Capacity-Based Bandwidth (CBB) Tariff Charges for Delivering IPTV over Wholesale Network Access:

Estimate of Marginal Bandwidth Costs

Prepared for:
TekSavvy

Prepared by:
Nordicity

September 16, 2014

225 (4) 09/14

Table of Contents

List of Figures

List of Tables

Executive Summary

In August 2014, TekSavvy engaged Nordicity to assess the feasibility of a potential IPTV service delivered by TekSavvy under the current capacity-based billing (CBB) wholesale rates established by the CRTC.

In response to TekSavvy's request, Nordicity developed a model that can be used as a baseline for investigating the feasibility of a potential IPTV service provided by TekSavvy. Overall, the results of this model show that the CRTC's current CBB wholesale tariffs establish very high rates for the delivery of IPTV over wholesale network access (WNA).[1]

This report provides the results of the assessment conducted by Nordicity on behalf of TekSavvy.

The table below summarizes the main results, showing the incremental bandwidth costs incurred by the IPTV traffic delivered over WNA using the current CBB rates charged by Bell, Rogers and Videotron.

[1] The term Wholesale Broadband Access (WBA) is used in several jurisdictions and regulatory environments (UK, EU) to denote wholesale broadband products that communications providers (CPs) provide for themselves and may offer to each other. It is important for consumers because these services are one of the building blocks of the retail broadband offers that consumers buy.
http://stakeholders.ofcom.org.uk/consultations/review-wba-markets/summary

Table 1. Comparison of incremental CBB costs related to IPTV over WNA

	Service Speed	Monthly Access Rate (per subscriber)	Monthly Capacity Rate (per 100 Mbps)	Incremental CBB Costs for IPTV Traffic (Excess Peak Demand, Overbooked)	Incremental CBB Costs due to IPTV Traffic (DVR stream)	Total Incremental CBB Costs (IPTV with DVR)	Total ITPV CBB Costs (IPTV with DVR) (including access rate)
		(Canadian dollars)		($ per IPTV session/sub)	($ per DVR session/sub)	($ per sub - IPTV+DVR session)	($ per sub - IPTV+DVR session)
Bell	7 Mbps	**$25.47**	$1,036.49	$23.25	$38.76	$62.01	$87.48
Bell	10 Mbps	**$25.61**	$1,036.49	$23.25	$38.76	$62.01	$87.62
Bell	12 Mbps	**$25.61**	$1,036.49	$23.25	$38.76	$62.01	$87.62
Bell	16 Mbps	**$25.60**	$1,036.49	$23.25	$38.76	$62.01	$87.61
Bell	25 Mbps	**$25.62**	$1,036.49	$23.25	$38.76	$62.01	$87.63
Rogers	10 Mbps	**$14.25**	$1,400.00	$31.41	$52.35	$83.76	$98.01
Rogers	15 Mbps	**$19.06**	$1,400.00	$31.41	$52.35	$83.76	$102.82
Rogers	25 Mbps	**$21.00**	$1,400.00	$31.41	$52.35	$83.76	$104.76
Rogers	50 Mbps	**$22.69**	$1,400.00	$31.41	$52.35	$83.76	$106.45
Videotron	7.5 Mbps	**$15.37**	$2,031.00	$45.57	$75.95	$121.51	$136.88
Videotron	15 Mbps	**$22.35**	$2,031.00	$45.57	$75.95	$121.51	$143.86
Videotron	30 Mbps	**$23.77**	$2,031.00	$45.57	$75.95	$121.51	$145.28
Videotron	50 Mbps	**$26.89**	$2,031.00	$45.57	$75.95	$121.51	$148.40

The following conclusions may be drawn:

- A "reserved IPTV capacity" approach, meaning one which reserves bandwidth for the Internet Protocol Television (IPTV) service at the Wholesale Network Access (WNA) interconnection point regardless of simultaneous use of Internet access, is the most realistic to determine the additional capacity requirements necessary for a competitive IPTV offering. That is because incumbent (cable and incumbent local exchange carrier, or ILEC) operators today have technical means of reserving bandwidth on their own networks to ensure good quality of service (QoS) for their IPTV service offerings;
- The additional capacity–based billing (CBB) costs are driven by the need for WNA-based providers to be able to offer the quality of TV experience equivalent to that of an incumbent's service offering.
- In a conservative scenario that assumes a single IPTV session per subscriber, the estimate of additional CBB costs range from $23.25 (Bell) over $31.41 (Rogers) to $45.47 (Videotron) per subscriber.
- In the alternative scenario where there are multiple viewing sessions per household, and/or where the IPTV offering includes Digital Video Recorder (DVR) functionality in the home (any additional viewing sessions require additional reserved capacity and associated costs), the additional CBB costs will be higher, as shown in Table 1. In this scenario, these costs (per additional session per user) range from $38.76 (Bell) over $52.35 (Rogers) to $75.95 (Videotron).
- Under the current CRTC wholesale tariff framework, the total estimated costs of delivering a potential IPTV service, under a CBB regime and for the considered cases, range from $87.48 (Bell) to $148.40 (Videotron).

1. Background information

As a provider over Internet over Wholesale Network Access (WNA), TekSavvy provides high-speed (broadband) Internet access to its customers using the access infrastructure of incumbent local exchange carriers (ILECs) and cable carriers. The CRTC requires ILECs and cable carriers to make wholesale high-speed access services available to independent service providers at regulated rates.

In the current regulatory regime, service providers can access WNA through using two alternative billing models that supplement the base interface charges:[2]

1. Flat rate model, where WNA-based providers pay a flat fee (to incumbents) per month regardless of usage; and

2. Capacity–based billing (CBB), where ISPs have to determine in advance the amount of capacity they need from the incumbent and are charged accordingly. In a CBB regime, WNA is based in part on an access fee—per subscriber line, dependent on access speed, and on the aggregate capacity fee—charged in increments of 100 Mbps of traffic delivered from the incumbent's infrastructure to TekSavvy at a Point of Interconnect, POI. A POI is a location which connects an independent service provider's network to the incumbent's network in order to access retail customers through high-speed access paths on the incumbent's network (ILEC or cable).

The objective of this study is to assess the incremental **data-related costs** of providing an IPTV service over WNA, based on current CBB pricing. This study does not take into account all other costs associated with the provision of an IPTV service, such as the costs related to programming services affiliation fees and interconnection, encoding and encryption, transport, customer-premises equipment, billing and ordering systems, and customer service and support.

[2] See Telecom Regulatory Policy CRTC 2011-703, *Billing practices for wholesale residential high-speed access* services (15 November 2011), http://www.crtc.gc.ca/eng/archive/2011/2011-703.htm; Telecom Regulatory Policy CRTC 2011-704, *Billing practices for wholesale business high-speed access services* (15 November 2011), http://www.crtc.gc.ca/eng/archive/2011/2011-704.htm.

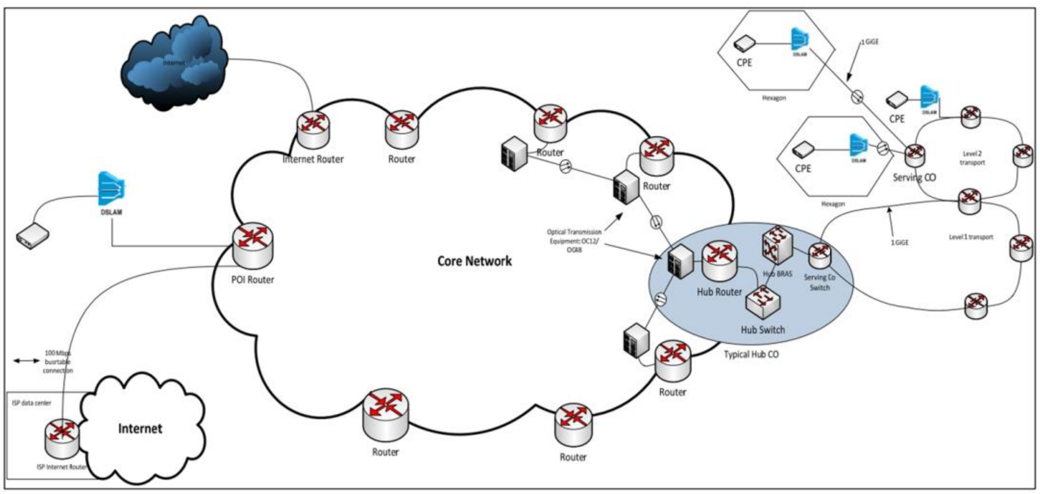
2. Generalized access model

For the particular incumbent cases that are investigated (Bell, Rogers and Videotron), there are two distinct architectural scenarios that describe how TekSavvy is offering Internet services to its subscribers using incumbent access infrastructure:

a. ILEC access model (applies to Bell), using Digital Subscriber Line (DSL);
b. Cable access model (applies to Rogers and Videotron), using hybrid fiber-coax (HFC).

The architectures of these two models are shown in the figures below.

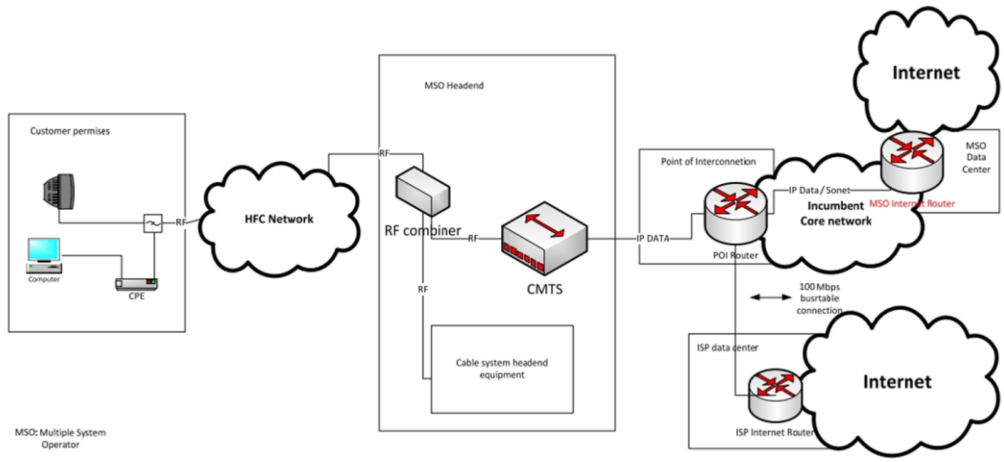
Figure 1. Typical ILEC access deployment architecture



Source: Bell Canada[3]

[3] Bell Canada, "Broadband Expansion Proposal, Follow up to Telecom Decision CRTC 2006-9, *Disposition of funds in the deferral accounts* (1 September 2006), http://www.crtc.gc.ca/public/partvii/2006/8638/c12_200602708/662133.zip (document "Part VII - Correspondence to CRTC - Bell Canada - Submission.DOC"), original submission.

Figure 2. Typical cable access architecture



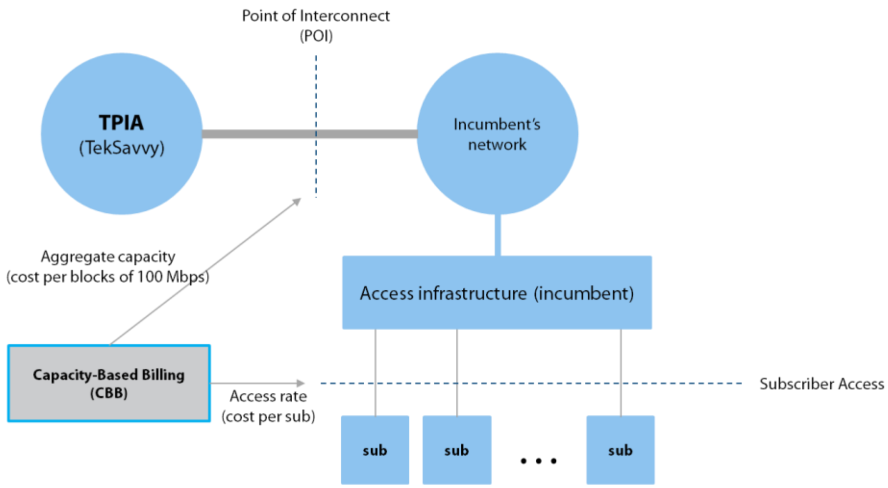
Source: Imagineering Telecom Inc. (for CRTC)[4]

Both of these architectures have been abstracted to the *generalized access model*, shown in the Figure 3, below. Consequently, in our analysis, this generalized access model was used.

---

[4] Imagineering Telecom Inc., Report On Third Party ISP Access To Major Canadian Cable Systems For the CRTC (2 January 2002), http://www.crtc.gc.ca/eng/publications/reports/isp/ispaccess.htm.

Figure 3. Graphical representation of the generalized WNA CBB model used in this study



3. Methodology

This report was prepared using secondary research methods. In particular, Nordicity conducted:

- A detailed market review on the current state-of-the-art of video streaming technologies as well as types and characteristics of video streaming options (SD, HD, 3D HD, 4K HD) and their streaming rates (throughput);
- Up-to-date statistics on users' TV viewing behaviour and typical household IPTV consumption patterns; and,
- Current CRTC regulations and wholesale tariffs.

We also took into consideration key video specifications, industry reports and vendor literature describing or outlining relevant topics in more detail.

In-house expertise and secondary research results were sufficient to determine a set of realistic key assumptions used in our analysis. Further examination and validation of data, as well as data processing and model development were done by the Nordicity team.

4. Assumptions

4.1 IPTV over Wholesale Network Access

The report adopts the following textbook definition for IPTV:

> *"IPTV is simply a way to deliver traditional broadcast channels to consumers over an IP network in place of terrestrial broadcast, CATV, and satellite services. Even though IP is used, the public Internet actually doesn't play much of a role. In fact, IPTV services are almost exclusively delivered over private IP networks, such as those being constructed by telephone companies in the United States and elsewhere. At the viewer's home, a set-top box is installed to take the incoming IPTV feed and convert it into standard video signals that can be fed to a consumer television."*[5]

It is important to make a distinction between IPTV and Internet video, i.e., over-the-top video content that is accessed over WNA but delivered from the Internet (e.g., Netflix, Hulu, and YouTube).

In practical terms, an IPTV offering represents a set of continuous streams of (Internet Protocol) traffic, delivering professionally produced content (such as broadcast feeds). IPTV encompasses potentially hundreds of channels which are commonly sharing uniform content format(s) and are delivered over private network and are viewed on consumer television sets by way of a set-top box. Historically, IPTV has been delivered mostly in the form of "walled garden" implementations, by facilities-based providers who own and operate underlying transmission facilities. In both cable TV and "walled garden" IPTV, transmission facilities for TV delivery are fully controlled by the facilities-based providers: this control encompasses technical means to reserve dedicated bandwidth for IPTV traffic. Doing so ensures higher standards for Quality of Service (QoS) and Quality of Experience (QoE) of the IPTV offering for the end-users and subscribers.

In the case of IPTV over WNA, IPTV streams are delivered using the Internet Protocol in an incumbent access network that, while managed, must contend with mixed traffic (Internet and IPTV) in the segment adjacent to the end-user. In order to ensure good quality and QoE, access in this mixed-traffic environment needs to have enough bandwidth to support IPTV video streaming. Providing IPTV over WNA requires reserving additional network capacity to

---

[5] Wes Simpson, *Video over IP : IPTV, Internet video, H.264, P2P, Web TV, and Streaming : A Complete Guide To Understanding the Technology* (Boston: Elsevier/Focal Press, 2008) at p. 2.

accommodate this traffic. This incremental network capacity – in addition to capacity required by Internet traffic – is a direct result of IPTV requirements. Under a CBB regime, the incremental capacity incurred by IPTV requirements translates into additional capacity costs.

Regardless of the way IPTV is delivered – using implementations that achieve a "walled garden" end-to-end, or which ride on managed mixed-traffic WNA – the TV viewing experience is the same as in "traditional" TV service delivery (cable, satellite). IPTV signals are delivered to set-top boxes, which are further connected to TV sets, or IPTV streams can be directly terminated on computers, laptops, tablets and smartphones and watched on them.

Set-top boxes for IPTV over WNA may also incorporate Digital Video Recorder (DVR) or Personal Video Recorder (PVR) functionality.

Additionally, the DVR functionality for both "walled garden" and WNA-based IPTV can be located in the "cloud" (i.e. be network-based), assuming it is permitted under copyright rules.

4.2 Video streaming: state-of-the-art

Over the last several years, there have been significant improvements in video coding techniques, allowing mass-delivery of video streamed content with real-time, continuous adjustment of streaming video rates. One such technology is Dynamic Adaptive Streaming over HTTP (MPEG-DASH, standardized in the form of ISO/IEC 23009-1), which allows multimedia content to be delivered from *conventional HTTP servers* to a multitude of end-user devices. Previously, end-user devices had to support specific video standards and have enough processing power in order to be able to receive and display video streams.

These developments are worth mentioning since some of the leading multimedia delivery companies have been adopting MPEG-DASH and are able to deliver streaming content to multiple devices: connected TVs, advanced set-top-boxes, desktop and laptop computers, tablets and smartphones alike.

The use of adaptive video streaming techniques allows users to enjoy content without interruptions under changed network conditions. The quality of the delivered video streams is adjusted in accordance with the available bandwidth and also taking into consideration quality of service indicators. In turn, this allows delivery of IPTV streams to more people and under different network utilization scenarios. Interestingly enough, it is the OTT providers who are expected to have the strongest interest in MPEG-DASH. Netflix, for instance, started using it before it was finalized as an official standard. [6]

4.3 General IPTV Characteristics

IPTV differs from most other types of Internet Protocol traffic:

- Video streaming sessions have much **longer duration** than other typical Internet activities (web browsing, email, etc.), and IPTV video streaming sessions may have longer duration than Internet video streaming sessions.
- Video streaming sessions are **bandwidth-intensive**.
- Video streaming is **highly asymmetrical**: the bulk of the traffic is going "downstream" – from the network to the end-users.

4.4 Streaming Throughput

Our analysis focused on standard definition (SD) and high definition (HD) video streams. While newer and higher bandwidth video standards are becoming available (3D HD and 4K HD), the adoption rates for the 3D TV and 4K HD TV streaming services are still low. For that reason, we restricted our analysis to two types of video streams, with the following streaming rates (throughput):

- **SD (representing 480p), using 2.5 Mbps**,
- **HD (1080i), using 7 Mbps**.

These values are conservative, and they fall within the range of values largely accepted in the industry (1.0 Mbps-2.5 Mbps for SD and 2.3 Mbps-10Mbps for HD – 720p to 1080p.[7]

---

[6] Nicholas Weil, "The State of MPEG-DASH Deployment" (8 April 2014), *Streaming Media Europe*, http://www.streamingmediaglobal.com/Articles/Editorial/Featured-Articles/The-State-of-MPEG-DASH-Deployment-96144.aspx.

[7] Marc Mignon *et al.*, "Scaling server-based channel-change acceleration to millions of IPTV subscribers," 19th International Packet Video Workshop (10–11 May 2012), http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6229721; Netflix, "How can I control how much data Netflix uses," https://help.netflix.com/en/node/87; Adobe, "Recommended bit rated for live streaming," http://www.adobe.com/devnet/adobe-media-server/articles/dynstream_live/popup.html; Barb Gonzales, "All About Internet Speed Requirements for Hulu, Netflix, and Vudu Movie Viewing," http://hometheater.about.com/od/internethometheater2/a/Internet-Speed-for-Netflix-Vudu.htm.

4.5 Multicast and unicast

"Walled garden" IPTV implementations can achieve significant network cost savings by using IP multicast – a technique which allows them to send the same content to a large number of terminals without incurring additional network resources (i.e. each video session is a part of the video streaming group, which a subscriber can join). In IP multicast, one IPTV stream carrying one TV programming is replicated to a number of streams at the point close to subscribers, thus eliminating the need to carry large number of streams carrying essentially the same TV content. In addition to IP multicast, "walled garden" IPTV implementations may also employ other advanced techniques such distributed caching, in order to achieve greater cost efficiencies and further optimize the use of network resources.[8]

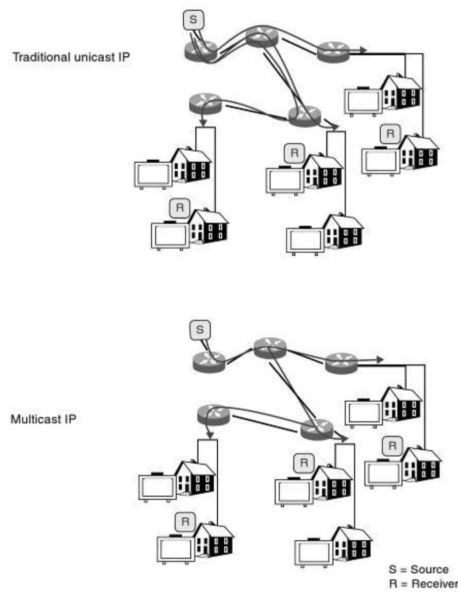
Unicast streams are IP streams carrying video content just to one subscriber (terminal). In broadcasting, Video on Demand is an example of unicast traffic.

In the case of IPTV over WNA, we are assuming that IPTV video streams are sent as **unicast** (i.e. each individual viewer is receiving a separate and dedicated IPTV stream), as the WNA-based provider does not own the physical access infrastructure and cannot easily (or at all) implement a cost-efficient multicast architecture, using existing wholesale broadband access arrangements with the incumbents.

---

[8] Alcatel-Lucent, Video Shakes Up the IP Edge: A Bell Labs Study On Rising Video Demand And Its Impact on Broadband IP Networks, Strategic White Paper (2012), http://www3.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=White_Papers/Video_Shakes_Up_IP_Edge_EN_Whitepaper.pdf.

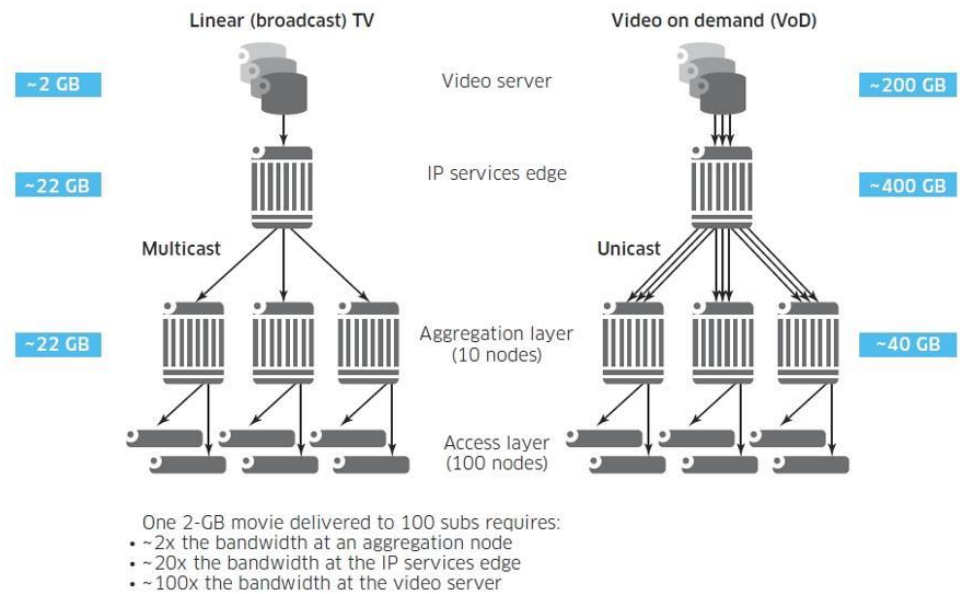
Figure 4. Unicast vs. multicast



Source: Daniel Minoli[9]

[9] Daniel Minoli, *IP Multicast with Applications to IPTV and Mobile DVB-H* (Wiley-IEEE Press, 2008) at p. 4.

Figure 5. Comparison of network bandwidth overhead between linear IPTV (multicast) and VoD (unicast)



Source: Alcatel-Lucent Bell Labs 2012[10]

4.6 IPTV viewing habits

To the end-user, IPTV service is presented as a form of ordinary digital TV service. For the purpose of this study we assumed that the Canadian TV audience is very similar and shares many of the viewing characteristics of the larger North American set of TV viewers. The rationale for this reasoning is:

- Canadian and US markets exhibit very similar technology adoption behavior;
- Canadian and US markets exhibit very similar (relative) viewing habits; and
- The window for primetime viewing is the same (6pm-11pm, peak 8pm-11pm).

Those TV viewing patterns have a significant impact on network capacity when IPTV is delivered over mixed-traffic WNA, in order to allow quality of experience to be comparable

[10] Alcatel-Lucent, Video Shakes Up the IP Edge: A Bell Labs Study On Rising Video Demand And Its Impact on Broadband IP Networks, Strategic White Paper (2012) at p. 6.

and competitive to that of TV delivered using the dedicated broadcast TV infrastructure (cable TV, satellite TV and "walled garden" IPTV).

4.6.1 Video mix (HD/SD ratio)

The assumption for the **potential HD/SD video mix** was based on the relative proportion of video-capable entertainment units, observed in the Nielsen Advertising report (May 2014)[11] and Television Bureau of Canada 2013-2014 statistics.[12] The most relevant statistics are captured in the table below. The Television Bureau of Canada report also provides an informative overview of time spent consuming major media (in Canada and in the US), which is provided in the figure below.[13]

It has been noted that the adoption of HDTV sets has surpassed 80%.[14] However, because the availability of HDTV content does not match the high adoption rates of HDTV sets, we have assumed that over an aggregate channel carrying video streaming traffic, the following mix of HD and SD streams would be present:

- **HDTV streams represent 40% of all IPTV traffic,**
- **SDTV streams represent 60% of all IPTV traffic**.

These percentages were made having in mind the observed ratios in real IPTV networks (Belgacom, Belgium, 2012[15]) and also observing the HDTV programming availability in the US[16] and in Canada,[17] as well as the recent trends in the adoption of HDTV sets. These

---

[11] Nielsen, *Advertising and Audiences: State of the Media* (May 2014), http://www.nielsen.com/us/en/insights/reports/2014/advertising-and-audiences-state-of-the-media.html.

[12] Television Bureau of Canada, *TV Basics 2013-2014*, http://www.tvb.ca/page_files/pdf/InfoCentre/TVBasics.pdf.

[13] Television Bureau of Canada, *TV Basics 2013-2014*.

[14] Nielsen, *The Digital Consumer* (February 2014), http://www.nielsen.com/content/dam/corporate/us/en/reports-downloads/2014%20Reports/the-digital-consumer-report-feb-2014.pdf at p. 5.

[15] Marc Mignon *et al.*, "Scaling server-based channel-change acceleration to millions of IPTV subscribers"; Marc Mignon *et al.,* "Scaling Server-Based Channel-Change Acceleration to Millions of IPTV Subscribers," http://www.employees.org/~acbegen/files/PV_05_2012_abegen.pdf.

[16] Deborah D. McAdams, "HDTV Adoption Surpasses 75 percent" (17 October 2012), http://www.tvtechnology.com/article/hdtv-adoption-surpasses--percent/215958.

[17] Television Bureau of Canada, *TV Basics 2013-2014;* Etan Vlessing, "Report: 58% of Canadians have HDTVs, but most don't view in HD" (13 November 2011), http://playbackonline.ca/2011/11/13/report-58-of-canadians-have-hdtvs-but-most-dont-view-in-hd/.

percentages are aligned with statistics observed in large OTT streaming networks (Netflix, 2013[18]).

In order to allow greater flexibility of our traffic model, this parameter was left as separately adjustable (settable). However, for the analysis performed, the above values were used, as they reflect realistic and conservatively chosen values.

4.6.2 Percentage of DVR/PVR

We assumed that **50%** of set-top boxes are equipped with DVR capabilities. This is aligned with the 2013-2014 statistics published by the Television Bureau of Canada. [19]

The effect of DVR use in IPTV will be the same whether the DVR functionality is implemented in the subscriber set-top box or in the network (cloud DVR): there will be additional IPTV streams (carrying DVR traffic) delivered to subscribers, and they will introduce additional bandwidth requirements in the access. For a WNA-based provider that wants to provide DVR functionality (which is a must-have feature in TV offerings today), this means that additional network capacity should be reserved and that additional CBB costs would be incurred.

It is worth noting that most of TV recording using DVR functionality take place during primetime. In that sense, from a network-delivery perspective, DVR traffic appears to be no different than live IPTV traffic. Therefore, the required incremental network capacity needs to encompass total IPTV requirements – for live IPTV and DVR.

---

[18] Bem Gilbert, "Netflix streaming most dominant on HDTVs, more than double PC and tablets" (22 January 2013), http://www.engadget.com/2013/01/22/netflix-streaming-usage-hdtv-pc/.
[19] Television Bureau of Canada, *TV Basics 2013-2014*.

Nordicity

Table 2. Comparison of major TV statistics between Canada and the United States

TVBasics 2013-2014

CANADA vs. THE UNITED STATES

		Canada	United States
1.	Population (2+ within TV households)	*34,056,000	**294,560,000
2.	Households	14,187,000	120,160,000
3.	BBM Markets, TV Markets – DMAs	42	210
4.	TV Households	13,946,000	115,811,000
	% TV Households	98.3%	96%
5.	Access to TV services - Cable, Satellite, IPTV (% of TV Households)	93.1%	90%
6.	TV Households with digital capability	85%	86%
7.	PVR (% of TV Households) 2013	52.5%	47%
8.	Multi-set (% of TV Households)	73.1%	85%
9.	Average Weekly Viewing (Hours:Minutes)		
	Persons 2+	27:18	34:15
	Adults 18+	28:48	38:08
	Adults 25-54	29:42	33:48
	Teens (12-17)	20:24	22:06
	Children (2-11)	20:42	25:16
10.	Advertising Volume (2012) - millions (CDN$); U.S. in U.S$	15,121	153,133
11.	TV Volume (2012) - millions (CDN$), U.S. in U.S$	3,578	62,019
12.	TV Expenditure Per Capita (2012) (CDN$), U.S. in U.S$	103	198
13.	Number of TV Stations 2012 (Conventional + Specialty & Pay stations)	350	1,381
14.	Commercial Time	Unlimited	***deregulated
15.	Commercial Time: Specialty Channels	12 min/hr	***deregulated

* Excludes Yukon, Northwest Territories and Nunavut
** Including Alaska and Hawaii
*** Practice varies from station to station, market by market, and by daypart with daytime generally having more commercial time than primetime.

Sources

Canada		United States	
1-5	BBM Canada, January 2014	1-8	The Nielsen Company, January 2014
6	Media Stats, September 2013	9	The Nielsen Company, Sep-Aug 2012-2013
7	BBM Canada, January 2014	10-12	TVB Net Ad Volume 2012
8	BBM Canada, January 2014	13-15	TVB U.S. 2012 VHF & UHF
9	BBM Canada, Sep-Aug 2012-2013		
10-12	TVB Net Ad Volume 2012		
13-15	CRTC		

Source: TVB Canada, 2013-2014

4.6.3 Viewing hours

According to the CRTC's Communications Monitoring Report (September 2013), average weekly television viewing hours have been 28.5 and 28.2 hours per week, respectively for 2011 and 2012. Additional statistics have been provided in Figure 6, and were taken from the TVB report.[20]

Figure 6. Overview of weekly hours spent on consumption of different media in Canada and the US

	TIME SPENT WEEKLY PER CAPITA HOURS	TOTAL CANADA	QUEBEC (French)
	Adults 18+	24.2	25.6
	Adults 18-34	16.6	18.0
	Adults 25-54	21.1	22.2
	Adults 55+	32.4	33.1
	Adults 18+	17.5	18.5
	Adults 18-34	13.5	14.5
	Adults 25-54	17.3	18.5
	Adults 55+	20.0	20.3
	Adults 18+	19.7	16.5
	Adults 18-34	30.0	25.9
	Adults 25-54	22.0	18.8
	Adults 55+	11.6	10.1
	Adults 18+	1.9	2.1
	Adults 18-34	0.6	0.6
	Adults 25-54	1.0	1.1
	Adults 55+	3.7	4.1
	Adults 18+	0.3	0.3
	Adults 18-34	0.1	0.1
	Adults 25-54	0.3	0.3
	Adults 55+	0.5	0.5

Source: BBM Analytics RTS Fall 2013 as presented in TVB Canada, 2013-2014

[20] Television Bureau of Canada, *TV Basics 2013-2014*.

4.6.4 Homes Using Television

Homes Using Television (HUT) (previously "Households Using Television") is a term widely used by the television industry. This metric, defined by Nielsen Media Research, is used to define the number of television homes using one or more sets during the average minute of a 15 minute time period. In other words, the term is commonly used to define the number of television homes using one or more television sets during a specified time period.[21] HUT is expressed in percentage format for all homes watching television. Nielsen's formula for calculating HUT (as a percentage) is the number of households with TV sets in use divided by the total household estimate.

Similarly, Persons Using Television (PUT) is another metric used in the broadcast TV industry. This term, defined by Nielsen Media Research, is used to designate the "percentage of persons using television at a given time." PUT may be further qualified by a certain demographic group. Nielsen's formula for PUT is the number of persons viewing TV divided by the *total persons universe*. Total persons universe or UE (universe estimate) is total number of persons or homes in a given population (e.g., TV households in Canada).[22]

In order to quantify the effects of additional required network capacity and related costs under the CBB regime driven IPTV service delivered over WNA, HUT was considered more relevant for this study. It is realistic to expect that IPTV subscribers would exhibit similar HUT rates.

For this study, we assumed an **IPTV HUT of 60%**. This assumption was based on 12-month average HUT values in the 2002-2013 period, as published by Nielsen.[23]

4.6.5 Multisets

As shown in Table 2, percentage of TV households in Canada with more than one TV is over 70%.

---

[21] Nielsen Media Research, "Television Audience Measurement Terms," http://www.nielsenmedia.ca/English/NMR_U_PDF/TV%20Terms.pdf; American Interactive Marketing, "Ratings, Share, HUTs and PUTs," http://americaninteractivemarketing.com/tag/h-u-t-houses-using-television.
[22] Nielsen Media Research, "Television Audience Measurement Terms."
[23] TVB, HUT/PUT National Prime Trends, http://www.tvb.org/media/file/TVB_Measurement_Monthly_HUT_Trend.xls.

4.7 Overbooking ratios

The most critical part of our assessment deals with *overbooking (oversubscription) ratios*.

Overbooking or oversubscription refers to the practice of dimensioning aggregate upstream network interfaces with a fraction of capacity needed to simultaneously satisfy maximum bandwidth requirements in the access network. By overbooking, we effectively apply statistical averaging to describe that not all the subscribers will be utilizing their access bandwidth at the same time. Overbooking has been a norm in the telecommunications industry and can be applied to scenarios involving subscribers using different access technologies (DSL, HFC/cable, FTTx).

As it applies to a large number of simultaneous users exhibiting similar network behavior, overbooking factors can be expressed on a per user basis.

Overbooking can also be hierarchically implemented throughout the network, where different tiers of network (interfaces) can be assigned different overbooking ratios. Typically, oversubscribing factors get higher as we approach the network core, as the statistical benefits to large scale averaging become dominant.

4.7.1 Overbooking

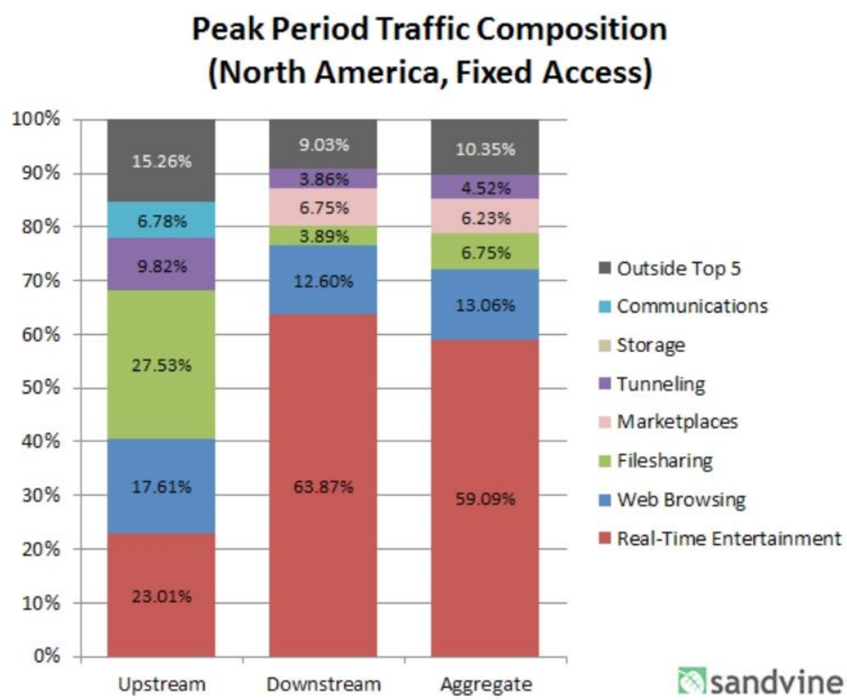
Overbooking or oversubscription allows WNA-based providers to benefit from the stochastic nature of IP traffic and the statistical multiplexing associated with it. In other words, the fact that end-users are not simultaneously using all their access bandwidth to its maximum (and related network resources) allows WNA-based providers to set overbooking ratios and save some network resources upstream – in the network. In the mixed-traffic WNA environment, overbooking is useful for dimensioning required POI capacity from the incumbents, but it has to take into consideration the knowledge of their POI architecture and subscriber distribution across POI, as well as consideration of typical subscriber online behavior and the actual traffic. Historically, in such environments it has not been uncommon to see overbooking ratios to range between 50:1 to 100:1. “Alcatel-Lucent Triple Play Service Delivery Architecture” whitepaper references overbooking factor of 70.[24]

---

[24] Alcatel-Lucent, “Alcatel-Lucent Triple Play Service Delivery Architecture” (2007), http://hhs.janlo.nl/articles/Triple-Play%20Service%20Delivery%20Architecture.pdf at p. 1.

With the proliferation of real-time entertainment, upstream overbooking factors have to be adjusted to accommodate increased consumption driven mostly by OTT video streaming. In fixed networks, up to 70% of all downstream traffic may be caused by real-time entertainment, as shown in the figure below.[25]

Figure 7. Peak period Internet traffic composition

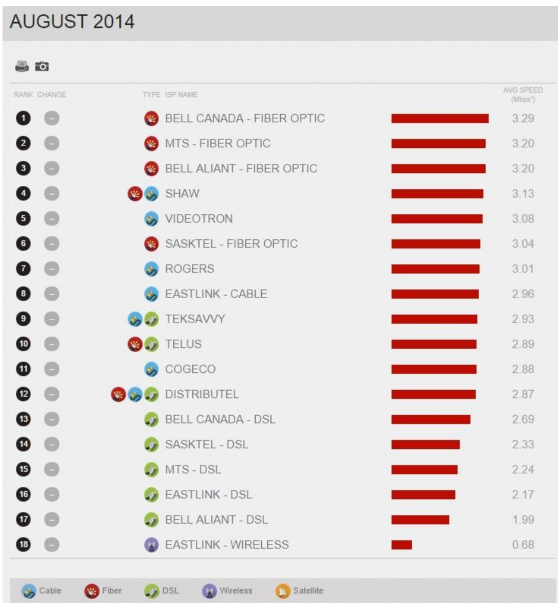


Source: Sandvine

[25] Sandvine, *Global Internet Phenomena Report*, 1H (2014), https://www.sandvine.com/downloads/general/global-internet-phenomena/2014/1h-2014-global-internet-phenomena-report.pdf at p.5.

In particular, Netflix streaming has had a very significant impact on broadband providers, and especially on WNA-based providers, as demonstrated in diagram below, which outlines average streaming throughputs per Netflix session for several Canadian ISPs.[26]

Figure 8. Canada ISP Speed Index



Source: Netflix

The Alcatel-Lucent whitepaper correctly anticipated this new reality:

> *"Video streaming through Web browsing is growing quickly to consume more bandwidth than all other traditional Internet voice and data traffic combined, impacting the core networks as much as the metro and regional networks. With this new requirement, HSI [High Speed Internet] can no longer be considered a best-effort service as end users are now expecting high quality streaming video on their personal computers. Therefore, operators must deliver more bandwidth to*

[26] Netflix, Canada ISP Speed Index (August 2014), http://ispspeedindex.netflix.com/canada.

consumers and cannot continue to engage in heavy oversubscription as previously done with best effort HSI services at the risk of increasing customer churn."[27]

In this study, our assumption was that upstream overbooking factors today would be in the range of 20:1 to 30:1, in order to allow for solid quality of viewing experience for OTT streaming such as Netflix.

Since overbooking is paramount for both WNA- and incumbent-based services, it is not surprising that there is very little or no public information about the actual overbooking factors used in the networks today.

We used the upstream overbooking factor of **20:1**, basing this assumption on limited publicly available information.[28] This value can be set by TekSavvy to reflect their network reality.

> *"In an unshared access network like DSL, the full capacity of the connection is only available for the customer served by that connection. The capacity cannot be handed over to another user. In contrast, in a shared medium, the total capacity is available for all customers. In reality though, not all users are active, and even if active, many applications produce an intermittent stream of packets. Statistically, a fixed ratio is found between the maximum bitrate and the averaged bitrate during 10 minutes of a service's peak hours. This ratio is called the overbooking factor. Today, an overbooking factor of about 20 applies. For a shared medium, this overbooking allows cable providers to offer broadband services with a bitrate 20 times larger than the available capacity per customer. For example, in the case of a EuroDOCSIS 3.0 service with 8 bonded channels of 416 Mbps together and 416 customers, there is a capacity of 1 Mbps available per customer. Thus the cable provider can deliver a 20 Mbps basic broadband service to all 416 customers."*[29]

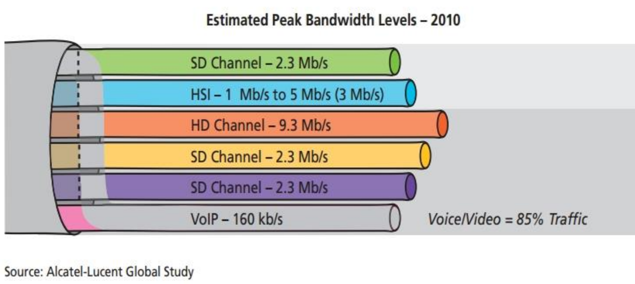
---

[27] Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007) at p. 2.
[28] TNO, *Evolution and prospects cable networks for broadband services: A technical perspective of the European and specifically the Dutch cable networks* (31 August 2012), http://nlkabel.nl/wp-content/uploads/2012/08/TNO_Evolution_and_propects_cable_networks_for_broadband_services.pdf.
[29] TNO, *Evolution and prospects cable networks for broadband services: A technical perspective of the European and specifically the Dutch cable networks* (31 August 2012) at p. 13.

4.7.2 "Walled garden" IPTV and overbooking

In "walled garden" IPTV implementations, IPTV is provisioned using dedicated access and network resources, guaranteeing high bandwidth for premium IPTV content. One example, where 9.3 Mbps is reserved for IPTV HD content is shown in the figure below.

Figure 9. Estimated peak bandwidth per user per traffic type

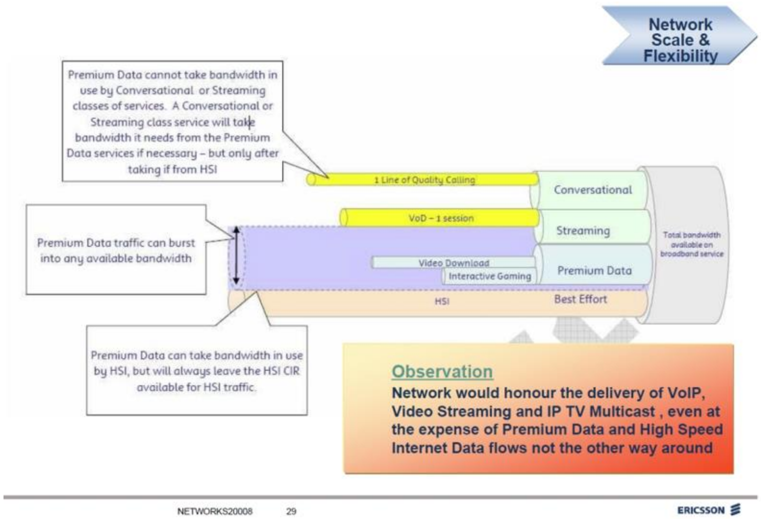


Source: Alcatel-Lucent[30]

Another example of reserved bandwidth for IPTV in a typical "walled garden" IPTV implementation is shown in the figure below.

[30] Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007) at p. 1.

Figure 10. Dedicated IPTV capacity (bandwidth) (referred below to as "premium data")



Source: Ericsson 2008[31]

IPTV traffic is of much longer duration and higher bandwidth than the other Internet traffic (web browsing etc.). Setting IPTV oversubscription factors to high values may result in under-dimensioning the delivery network and this can lead to decrease in QoS for the active video streams, which can seriously affect and degrade the QoE for the end users.

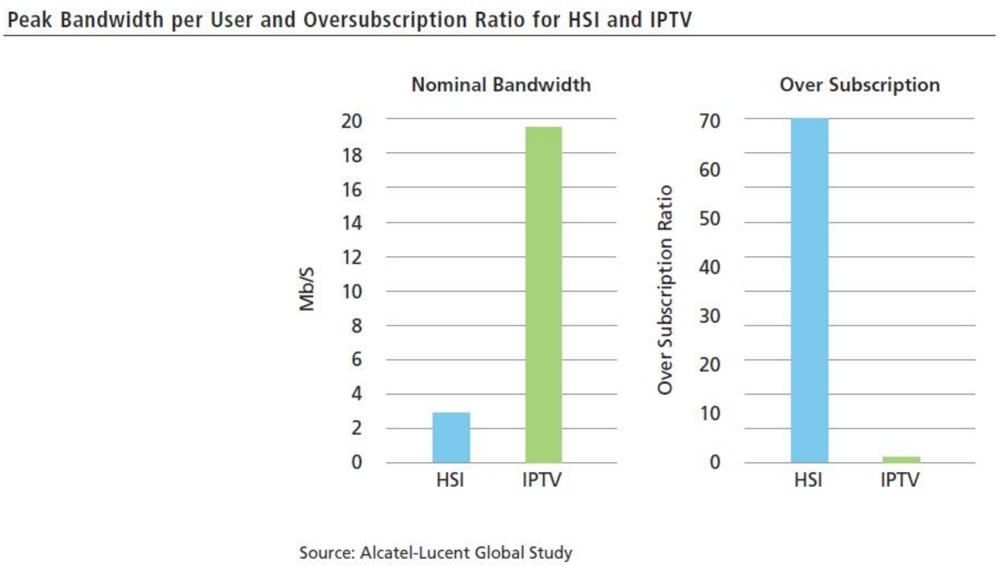
Even in "walled garden" IPTV implementations, where dedicated bandwidth is reserved for to IPTV traffic, the practice of overbooking (oversubscription) has been followed in order to optimize the use of upstream network resources.

Historically, the overbooking factors used for IPTV "walled garden" implementations were in the range between 1.0 and 2.0, as presented in the figure below.

---

[31] Rajiv Chaudhuri, End to End IPTV Design and Implementation, How to avoid Pitfalls (2008), http://www.networks2008.org/data/upload/file/Tutorial/T6_Chaudhuri.pdf at p. 29.

Figure 11. Comparison of peak bandwidth and overbooking factors for High Speed Internet and IPTV



Source: Alcatel-Lucent[32]

[32] Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007) at p. 2.

4.7.3 IPTV over WNA and overbooking

Understanding that IPTV over WNA would be quite similar to "walled garden" IPTV – from the throughput (traffic requirement) and user behaviour perspectives, we used IPTV overbooking factor of **10:6**, largely based on 60% of HUT and the assumption that 60% of subscribers would be active. This conservative value was chosen to reflect the reality of IPTV delivery over WNA.

> *"Unlike best-effort services, which can benefit from a significant level of oversubscription in the network, IPTV-based services cannot. The almost constant bandwidth demands of video simply do not accommodate statistical multiplexing. As a consequence, IPTV not only requires a significant increase in access capacity, it also has a dramatic impact in the average bandwidth consumption per user deeper in the network."*[33]

There are additional techniques (call admission control, QoS, policing, queuing)[34] that are usually deployed—along with many other techniques and technologies—to ensure large-scale delivery of video streams with subscriber prioritization and guaranteed QoS. Investigation of these technologies and techniques was beyond the scope of this study.

4.7.4 Modeling of VoD and DVR streams

Video on demand and DVR streams need capacity and therefore introduce additional associated costs. Due largely to the non-deterministic nature of this traffic, it is hard to apply any overbooking factors. In order to model VoD and DVR traffic, **overbooking factors for VoD and DVR IPTV streams were set to 1** (i.e. no overbooking was applied). This is consistent with industry findings.

> *"Bandwidth consumption is particularly high for video on demand (VoD), where the use of statistical multiplexing gains in the aggregation network would inevitably result in dropped packets."*[35]

---

[33] Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007) at p. 1.
[34] Alcatel-Lucent, Video Shakes Up the IP Edge: A Bell Labs Study On Rising Video Demand And Its Impact on Broadband IP Networks, Strategic White Paper (2012).
[35] Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007) at p. 2.

4.8 POI utilization rate

POI utilization rate is the factor describing the efficiency of the POI interface. Because of different networking protocols used and overhead involved, it is never possible to fully utilize the POI interface for subscriber traffic.

In our calculations, the utilization level of this interface was set to **90%** of the nominal line rate. In case of a 100 Mbps interface, this would translate to 90 Mbps being effectively used for subscriber traffic.

The POI utilization rate can be set by TekSavvy to best describe their network realities.

4.9 Minimum access capacity

In order for SD and HD IPTV streams to be delivered to end users over mixed-traffic WNA, some minimal access conditions have to be met: nominal Internet Protocol access rates need to be higher that the video streaming throughput. For the delivery of SD IPTV streams, it is realistic to expect that minimal (nominal) Internet access capacity be **above 7 Mbps**; for HD IPTV streams, this minimal capacity has been estimated at **10 Mbps**.

In other words, WNA end-users who want to subscribe to an IPTV service need to have access speeds that would be able to deliver this new "IPTV over WNA" service to them. This was done having in mind the video quality and required bandwidth for streaming outlined earlier.

It is worth noting that there are new IPTV over WNA entrants into the Canadian broadcasting market, with offers that are requiring less capacity than stated here.[36] At this point, it is unclear how these IPTV service offerings compare to market dominant service offerings from video quality perspective.

[36] VMedia, http://www.vmedia.ca/.

5. Our Approach

Estimation of additional capacity needed for delivery of IPTV over WNA is ultimately a traffic engineering problem. There are several possible ways of approaching this estimation: considering the end-user bandwidth consumption, along with demographic profiles and typical user behaviour models; looking at the IPTV service delivery chain and modelling the network architectures and required network capacities; or go as far to perform simulation of IPTV traffic to do the estimate of requirements. All of the approaches need to take into consideration the reality of massive delivery of large number of video streams over broadband, as well as the reality of TV consumption by the end users.

In this study, our approach was as follows:

1. We modeled large-scale delivery of unicast IPTV streaming sessions, and looked at the **incremental capacity requirements** and **related incremental costs** needed to sustain the **excess peak demand** of an IPTV service delivered over WNA.
2. IPTV demand was observed during peak viewing hours (also called primetime).[37] Because of this, we used the term "**excess peak IPTV demand"** to describe the *incremental* traffic demand specifically caused by the IPTV streaming (in addition to the other IP traffic), which is driving incremental capacity requirements and related costs to support the delivery of this IPTV traffic.
3. We modeled additional **reserved IPTV capacity** and related costs. This reserved IPTV capacity is dedicated additional capacity (planned and paid for by the IPTV over WNA provider) needed in order to support the envisioned peak IPTV traffic demands (at primetime).

With the reserved IPTV capacity approach, we are providing an equivalent model to typical IPTV "walled garden" implementations, where facility-based incumbent operators have technical means of reserving a certain portion of subscriber's access speed **only** for the delivery of IPTV (and also associating separate and dedicated quality of service, QoS, for this IPTV delivery).

---

[37] In general, primetime is assumed to encompass hours between 6 pm and 11 pm on weekdays and Sundays, with peak between 8pm and 11pm. Several studies have shown that TV viewing demand is highest during the Sunday primetime.

As outlined in this document, we used the following assumptions:

1. SDTV throughput of 2.5 Mbps (480p equivalent);
2. HDTV throughput of 7 Mbps (1080i equivalent);
3. HDTV "fill rate" assumed to be 40% (i.e. percentage of HDTV in all IPTV streams);
4. Unicast IPTV streaming; each subscriber was modeled with one IPTV stream;
5. POI utilization set at 90%;
6. Overbooking factor of 20:1;
7. HUT of 60%. This metric was used to set IPTV overbooking factor to 10:6;
8. Overbooking factors for VoD and DVR streaming set to 1 (1:1);
9. DVR capabilities exist in 50% of IPTV set-top boxes.

The following steps were taken:

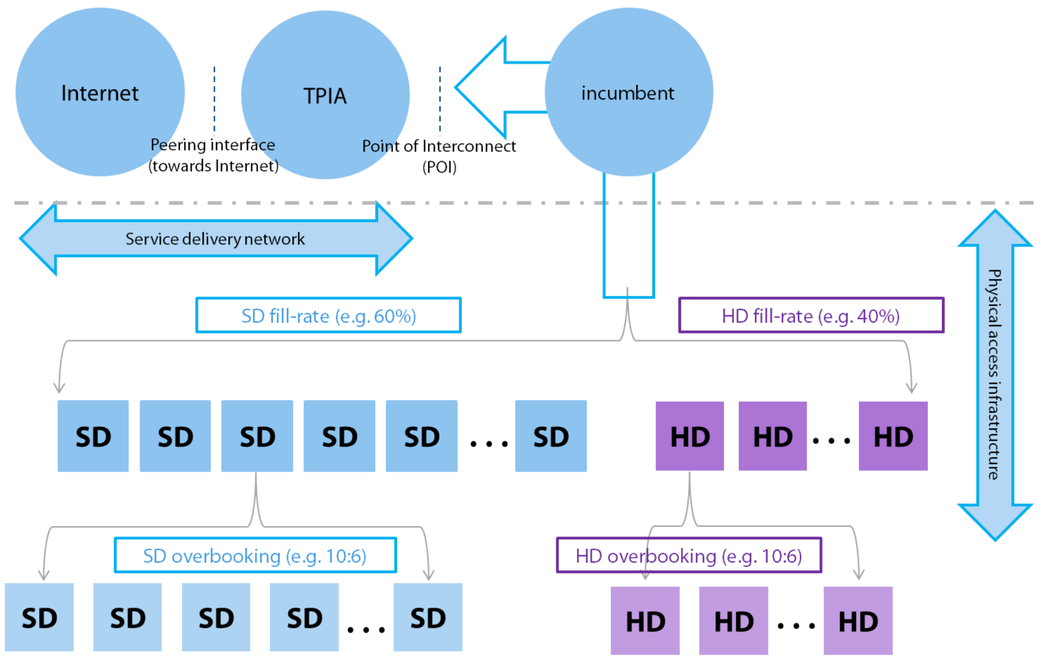
- Using assumptions 1-9, we calculated the number of overbooked IPTV subscribers which can be used to spread the additional capacity-related costs.
- Using the CRTC's published wholesale tariffs, we calculated total costs needed to support IPTV peak demand;
- We performed the calculations for three sets of published tariffs (Bell, Rogers and Videotron); and
- Provided comparison and analysis of results.

We are confident that our approach and the assumptions:

- Realistically characterize bandwidth requirements for IPTV over WNA (SD and HD);
- Provide a realistic mix of HD and SD streams;
- Allow for realistic oversubscribing (overbooking) factors for Internet and IPTV;
- Take into consideration current wholesale CBB pricing established by the CRTC.

The following figure graphically represents our approach and steps as explained in 5.1.

Figure 12. Graphical representation of the IPTV over WNA model



6. Calculations and Results

Incremental bandwidth costs for IPTV service were calculated as:

$$C_{HSI} = T_{100} / \{(100 * U_{POI}) / (R_{sub} * O_{HSI})\}$$

$$C_{IPTV} = T_{100} / [O_{IPTV} * \{(100 * U_{POI} * HD_{perc}) / HD_{rate} + \{(100 * U_{POI} * HD_{perc}) / HD_{rate}\}]$$

$$C_{VoD} = T_{100} / [O_{VoD} * \{(100 * U_{POI} * HD_{perc}) / HD_{rate} + \{(100 * U_{POI} * HD_{perc}) / HD_{rate}\}]$$

Where the variables are:

Subscriber Access Rate, R_{sub} (as per table)

Capacity-based wholesale tariff for 100 Mbps, T_{100} (as per table)

POI Utilization, U_{POI} (= 90%)

HD “fill-rate”, percentage of HDTV streams, HD_{perc} (40%)

SD “fill-rate”, percentage of HDTV streams, SD_{perc} (60%)

HD throughput, HD_{rate} (= 7 Mbps)

SD throughput, SD_{rate} (=2.5 Mbps)

Overbooking for HSI, O_{HSI} (=20/1)

Overbooking for IPTV, O_{IPTV} (=10/6)

Overbooking for VoD, O_{VoD} (=1/1)

Capacity-related CBB cost, C_{HSI} (as per table)

Incremental CBB cost due to VoD, C_{VoD} (as per table)

Incremental CBB cost due to IPTV, C_{IPTV} (as per table)

The table below summarizes the main results, showing the incremental bandwidth costs incurred by the IPTV traffic delivered over WNA using the current CBB rates charged by Bell, Rogers and Videotron.

Table 3. Comparison of incremental CBB costs related to IPTV over WNA

	Service Speed	Monthly Access Rate (per subscriber)	Monthly Capacity Rate (per 100 Mbps)	Incremental CBB Costs for IPTV Traffic (Excess Peak Demand, Overbooked)	Incremental CBB Costs due to IPTV Traffic (DVR stream)	Total Incremental CBB Costs (IPTV with DVR)	Total ITPV CBB Costs (IPTV with DVR) (including access rate)
		(Canadian dollars)		($ per IPTV session/sub)	($ per DVR session/sub)	($ per sub - IPTV+DVR session)	($ per sub - IPTV+DVR session)
Bell	7 Mbps	**$25.47**	$1,036.49	$23.25	$38.76	$62.01	$87.48
	10 Mbps	**$25.61**	$1,036.49	$23.25	$38.76	$62.01	$87.62
	12 Mbps	**$25.61**	$1,036.49	$23.25	$38.76	$62.01	$87.62
	16 Mbps	**$25.60**	$1,036.49	$23.25	$38.76	$62.01	$87.61
	25 Mbps	**$25.62**	$1,036.49	$23.25	$38.76	$62.01	$87.63
Rogers	10 Mbps	**$14.25**	$1,400.00	$31.41	$52.35	$83.76	$98.01
	15 Mbps	**$19.06**	$1,400.00	$31.41	$52.35	$83.76	$102.82
	25 Mbps	**$21.00**	$1,400.00	$31.41	$52.35	$83.76	$104.76
	50 Mbps	**$22.69**	$1,400.00	$31.41	$52.35	$83.76	$106.45
Videotron	7.5 Mbps	**$15.37**	$2,031.00	$45.57	$75.95	$121.51	$136.88
	15 Mbps	**$22.35**	$2,031.00	$45.57	$75.95	$121.51	$143.86
	30 Mbps	**$23.77**	$2,031.00	$45.57	$75.95	$121.51	$145.28
	50 Mbps	**$26.89**	$2,031.00	$45.57	$75.95	$121.51	$148.40

7. Conclusions

The following conclusions may be drawn:

- A "reserved IPTV capacity" approach, meaning one which reserves bandwidth for the Internet Protocol Television (IPTV) service at the Wholesale Network Access (WNA) interconnection point regardless of simultaneous use of Internet access, is the most realistic to determine the additional capacity requirements necessary for a competitive IPTV offering. That is because incumbent (cable and incumbent local exchange carrier, or ILEC) operators today have technical means of reserving bandwidth on their own networks to ensure good quality of service (QoS) for their IPTV service offerings;
- The additional capacity–based billing (CBB) costs are driven by the need for WNA-based providers to be able to offer the quality of TV experience equivalent to that of an incumbent's service offering.
- In a conservative scenario that assumes a single IPTV session per subscriber, the estimate of additional CBB costs range from $23.25 (Bell) over $31.41 (Rogers) to $45.47 (Videotron) per subscriber.
- In the alternative scenario where there are multiple viewing sessions per household, and/or where the IPTV offering includes Digital Video Recorder (DVR) functionality in the home (any additional viewing sessions require additional reserved capacity and associated costs), the additional CBB costs will be higher, as shown in Table 1. In this scenario, these costs (per additional session per user) range from $38.76 (Bell) over $52.35 (Rogers) to $75.95 (Videotron).
- Under the current CRTC wholesale tariff framework, the total estimated costs of delivering a potential IPTV service, under a CBB regime and for the considered cases, range from $87.48 (Bell) to $148.40 (Videotron).

8. List of Abbreviations

BTV	broadcast TV
CBB	capacity-based billing
CRTC	Canadian Radio-television and Telecommunications Commission
DASH	Dynamic Adaptive Streaming over HTTP
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
DVR	Digital Video Recorder
FTTH	fibre to the home
FTTN	fibre to the node
FTTP	fibre to the premise
FTTx	fiber to the (premise/home/node)
HD	high definition
HDTV	high definition TV
HFC	hybrid fibre-coax
HSI	high speed Internet
HTTP	hypertext transfer protocol
HUT	Homes using television
ILEC	Incumbent Local Exchange Carrier
IPTV	Internet Protocol TV
LTV	linear TV
MPEG	Moving Pictures Expert Group
OTT	over-the-top
POI	Point of Interconnect
PUT	Persons using television
PVR	Personal Video Recorder
QoE	Quality of Experience
QoS	Quality of Service
SD	standard definition
SDA	service delivery architecture
SDTV	standard definition TV
STB	set-top box
UE	universe estimate
VoD	video on demand
WBA	wholesale broadband access
WNA	wholesale network access

9. References

Adobe, "Recommended bit rated for live streaming," http://www.adobe.com/devnet/adobe-media-server/articles/dynstream_live/popup.html.

Alcatel-Lucent, "Alcatel-Lucent Triple Play Service Delivery Architecture" (2007), http://hhs.janlo.nl/articles/Triple-Play%20Service%20Delivery%20Architecture.pdf.

Alcatel-Lucent, Video Shakes Up the IP Edge: A Bell Labs Study On Rising Video Demand And Its Impact on Broadband IP Networks, Strategic White Paper (2012), http://www3.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=White_Papers/Video_Shakes_Up_IP_Edge_EN_Whitepaper.pdf .

American Interactive Marketing, "Ratings, Share, HUTs and PUTs," http://americaninteractivemarketing.com/tag/h-u-t-houses-using-television.

Bell Canada, "Broadband Expansion Proposal, Follow up to Telecom Decision CRTC 2006-9, *Disposition of funds in the deferral accounts* (1 September 2006), http://www.crtc.gc.ca/public/partvii/2006/8638/c12_200602708/662133.zip (document "Part VII - Correspondence to CRTC - Bell Canada - Submission.DOC"), original submission.

Chaudhuri, Rajiv, End to End IPTV Design and Implementation, How to avoid Pitfalls (2008), http://www.networks2008.org/data/upload/file/Tutorial/T6_Chaudhuri.pdf.

Gilbert, Bem, "Netflix streaming most dominant on HDTVs, more than double PC and tablets" (22 January 2013), http://www.engadget.com/2013/01/22/netflix-streaming-usage-hdtv-pc/.

Gonzales, Barb, "All About Internet Speed Requirements for Hulu, Netflix, and Vudu Movie Viewing," http://hometheater.about.com/od/internethometheater2/a/Internet-Speed-for-Netflix-Vudu.htm.

Imagineering Telecom Inc., Report On Third Party ISP Access To Major Canadian Cable Systems For the CRTC (2 January 2002), http://www.crtc.gc.ca/eng/publications/reports/isp/ispaccess.htm.

McAdams, Deborah D., "HDTV Adoption Surpasses 75 percent" (17 October 2012), http://www.tvtechnology.com/article/hdtv-adoption-surpasses--percent/215958.

Mignon, Marc *et al*., "Scaling server-based channel-change acceleration to millions of IPTV subscribers," 19th International Packet Video Workshop (10–11 May 2012), http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6229721

Mignon, Marc *et al*., "Scaling Server-Based Channel-Change Acceleration to Millions of IPTV Subscribers," http://www.employees.org/~acbegen/files/PV_05_2012_abegen.pdf.

Minoli, Daniel, *IP Multicast with Applications to IPTV and Mobile DVB-H* (Wiley-IEEE Press, 2008).

Netflix, "How can I control how much data Netflix uses," https://help.netflix.com/en/node/87.

Netflix, Canada ISP Speed Index (August 2014), http://ispspeedindex.netflix.com/canada.

Nielsen Media Research, "Television Audience Measurement Terms," http://www.nielsenmedia.ca/English/NMR_U_PDF/TV%20Terms.pdf;

Nielsen, *Advertising and Audiences: State of the Media* (May 2014), http://www.nielsen.com/us/en/insights/reports/2014/advertising-and-audiences-state-of-the-media.html.

Nielsen, *The Digital Consumer* (February 2014), http://www.nielsen.com/content/dam/corporate/us/en/reports-downloads/2014%20Reports/the-digital-consumer-report-feb-2014.pdf.

Ofcom, Review of the wholesale broadband access markets, Consultation, June 2013, http://stakeholders.ofcom.org.uk/consultations/review-wba-markets/summary

Sandvine, *Global Internet Phenomena Report*, 1H (2014), https://www.sandvine.com/downloads/general/global-internet-phenomena/2014/1h-2014-global-internet-phenomena-report.pdf.

Simpson, Wes , *Video over IP : IPTV, Internet video, H.264, P2P, Web TV, and Streaming : A Complete Guide To Understanding the Technology* (Boston: Elsevier/Focal Press, 2008).

Telecom Regulatory Policy CRTC 2011-703, *Billing practices for wholesale residential high-speed access* services (15 November 2011), http://www.crtc.gc.ca/eng/archive/2011/2011-703.htm.

Telecom Regulatory Policy CRTC 2011-704, *Billing practices for wholesale business high-speed access services* (15 November 2011), http://www.crtc.gc.ca/eng/archive/2011/2011-704.htm.

Television Bureau of Canada, *TV Basics 2013-2014*, http://www.tvb.ca/page_files/pdf/InfoCentre/TVBasics.pdf.

TNO, *Evolution and prospects cable networks for broadband services: A technical perspective of the European and specifically the Dutch cable networks* (31 August 2012), http://nlkabel.nl/wp-content/uploads/2012/08/TNO_Evolution_and_propects_cable_networks_for_broadband_services.pdf.

TVB, HUT/PUT National Prime Trends, http://www.tvb.org/media/file/TVB_Measurement_Monthly_HUT_Trend.xls.

Vlessing, Etan, "Report: 58% of Canadians have HDTVs, but most don't view in HD" (13 November 2011), http://playbackonline.ca/2011/11/13/report-58-of-canadians-have-hdtvs-but-most-dont-view-in-hd/.

Weil, Nicholas, "The State of MPEG-DASH Deployment" (8 April 2014), *Streaming Media Europe*, http://www.streamingmediaglobal.com/Articles/Editorial/Featured-Articles/The-State-of-MPEG-DASH-Deployment-96144.aspx.