ENGINEERING ECONOMICS – DOCSIS 3.0 CHANNEL BONDING FOR IMPROVED NETWORK ECONOMICS

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Abstract

DOCSIS 3.0 (D3) enables channel bonding, i.e. multiple downstream (DS) and multiple upstream (US) RF carriers that can be combined to provide a wideband service.

In this paper, we demonstrate that channel bonding not only provides multi-system operators (MSOs) with the opportunity to offer faster speeds to their customers, but also provides an opportunity to reduce capital required to meet the growing traffic demand. Combinatorial models were used to assess the opportunity for such load balancing gains. Later, empirical data was used to measure the load balancing gains achieved on a plant with D3 cable modem termination systems (CMTSs). Eventually, results from a trial with paying subscribers demonstrated the impact of providing D3 modems to select customers.

The paper demonstrates that instantaneous load balancing achieved through channel-bonding provides carriers with substantial improvement in engineering economics.

A NEED FOR SPEED

The Internet eco-system is flourishing; subscribers love the ease and convenience of broadband access, while content providers have embraced this new platform to provide an ever-increasing plethora of data intensive services – video email, video chat, video-conferencing, music, streaming video, cloud storage and cloud computing to name but a few.

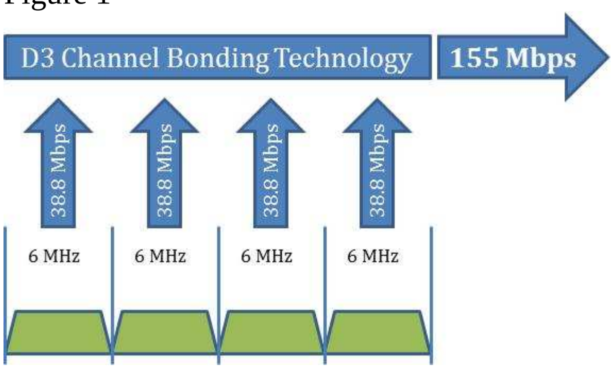
Over the last 15 years the Internet has grown from a novelty to a necessity. Be it communications, travel plans, information, education, news or entertainment, individuals are very likely to use the Internet. Over the same period, internet access has undergone a massive shift, from dial-up modems providing 14.4 kbps to always-on broadband access at DS speeds in excess of 100 Mbps as consumers have embraced faster and faster broadband speeds. MSOs have been leading the way in providing broadband access – by embracing DOCSIS as a way to provide broadband services to their customers. Until a few years ago, in the absence of cable's competitive broadband services, the only way to get a 1.5Mbps service was to pay upwards of $1,000 per month for a T1 from the local or competitive telephone company. Today, the most common broadband packages, with DS speeds in excess of 6Mbps, start at around $40 to $50 per month.

In the early days of DOCSIS, MSOs in North America provided broadband service by using a single 6 MHz channel for DS, and another 3.2 MHz carrier to provide US service. Improvements in modulation eventually enabled ~38 Mbps DS and ~ 10 Mbps US with each of these carriers. And, until recently, a single 38Mbps DS carrier was shared across a group of subscribers (service group) to provide customers with economical access to broadband speeds, while ensuring that customers received a desirable experience.

The development of the DOCSIS 3.0 standard changed that. D3 enabled multiple channels to be bonded into a single service group and was a direct result of subscribers' appetite for faster and faster speeds. To provide speeds in excess of 38 Mbps bonded RF channels become an absolute necessity as the service speeds exceed the offered line rate.

Today, MSOs in North America are typically bonding 4 to 8 DS channels and are beginning to bond 2 to 3 US channels. Channel bonding has enabled DS speed offers in excess of 100 Mbps, while demonstrating DS speeds of up to 1 Gbps. US speeds of 20 Mbps have been offered to customers; US speeds of up to 100 Mbps have been tested. This growing ecosystem has resulted both in an increase in number of subscribers using broadband, as well as increased demand per subscriber. In recent years, demand per subscriber has been growing at ~45 to 50% CAGR. For an MSO, this translates into the need to double the capacity of their high speed data (HSD) networks every 18-24 months.

Figure 1



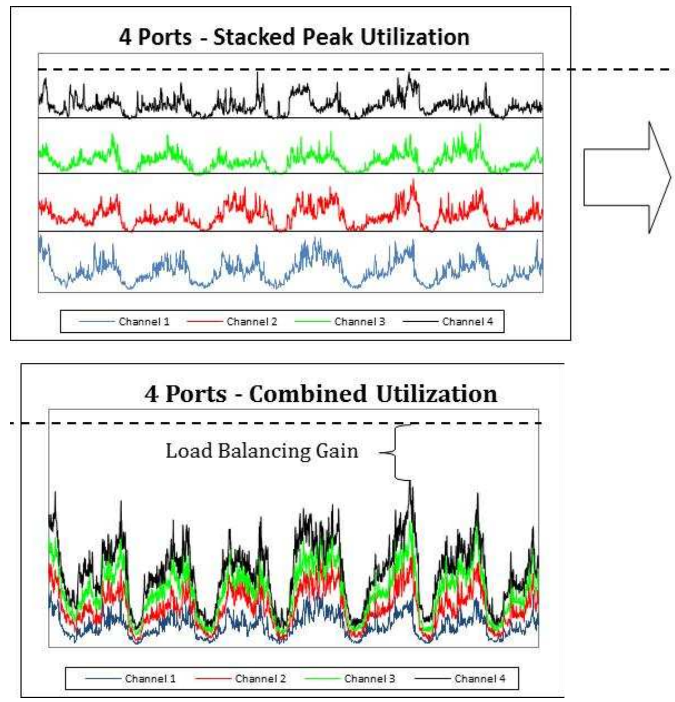
WHAT OTHER ADVANTAGES MIGHT ARISE OUT OF CHANGES IN ARCHITECTURE?

Once the D3 rollout began, there was an increased interest in understanding what other benefits might be derived from the bonded channels – something akin to increased operational efficiency of trunks as explained with Erlang math – fatter pipes are more efficient. Specifically, did channel bonding enable any statistical multiplexing or load balancing gains?

LOAD BALANCING GAINS

Load Balancing enables better use of network bandwidth by managing the network to the Peak of the bonded group and not by managing each port to its own peak. In our case, while observing the utilization of individual DS channels, it was noted that the peaks for multiple channels rarely occur at the same instance. For our purposes, the diagram below illustrates how we viewed the opportunity for statistical load balancing gains.

Figure 2



The top chart has peaks stacked, one upon the other; the bottom has traffic layered. The latter provides stat-mux gain over the former.

Early on, it was very clear to us that channel bonding could unlock some fairly significant network efficiencies as we increase the number of channels included in each SG. Our work helps determine the ranges of those gains and efforts that might be needed to capture those gains.

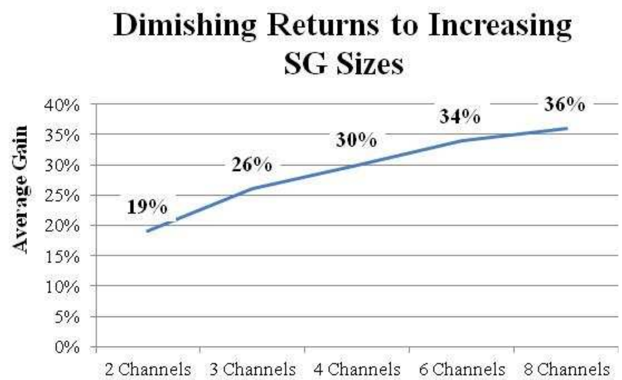
COMBINATORIAL ANALYSES TO APPROXIMATE STATISTICAL MULTIPLEXING GAINS

Prior to deployment of actual D3 networks, attempts were made to quantify the magnitude of hypothetical statistical multiplexing gains that could be possible. To that end, combinatorial models[1] were used to combine pools of existing DS channels into hypothetical service groups of 2, 3, 4, 6 and 8 channel combinations.

1. 5-minute channel utilization records were used.
2. All ports were combined into 2,3,4,8 channel bonded-groups.
3. Peak utilization for the period for each DS channel in the hypothetical SG used in the calculation was noted.
4. A SG peak for the combination was calculated by layering each of the 5-minute values for the channels that made up the hypothetical SG and finding the SG peak value. [Value A]
5. Gains were calculated by dividing the calculated SG peak by the sum of the individual peaks of the channels comprising the SG [Value B] and subtracting 1.
6. Distributions of these potential gains i.e. [(Value B-Value A)/Value B] are summarized in Figures 3 and 4.

Later, larger samples that included more channel/SG combinations from multiple markets were developed to evaluate the gains. Evidence indicates diminishing returns. 2 channels provide 19% gain, 3 channels provide 26% gain, or an incremental 7% points over 2 channel. 4 channels provide 30% gain, or an incremental 4% points over 3 channels, etc.:

Figure 3

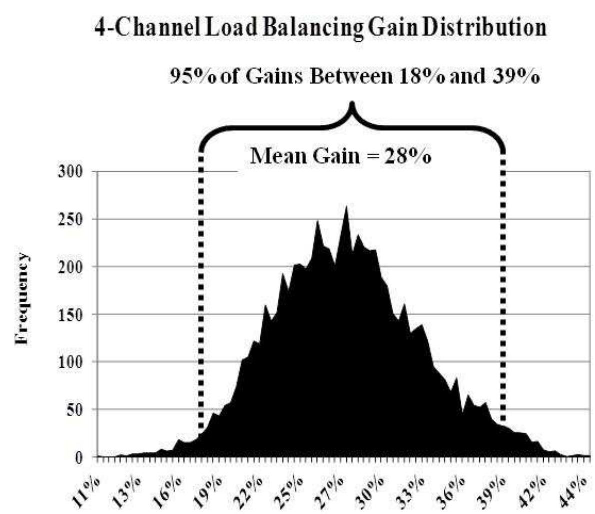


THERE IS A DISTRIBUTION WITH RESPECT TO LOAD BALANCING GAINS

While we were able to calculate the average gains from 2, 4, 6, and 8 port combinations, a quick glance at the distribution chart in Fig. 4 illustrates the fact that the gains are not uniform, but are normally distributed.

Our initial work focused on a single CMTS with 22 ports. We grouped the 22 ports into 7,315 4-Port SG combinations ($_{22}C_4$) and calculated the gain for each.

Figure 4



In this set, we found that the "worst" combination provided a gain of 11%, while the "best" was nearly 45%.

[1] Models implemented in Matlab. Neha Gadkari performed simulations in support of this analysis.

For our purposes, it appeared that network efficiency gains of approximately 25 to 30% could be realized for the (then) typical DS SG deployment of 3 or 4 channels.

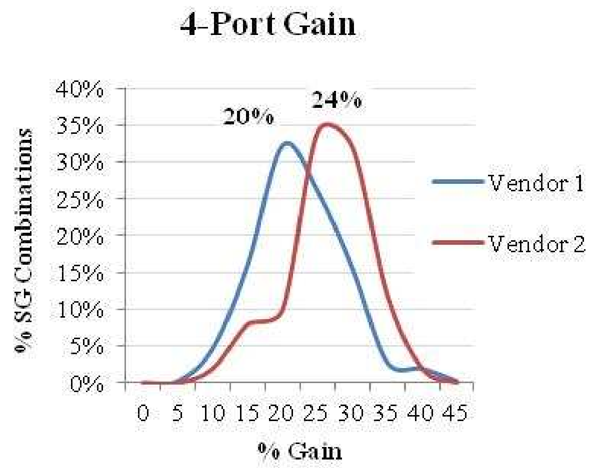
PRODUCTION D3 SERVICE GROUPS EVALUATED FOR REMAINING STAT MUX GAINS

As empirical data became available on production D3 service groups, additional combinatorial analyses were performed to determine if there was any load balancing opportunity remaining as the CMTS vendors had implemented load-sharing algorithms to balance traffic on SGs where majority of cable modems were still not D3. Our data set for this portion of the analysis consisted of over 300 4-channel service groups.

The data showed that most of the 25-30% load balancing gain was still on the table. For one vendor, the average opportunity was~ 20%, while it was closer to ~24% for the other vendor. This led us to conclude that significant gains could be achieved only through instantaneous statistical load balancing.

While vendors raced to develop various load-sharing algorithms to help balance demand across multiple RF channels, it was clear that without the deployment of significant numbers of D3-enabled devices that these significant statistical multiplexing gains would prove elusive as D3-devices enable instantaneous load balancing.

Figure 5



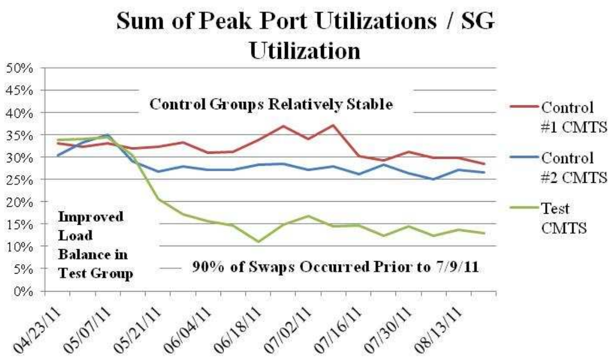
TESTING THE HYPOTHESIS

To further our understanding of what additional stat mux gains could be attained, we conducted an experiment where we provided D3-enabled gear to a large number of subscribers on a CMTS in one Comcast market. Two additional CMTSs in the same market were used as controls.

Over a period of approximately 2 months, select customers were provided new D3 CPE or modem and self-install kits. In addition, all new additions in the market (test as well as control CMTSs) were provided D3-CPE to prevent new users from inadvertently influencing results.

Measurement of the available gains on the SGs of the test CMTS as well as those on the controls indicated that there were about 30 to 35% gains available at the beginning of the study. As targeted modems on the Test CMTS were swapped by our customers and as new customers were supplied D3-enabled gear, we found that the deployment of the D3 gear was generating the desired effect – that load balancing gains were being generated (see Fig. 6). That is, the sum of the peaks of the individual channels that made up the SG and the actual SG peak were converging.

Figure 6



IMPLICATIONS FOR NETWORK EFFICIENCIES

Given a sufficient penetration of D3 gear that most, if not all of the hypothetical gains can be realized. A one-time gain of 20-30% in network capacity offers meaningful returns and can be exploited by MSOs to improve the bottom line as load balancing gains provide savings for years to come.

A simple model illustrates the annual network impacts of a 20%, 1-time gain (see Fig. 7.) In year 1, a 20% impact is recorded. Capital expenditures in that year plummet 64% vs. the business as usual (BAU) view.

Figure 7

	Demand Index - BAU	Demand Index with 20% Gain	Incremental - BAU	Incremental with 20% Gain	% Reduction in Annual Incremental Demand
Year 0	1.00	1.00			
Year 1	1.45	1.16	0.45	0.16	-64%
Year 2	2.10	1.68	0.65	0.52	-20%
Year 3	3.05	2.44	0.95	0.76	-20%
Year 4	4.42	3.54	1.37	1.10	-20%
Year 5	6.41	5.13	1.99	1.59	-20%
Year 6	9.29	7.44	2.88	2.31	-20%

However, the gain is the gift that keeps on giving; with annual expenditures continuing to track 20% below BAU figures.

CONCLUSIONS

While channel bonding has enabled MSOs to offer DS speeds in excess of 100 Mbps and US speeds in excess of 20 Mbps, it offers significant engineering economics. With 4 or 8 bonded channels, MSOs can expect 25-30% gain in network efficiencies through instantaneous load balancing. As more cable modems are upgraded to D3 over the next few years MSOs will benefit from these engineering efficiencies in their capital outlay for years to come.