results of the comparison revealed that the EPON overlay had the highest infrastructure cost, the highest success-based cost, and the longest build out time of the group. The other solutions were then compared to EPON on a percentage basis.

Mid-split

Changing the upstream/downstream split boundary in existing HFC networks is an economical approach to providing additional upstream bandwidth. Only the active elements in the network need to be upgraded to alter the split boundary. The amplifiers will need modified diplex filters to be substituted, and the nodes will likely need upgraded DFB lasers to handle the additional QAM traffic load. Infrastructure costs for this conversion using the stated assumptions were calculated to be on the order of 23% of the EPON overlay for traditional Node + X amps in cascade architectures, and 29% for Node + 0 architectures (Figure 18). This represents the lowest enablement costs and fastest time to market solution out of those considered (Figure 19).

Tri-Split

The overlay approach requires much more material and effort. The upstream traffic will be shifted to a spectral area above 1 GHz which the taps and passives will not cleanly pass. Therefore, all the taps and passives would have to be replaced with upgraded versions. This could possibly be done with faceplate upgrades to minimize cost, time to market and customer disruption. Each amplifier would have to be retrofitted or replaced, in order to filter and amplify the new upstream frequency band. Each node would have to be retrofitted or replaced, in order to filter, amplify and optically transmit the new frequency band. A new receiver arrangement in the headend or hub would be necessary to receive an convert the optical signals to RF in the appropriate frequency range of the termination system. Infrastructure costs for this conversion using the stated assumptions were calculated to be on 54% of EPON overlay for traditional Node + X amps in cascade architectures, and 61% for Node + 0 architectures (Figure 18). This represents mid-level enablement cost solution with a much longer time to market over the mid-split (Figure 19)

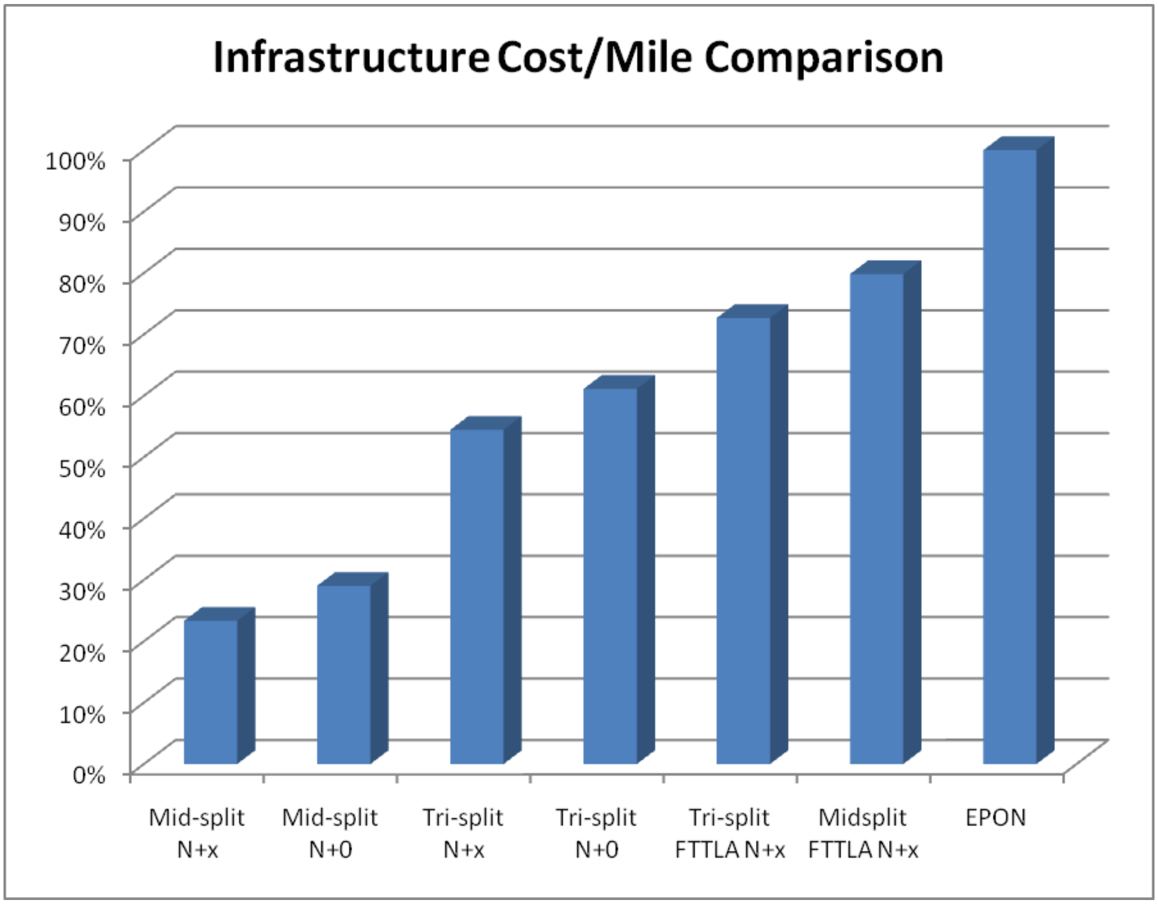


Figure 18—Infrastructure Cost per Mile Compared to FTTx & EPON Overlay

Fiber to the Last Active (FTTLA)

Converting an existing Node + X architecture to a Node +0 architecture is commonly known as a Fiber to the Last Active (FTTLA) upgrade. If this approach is combined with the previous mid-split and overlay approaches, then the additional costs of extending the fiber and converting the current amplifiers to nodes is added. The additional fiber cost isn't affected by which solution the FTTLA is combined with, but the active cost burden for the overlay is shared with the FTTLA conversion, so some economies are realized. When upgrading to mid-split along with FTTLA the cost increases to 80% of EPON overlay. However upgrading to overlay along with FTTLA increases the cost to 73% (Figure 18). These solutions represent the highest cost HFC solution with the longest time to market of the HFC approaches (Figure 19).

EPON Overlay

Extending fiber to every customer premise is a well known solution for high rate symmetrical data delivery. Overlashing in the existing aerial plant, and trenching and boring would likely be required in most underground areas to add the required fiber to overlay an EPON system. Even with very moderate construction labor estimates, this solution is significantly more expensive that the HFC upgrade scenarios.

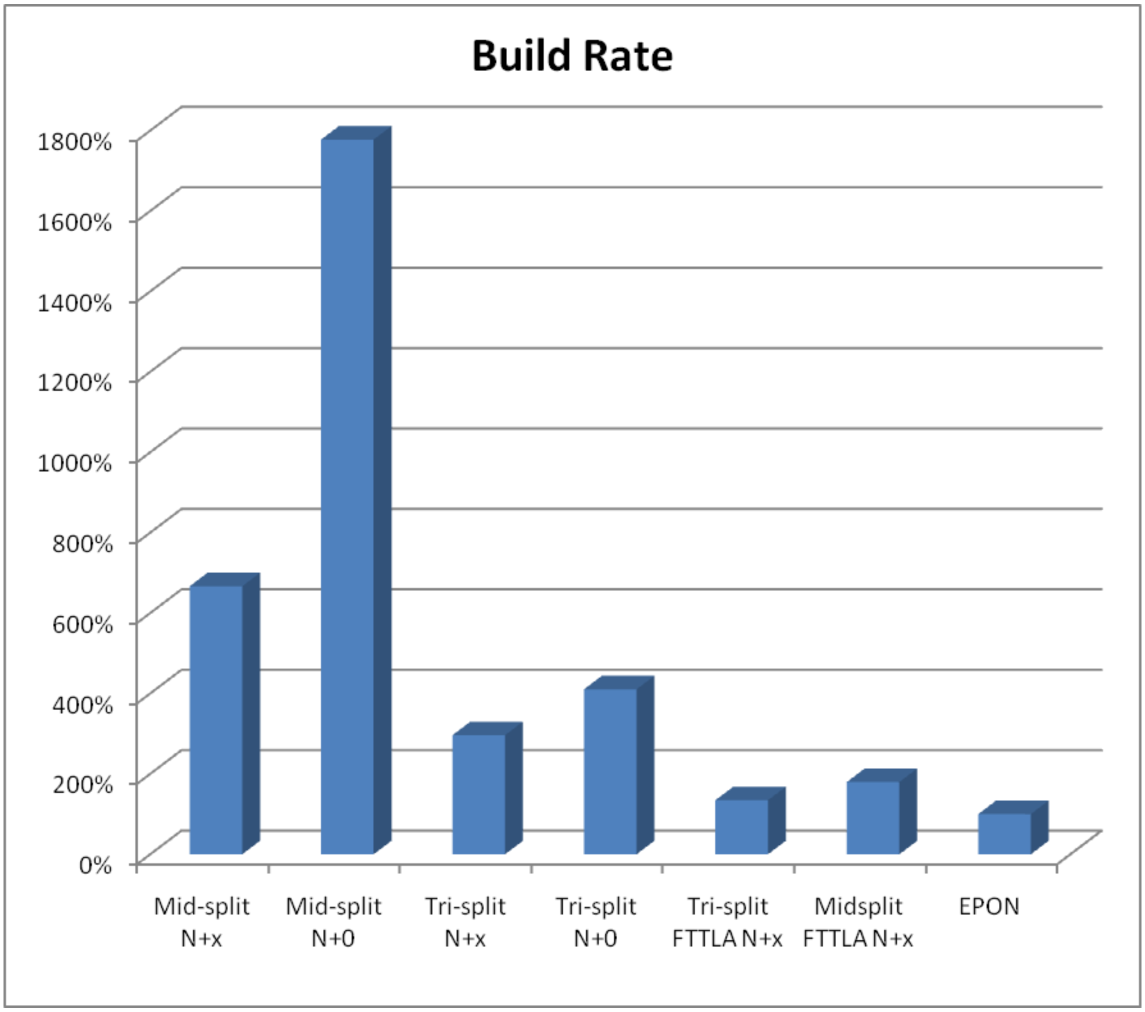


Figure 19—Build Rate Time to Market Advantage When Compared to EPON

Success Based Costs

Once the infrastructure is available, the costs to provide service must also be considered. In this analysis, it was assumed that the HFC plant is mature and drop facilities exist to the typical customer premise. This is not true however, for the EPON solution since it is fiber based all the way to the side of the premise. It is also assumed that the CPE costs for a next gen cable modem and EPON ONU are similar for the same throughput capability. The assumptions listed yield 15 customers per mile. Again using the EPON solution as the benchmark, the HFC solutions were compared with 15% take rate. The relationship is shown in Figure 20.

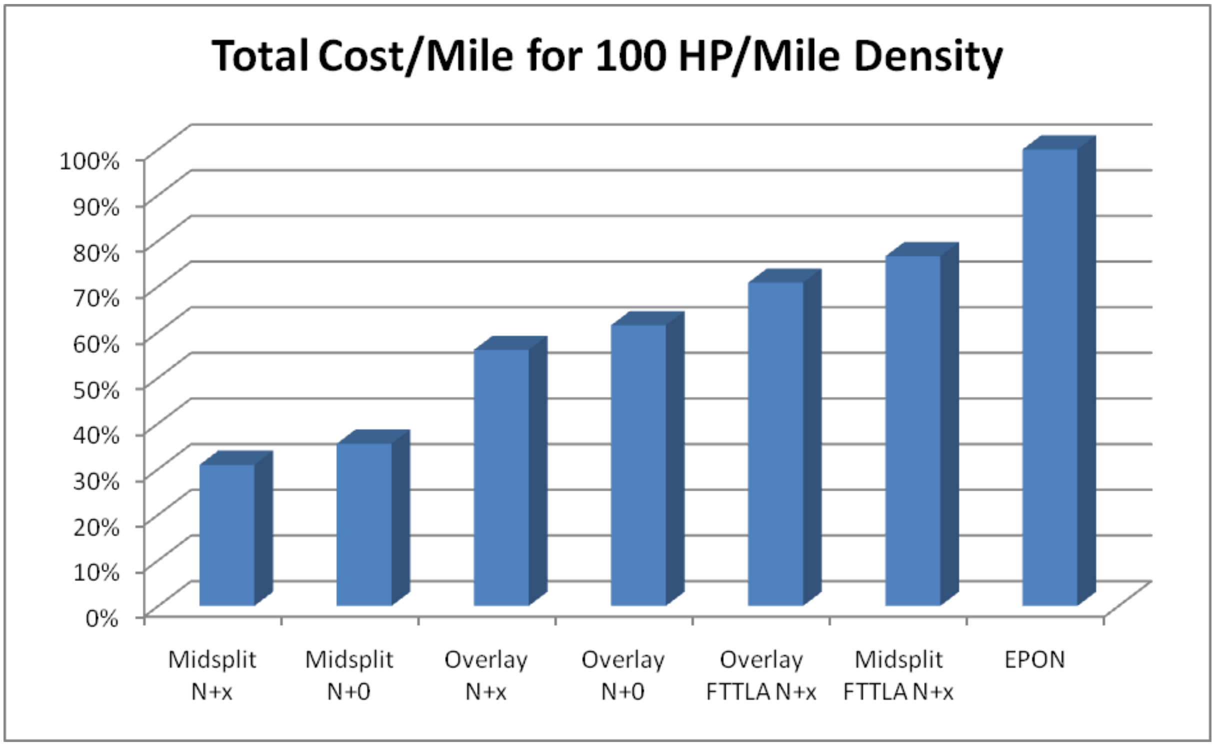


Figure 20—Total Cost per Mile Compared to FTTx & EPON Overlay

CONCLUSIONS

The cable industry may be part of a significant business and technical transition driven from considerable changes in technology, consumer demand and competition. The cable operators will have the ability to transform their business and network from largely a broadcast oriented content delivery service to an increasingly more personalized customer experience. While the demands of the business change, the network, as illustrated in this paper, is incredibly nimble and flexible to accommodate this transition. As the cable industry transforms their network to a unicast service delivery platform it is likely that an increase in spectrum and bandwidth allocation will be allocated to IP based network technologies to address consumer demands and competition. The use of upstream augmentation allows the cable industry to address competitive threats posed by fiber to the premise (FTTP) providers. The Next Generation – Gigabit Coaxial Access Network is capable of delivering multi-gigabit IP services to the home while having the ability to eventually support 1 Gbps from the home, all while leveraging one of cable's most valuable assets the existing coaxial network to the home.

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LIST OF ABBREVIATIONS AND ACRONYMS

BPON	Broadband PON
CAGR	Compound Annual Growth Rate
DBS	Digital Broadcast System
DOCSIS	Data Over Cable Service Interface Specifications
DTA	Digital Terminal Adapter
EoC	Ethernet over Coax
EPON	Ethernet Passive Optical Network
FDM	Frequency Division Multiplexing
FTTH	Fiber To The Home
FTTLA	Fiber to the Last Active
FTTP	fiber to the premise
Gbps	Gigabits per Second
GCN	Gigabit Coax Network
GPON	Gigabit PON
HFC	Hybrid Fiber Coaxial Cable
HHP	Households Passed
HPNA	HomePNA Alliance
HSD	High Speed Data
IP	Internet Protocol
IPTV	TV (video) over IP networks
MAC	Media Access Layer
Mbps	Megabit per Second
MoCA	Multimedia over Coax Alliance
MSO	Multiple Service Operator
OFDM	Orthogonal Frequency Division Multiplexing
OTT	Over The Top
P2P	Peer-to-peer
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RFoG	RF Over Glass
SDV	Switch Digital Video
US	Upstream
VBR	Variable bitrate
VDSL	Very High Bitrate DSL
VDSL2	Very High Bitrate DSL2
VoD	Video on Demand