

MAKING BUSINESS SENSE OUT OF THE WIDEBAND PROTOCOL FOR A DOCSIS NETWORK

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Abstract

To date, cable operators have enjoyed an upper hand in the competition to deliver high-speed services because of their network capacity and bundling strategy. In the U.S., telcos' attempts to counter this advantage by reliance on digital subscriber line (DSL) service have been somewhat successful in attracting new subs. But because of data throughput restrictions and the carrier's reluctance to enter the video space, these services did not threaten cable operators' advantage. However, with recent announcements of fiber-to-the-X (FTTX) and metro Ethernet architectures in the U.S., and deployments of advanced DSL, fiber networks and true triple play services elsewhere in the world, the playing field looks much more level and the true battle is ready to begin. The situation is even more intense in the Asia Pacific, Japan, and European regions where competitive broadband services are showing a growing traction with residential customers. So how can cable operators respond to these threats and the telco promise of 25, 50 or even 100 Mbps and greater broadband service to the home?

Fortunately for the cable industry, the answer does not lie in replicating its \$80+ billion investment to add new physical capacity on top of existing networks or matching the \$10 to 20 billion telcos will invest in fiber-based IP services. The answer lies in unleashing the full power of the cable industry's existing hybrid fiber coax (HFC) networks.

With sixty percent of today's HFC spectrum being used to carry less than two percent of its data capacity, the goal is to take the available HFC bandwidth and data capacity and use them more efficiently. By simply modifying the connectivity of the backbone to the plant, operators will achieve ten times, 100 times, or even 1000 times of today's cable data capacity and at significantly lower price points than existing per-port broadband costs.

The technology that makes this possible is the wideband protocol for a Data Over Cable Service Interface Specification (DOCSIS®) network. The technology promises to leapfrog the telco fiber strategy, dramatically alter the communications industry competitive landscape, and unlock more upside revenue potential for the cable industry than the original specifications.

TECHNOLOGY OVERVIEW

In order to fully understand the potential of existing HFC networks, let's first look at an example of how HFC plant capacity is used today. The chart below details the current utilization of a cable network supporting 100k HHP.

HFC Plant Capacity

Case Study

100K HHP HFC Plant
500 HHP per
Fiber Node

Service Group (SG) is
the no. of fiber nodes
with the same
service offering

Service	# Channels		Digital BW	SG Size	Capacity	
Analog	79	60%	x 3.75 Mbps	x 1 SG =	0.3 Gbps	2%
Digital	43	33%	x 38 Mbps	x 1 SG =	1.6 Gbps	8%
VoD & DOCSIS	9	7%	x 38 Mbps	x 200 SG =	17.1 Gbps	90%
BW Used Today	Total				19 Gbps	
+						
Total Available BW	Capacity	131 Channels	x 38 Mbps	x 200 SG =	1000 Gbps	
=						

Efficiency

1.9%

An analog video channel occupies (in this example) 6 MHz of RF bandwidth, but it only carries one video signal. Also, because of the broadcast nature of the network, the 6 MHz of bandwidth effectively serves a single service group: the entire 100k HHP. The bottom line is that sixty percent of the HFC network's bandwidth currently yields less than two percent of the network data capacity. The spectrum utilization efficiency increases in the case of digital video, where typically up to 10 or 12 video channels can be transmitted in a 6 MHz RF channel, but cable operators are only starting to scratch the surface of their investment potential with adoption of video on demand (VoD) and DOCSIS.

The take away from this exercise is shocking. With 1000 Gbps available in today's cable networks, less than two percent of its total capacity is used today!

Let's look at the way current DOCSIS technology makes use of HFC capacity. In North America, DOCSIS 1.0 and 1.1—collectively known as DOCSIS 1.x—support 30.34 Mbps to 42.88 Mbps (approximately 27 Mbps to 38 Mbps usable throughput) in a single downstream RF channel, and 320 kbps to 10.24 Mbps (approximately 300 kbps to 9 Mbps usable throughput) in a single upstream RF channel. DOCSIS 2.0 moved the bar higher yet, allowing symmetrical data transmission by increasing the upstream raw data rate to as much as 30.72 Mbps in a single RF channel. DOCSIS 2.0's downstream technology though has remained the same as DOCSIS 1.0 and 1.1.

With the adoption of emerging Internet applications such as music and video download or interactive on-line gaming, per-channel data throughput is rapidly becoming a bottleneck. In order for cable operators to meet subscribers' growing bandwidth requirements, the downstream and upstream data rate limits will need to be increased. A

number of approaches have been suggested to achieve this goal. The accompanying table summarizes the pros and cons of these methods.

Data Throughput Enhancement	Pros	Cons
Use higher order modulation (e.g., change from 64- to 256-QAM, or 256-QAM to 1024-QAM)	Low silicon risk Minimum MAC change	Requires very clean plant Higher carrier-to-noise ratio necessary for same BER
Different PHY layer technology (OFDM, Wavelet, etc.)	Improved per-channel data capacity	Incompatible with existing cable modems Requires fork-lift upgrade Not proven technology in cable networks Extensive MAC changes
Increase cable network's operating RF bandwidth (e.g., from 50-860 MHz to 50-1000 MHz)	Low risk technology Increase available downstream spectrum and channel capacity	Requires major rebuild or upgrade Capital expense to upgrade plant
Change from subplit to midsplit band plan (e.g., reverse spectrum 5-108 MHz rather than 5-42 MHz)	Increase upstream spectrum RF bandwidth Low-risk technology	Requires changing diplex filters in all actives Requires changing actives if diplex filters are hard-wired Must balance/sweep align all actives after diplex filter mods Need to make

Data Throughput Enhancement	Pros	Cons
		<p>sure reverse amplifier modules/circuits work to 108 MHz; if not, replacement required</p> <p>Loss of some downstream RF spectrum</p>
Node splits	<p>Backward compatible</p> <p>Well-understood</p> <p>Being done by many cable operators now</p> <p>Increases effective RF bandwidth per subscriber</p>	Capital expense to upgrade plant (materials and labor)

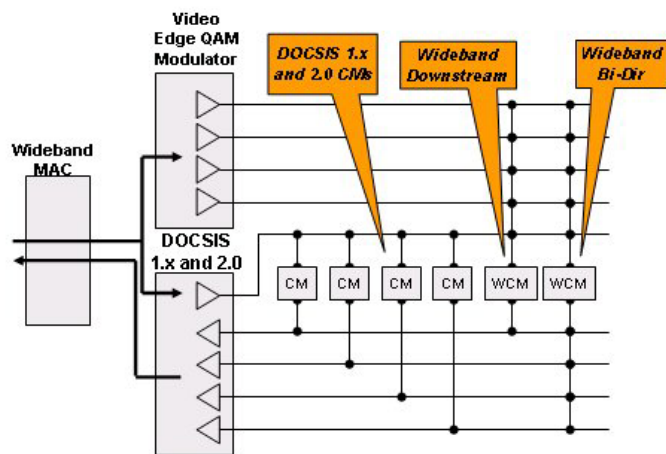
This table was adapted from “Next Gen Full-Service, All-Digital HFC Network Beyond DOCSIS 2.0”, a paper presented by John Eng at the Society of Cable Telecommunications Engineers’ 2004 Conference on Emerging Technologies. All of the alternatives in this table have a substantial impact on CapEx and/or OpEx. Of those listed, splitting nodes is the only one being done to any extent by the cable industry.

Given the spectrum inefficiencies of one analog TV channel per 6 MHz of RF bandwidth, along with the maximum per-channel throughput limitation in DOCSIS 1.x and 2.0 technology, it’s clear that cable network capacity has room to grow. That growth doesn’t require increasing the available RF spectrum, but rather making better use of the spectrum.

One solution, originated by the author in 2001 and under development by Cisco Systems® Inc., is known as the wideband protocol for a DOCSIS network. It solves bandwidth and throughput problems by logically bonding multiple RF channels together to form a wideband “channel,” and works equally well in the downstream or upstream.

Using the wideband protocol, data is striped across multiple quadrature amplitude modulation (QAM) channels, yielding a single logical channel—a wideband channel—the aggregate capacity of the individual QAM channels. The number of QAM channels logically bonded is dynamically configurable, providing the flexibility to increase the aggregate channel capacity with simple software configuration. For instance, by bonding four 256-QAM channels, one would obtain a wideband channel with a data rate of 171.52 Mbps (~152 Mbps). If downstream data were striped across 24 256-QAM channels, the result would be a wideband channel with a data rate of 1.029 Gbps (~912 Mbps). This approach allows operators to overcome the current DOCSIS per-channel downstream limit, without changes at the physical (PHY) layer. The same 64-QAM or 256-QAM modulation formats used today by DOCSIS 1.x/2.0 can be used for each of the channels in the wideband bundle) and without touching at all the network topology.

The following figure shows a high-level view of wideband technology overlaid on a DOCSIS 1.x and 2.0 network.



The wideband protocol is designed to be backwards-compatible with existing DOCSIS 1.x and 2.0 networks. It also delivers some of the benefits of CableLabs' Modular CMTS (M-CMTS™) architecture, such as separation of media access control (MAC) and PHY, or the use of edge-QAM devices using today's technology.

As we will see in the next section, it not only addresses the increasing data capacity and throughput demands, but it does so leveraging current cable modem termination system (CMTS) technology and existing edge-QAM devices to provide a lower cost per port than current DOCSIS QAM technology. In addition, we will see how cost efficiencies are possible because additional downstreams may be added independent of upstreams and existing RF spectrum can be used without impacting cable plant infrastructure costs.

ECONOMIC BENEFITS OF THE WIDEBAND PROTOCOL FOR A DOCSIS NETWORK

This section outlines the economic and business benefits of the wideband protocol for a DOCSIS network. Benefits can be effectively categorized as follows:

Increase Revenue

- Grow subscriber base: Attract new customers, retain existing subscribers, and fend off competitive threats with higher speed services
- Increase average revenue per user (ARPU): ability to offer higher tier services and expand service portfolio to allow operators to benefit from higher average revenue per user

Optimize CapEx Investment

- Fully exploit today's HFC plant potential: no network upgrades are required to take advantage of the throughput increase offered by the wideband protocol
- Leverage existing CMTS platforms: implementations will enable existing CMTS platforms to support the new protocol, lowering incremental capital expense
- Reduce downstream port cost: leverage lower prices of QAM technology and enable operators to use existing edge QAM devices
- Eliminate port under-utilization (stranded ports): add upstream and downstream ports independent of one another to accommodate traffic requirements
- Improve network efficiency: increase the subs/port ratio by taking advantage of the enhanced statistical multiplexing characteristics provided by a larger pipe
- Scale to future requirements: wideband components are designed to meet rapidly changing subscriber demands which in turn will protect initial investment.

broadband portfolio will grow more complex and bandwidth-intensive. The wideband protocol removes the bandwidth bottlenecks existing today and provides the opportunity for cable operators to re-think their business models in the context of emerging applications. Whether capturing a portion of the music download business with iTunes-like portals, hosting IP-based video download libraries, or rolling out multi-media rich interactive gaming services, cable operators can dramatically expand their service portfolio. In the process, they can significantly increase the average revenue generated per subscriber.

Optimize CapEx Investment

Fully Exploit Today's HFC Plant Potential

A key objective of cable operators today is to find ways to leverage the powerful data capacity of their HFC networks—estimated to use less than two percent of the total available capacity. As seen in the previous section, there are a number of alternatives available, but unfortunately, these are either cost- or labor-intensive (or both).

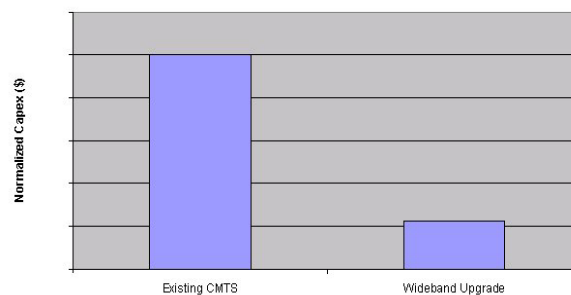
By taking advantage of flexible channel management techniques and channel bonding of up to 24 channels in the first generation of products, the wideband protocol for a DOCSIS network is able to transport packets at Gigabit Ethernet speeds using existing modulation formats—whether they are 64- or 256-QAM. This gives operators the ability to quickly take advantage of the available spectrum on the existing HFC plant, optimizing CapEx investments.

Leverage Existing CMTS Platforms

The flexibility of the wideband protocol for a DOCSIS network does not stop with modulation choices or channel bonding techniques. The protocol can be deployed in parallel with DOCSIS 1.x/2.0 technology, leveraging the investment made in existing CMTSs. Existing edge-QAM modulators can be leveraged as well and physically connected to a wideband module in an existing CMTS. Downstream traffic is now supported from either existing CMTS line cards (DOCSIS 1.x/2.0) or edge-QAM modulators (wideband), and upstream traffic for both variants is supported from DOCSIS 1.x/2.0 line card ports.

The figure below compares the normalized costs for a DOCSIS 1.x/2.0 CMTS with the incremental costs required to upgrade the CMTS to support the wideband protocol. The chart illustrates that with first generation wideband technology, you can more than double the downstream throughput, at less than one fourth the cost! This is the first step towards fulfilling the wideband objective of delivering ten times the throughput at one tenth the cost.

Incremental CapEx



Reduce Downstream Port Cost

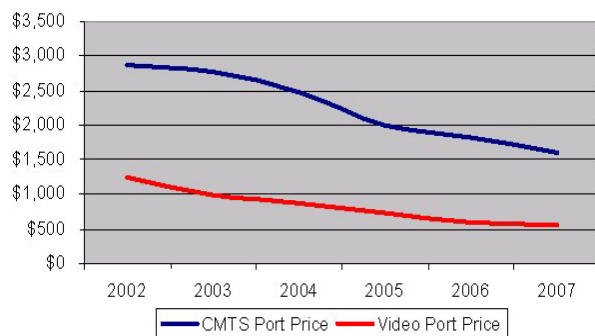
Current CMTS designs are optimized for synchronous traffic for multiple IP-based services. As a result, CMTS line cards are more complex than single-purpose edge-

QAM devices used for uni-directional, asynchronous traffic. This complexity bears with it incremental infrastructure costs.

The proposed wideband technology separates the channel bonding functionality (performed by a wideband module on an existing CMTS) and the Physical Layer adaptation to the RF plant. The latter can be performed by an external edge-QAM device, offering a significant opportunity to leverage declining costs of QAM device designs, and provide a graceful evolution towards a Modular CMTS architecture. In advance of the availability of standards-based products, operators can plan an evolutionary option that saves infrastructure costs.

The following chart depicts the relative costs per port for CMTS and edge-QAM devices. The chart shows that edge QAM devices used in video applications hold a significant price advantage over equivalent CMTS port costs. A CMTS supporting the wideband protocol leverages this advantage by allowing the use of existing QAM devices, thus, lowering the cost of implementation.

CMTS and Video Port Comparison



Source: Infonetics, In-Stat/MDR, Cisco Analysis

Eliminate Port Under-Utilization (Stranded Ports)

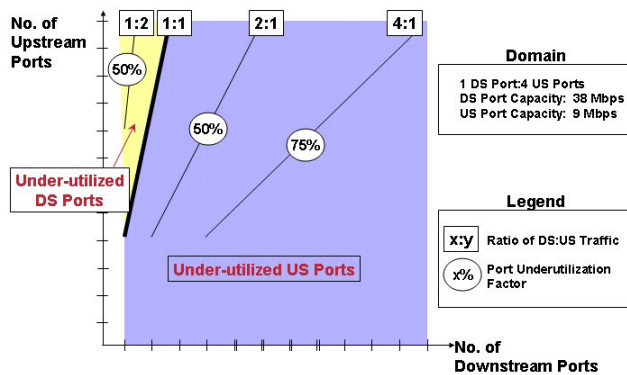
CMTS port assignments were designed around a traffic formula based on studies of anticipated preliminary broadband services and subscriber usage when DOCSIS was

originally formulated. This resulted in the simultaneous support of traffic in upstream and downstream directions and line cards equipped with a fixed ratio of upstream and downstream ports. Typical calculations held to a calculated ratio of one downstream per four or six upstream ports.

The ratio, understandably, was very conservative in the assumptions it made. In addition, it was difficult to predict or anticipate the development of new IP applications that dramatically challenge these assumptions and prevent operators from optimizing port utilization. The net result of this is that some number of ports (either upstream or downstream) will be under-utilized.

The following figure shows how line cards, deployed with a 1:4 port domain are under-utilized for various traffic scenarios. Since the capacity of a downstream channel is roughly four times the capacity of an upstream channel in this example (256 QAM in the downstream, 16 QAM/3.2 MHz in the upstream), the ports in the one downstream – four upstream domain are 100% utilized if the downstream traffic required on the network is equal to the upstream traffic (1:1 traffic ratio line). In the cases where twice as much traffic is required for the downstream than for the upstream (2:1 traffic ratio line), the upstream ports will be 50% underutilized. Finally, if the traffic in the downstream is four times the upstream traffic (4:1 traffic ratio line), the 1:4 port ratio will translate into a 75% upstream port under-utilization.

CMTS Port Utilization



The only way to avoid the under-utilization of upstream or downstream ports is to be able to assign upstream and downstream ports independently of one another. CableLabs' M-CMTS initiative aims at providing this benefit. The wideband technology achieves the same goal with today's CMTS and edge-QAM technology, yielding better utilization of infrastructure and lower cost per subscriber.

Improve Network Efficiency

As a shared access medium, cable networks hold an economic advantage over other access technologies due to the ability to oversubscribe the access plant. Not all users are going to be actively transmitting data at the same time. The determination of an appropriate oversubscription rate is a complex effort—and dependent upon a number of factors such as customer usage patterns, the size and frequency of the traffic bursts, the nature of the content carried, the priority levels for the various types of traffic, and the ratio of peak customer traffic to offered capacity. Cable operators are constantly trying to balance subscriber satisfaction metrics with the need to maintain oversubscription as high as possible in order to have a large number of subscribers sharing the same port, thus reducing the cost per sub.

The wideband protocol offers a simple, yet powerful tool: a “larger pipe”. Complex mathematical models have demonstrated that in the case of bursty traffic, such as the traffic generated by Internet users, a higher capacity transmission medium will show better statistical multiplexing characteristics since the probability of transmission collisions are reduced. Wideband offers such statistical multiplexing gain by logically bonding multiple QAM channels and increasing the total channel capacity. In other terms, this means that logically bonding multiple QAM channels will increase the number of subscribers per QAM (or per port).

Looking ahead, both higher data rate tiers, as well as emerging applications such as IP-based video will change the traffic characteristic. In this scenario, the number of subscribers that will be able to share a single channel will be significantly reduced, making the current technology less and less profitable. The wideband protocol offers the ability to maintain the same level of oversubscription rates, despite increasing customer demands for higher throughput.

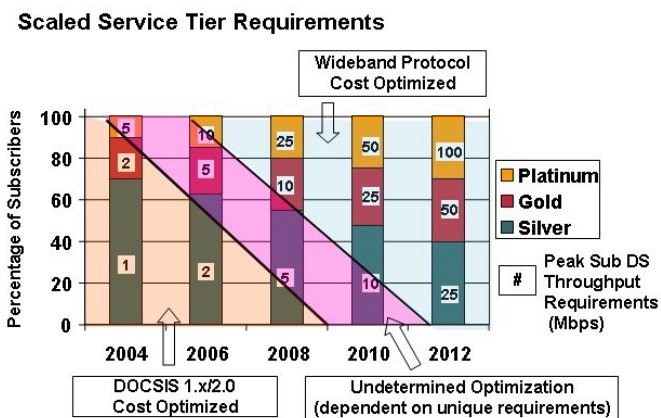
Scale to Future Requirements

Wideband technology offers deployment flexibility. Because a wideband logical channel can be dynamically defined to be a bundle of two, four or any number of QAM channels up to 24, as defined in my initial proposal for DOCSIS 3.0, cable operators will be able to choose, over time, the required channel capacity according to their business needs.

On the modem side, cable modem tuner technology is available today to allow multiple QAM channels to be received simultaneously, enabling wideband service. Such technology represents an important evolution because it allows multiple channels to be demodulated by a single, digital

multichannel receiver chip, instead of multiple discrete traditional receivers, adding complexity and cost to the modem. This means that first generation wideband modems will have built-in capability to receive up to 16 channels, enabling the operator to scale to future bandwidth and throughput requirements, without changing the wideband installed base.

The figure below illustrates projected high-speed data services that cable operators may see in the coming years. In each case, the service offering is split into three or more tiers. A graphic (the diagonal stripe) is superimposed on the chart, indicating the long-term costs of using wideband protocol versus DOCSIS 1.x/2.0 technology. The precise placement of this diagonal stripe is determined by exact costs for the CMTS and cable modem expenses, as well as oversubscription rates.



Regardless, the conclusion is that for many years to come, the most cost-effective network is one that simultaneously delivers services to both sets of customers.

Minimize Operational Cost

Backwards-Compatible with DOCSIS 1.x/2.0

Cable operators must consider how to continue to innovate and introduce new services to the market, without abandoning

their current customer base or requiring costly equipment upgrades. The wideband protocol for a DOCSIS network addresses this by leaving unchanged the DOCSIS 1.x/2.0 network and the subscribers it supports. Yet it provides incremental opportunities to begin servicing customers that demand higher data rates.

Looking ahead, cable operators will increasingly support service tiers and packages that offer varying throughput speeds and quality assurances. This will inevitably fragment customer requirements; many will focus on lower-speed, value-priced services, while a smaller percentage will demand higher-speed services. The challenge to cable operators will be to cost-effectively serve all customers.

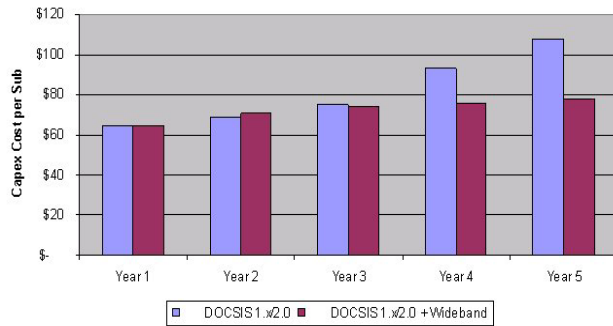
The wideband protocol is ideally suited for this situation. Because it builds upon existing CMTSs and the DOCSIS 1.x/2.0 protocol, it does not affect the customers that are currently served on the plant today. New customers can be served simultaneously with DOCSIS 1.x/2.0 customers from the same CMTS. Additionally, existing provisioning systems and operational processes can be leveraged. This offers an ideal environment for cable operators to employ, given the flexibility that is offered.

WIDEBAND BUSINESS CASE SUMMARY

The previous sections have detailed a multitude of factors that each contribute to the business case for wideband technology. This section illustrates the combined effect of each of these factors in providing a compelling business case for deploying the wideband protocol. The charts that follow summarize the financial results for two deployment scenarios: one using DOCSIS 1.x/2.0 technology, and one using both DOCSIS 1.x/2.0 and wideband. The model is based upon a cable footprint of 1 million HHP, with

existing high-speed data take rates of 25% in year 0 (to reflect the embedded base of equipment and customers) increasing up to 40% in year 5. The chart illustrates how the wideband technology significantly lowers CapEx per subscriber.

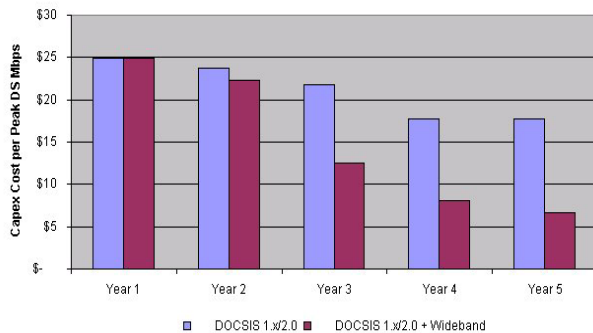
CapEx Cost Comparison – Same Service Mix



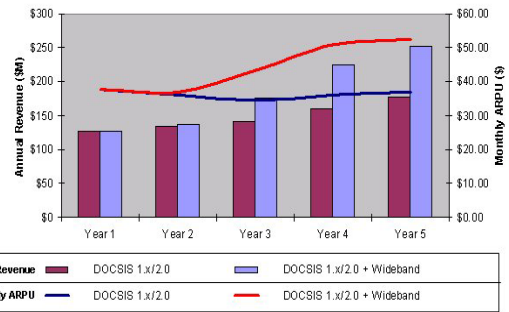
But this direct comparison tells only half of the story. A primary reason for using wideband technology is to offer even higher service throughputs, delivering more value, and capturing more revenue. The remaining charts summarize the financial benefits when the wideband protocol is deployed, enabling cable operators to deliver services as high as 100 Mbps data throughput.

The CapEx cost per Mb will decrease significantly as a result of using the wideband protocol. The improved revenue and earning results speak volumes to the benefits of being able to offer higher-speed services.

CapEx Cost Comparison – Different Service Mix



Revenue Comparison – Different Service Mix



Earnings Comparison (EBITDA) – Different Service Mix



The following conclusions can be made from this business analysis:

- Wideband can dramatically lower network CapEx as subscriber throughput rates increase
- CapEx incremental costs required to support the wideband protocol are modest and significantly drive down per Mb cost
- Wideband offers the ability to retain and continually upsell existing customers to higher service tiers
- Wideband offers the ability to deliver higher-value and revenue
- Operating margins can be improved by offering higher priced service tiers

This analysis captures only the cost of delivering data capacity. Incremental services delivered over this transport offer further upside, particularly in the case of higher data rate services

FULFILLING CABLE’S VISION

Cable operators were the first, and arguably the most credible service providers

to articulate the vision of an intelligent, flexible, secure, scalable network suitable for supporting multiple services simultaneously. The use of IP, and the framework established by DOCSIS have been key factors leading to the articulation and fulfillment of that vision. But the vision can only be fulfilled if the full capacity of the network is leveraged and made available to the end user.

The wideband protocol for a DOCSIS network, with its ability to unleash the full potential of the HFC network, is the key to making this happen. No longer will cable operators be blocked by artificial restrictions imposed by historical assumptions and RF channel management techniques. For as much of the spectrum an operator allocates towards IP-based services, a customer can theoretically access. But while the wideband protocol for a DOCSIS network can provide access to this inherent competitive advantage, the real challenge will come in how operators translate this potential into a true strategic business initiative.

Cable won the initial battle of broadband and the triple play. Will the industry be able to win the next round? Wideband and subsequent strategies lay the foundation for this and provide the catalyst for change for years to come. The outlook for the cable industry's success very much depends upon how effectively cable operators leverage this advantage. But there is an additional benefit that is as important if not more so. While the wideband protocol for a DOCSIS network makes more efficient use of the bandwidth inherent in the HFC network, it also gives operators the ability to unleash the full power of IP, as well as take a major step towards achieving true network and service convergence. As the subject of follow-on papers, this will be the remaining piece to our challenge in achieving a successful business plan that embraces a true wideband perspective.

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ABOUT THE AUTHOR

John T. Chapman is currently a Distinguished Engineer and the Chief Architect for the Cable Business Unit at Cisco Systems in San Jose, California. As a founding member of the Cisco Cable BU, John has made significant contributions to Cisco and the cable industry through his pioneering work in DOCSIS and development of key technologies and concepts critical to the deployment of IP services over HFC plants.

Included in these achievements are being the primary author of significant portions of the DOCSIS and PacketCable specifications as well as the originator of DOCSIS Set-top Gateway (DSG) and evolving specifications for DOCSIS Wideband and Modular CMTS architectures for the industry's Next Generation Network Architecture (NGNA) initiative. John has also published a number of ground breaking whitepapers on Multimedia Traffic Engineering (MMTE), DSG, QoS, and high availability and is a respected and frequently requested speaker at industry events.

John has 18 patents issued and 27 patents pending in a variety of technologies including telephony, VoIP, wide area networking, and broadband access for HFC cable networks. In his spare time, John enjoys spending time with his wife and two daughters. John is a 6th Degree Black Belt Master in Tae Kwon Do and enjoys white water canoeing and skiing.

Previous papers by John may be found at <http://www.johntchapman.com>