ATTACHMENT A

REPORT OF ANDREW ODLYZKO

Introduction

[1] There is no evidence of wireline Internet traffic growing so fast as to require intrusive traffic interference to control it. While there is still vigorous traffic growth, it is at levels that can be accommodated with approximately the current levels of capital expenditure. Just as the computers that we buy provide increased processing power and storage each year for the same price as earlier machines, due to technology progress, telecommunications networks can handle higher levels of traffic each year at the same cost as before. And traffic growth rates have been declining, to levels slower than the rate of improvement of latest transmission equipment.

Background Information

[2] My studies of Internet traffic growth started in 1997, when I was at AT&T Labs - Research. Kerry Coffman and I were the first ones to demonstrate the falsity of the myth of "Internet traffic doubling every 100 days" that inspired so much of the Internet bubble and led to the subsequent collapse of the telecom sector. At that time, in the late 1990s, we showed that Internet traffic was doubling about every year.

[3] After I moved to the University of Minnesota in 2001, I started up the MINTS (Minnesota Internet Traffic Studies) project, which makes its results public on its web site.[1] Its goal is to track trends in Internet traffic, and study the implications of such trends for technological innovation. Support for the MINTS project has come overwhelmingly from an endowed chair I held, and to much smaller extent from other internal University of Minnesota resources, and recently, to an even smaller extent, from a grant from the U.S National Science Foundation. Very minor contributions came indirectly from industrial funding that was provided to the Digital Technology Center (of which I was the founding Director until the summer of 2008) by its affiliates, only one of which, ADC Telecommunications, a systems supplier, has any substantial participation in the telecom sector.

[4] The MINTS web site collects and analyzes data from many sites around the world that make their traffic statistics public. It also presents pointers to other sources of information about Internet traffic.

[5] My work at AT&T had led to a conjecture that wireline Internet traffic would continue to approximately double every year for the foreseeable future. That conjecture has been disproved by the evidence of the last half a dozen years. There has been a substantial slowdown of traffic growth, to a range of 50-60% per year. If these levels of

[1] http://www.dtc.umn.edu/mints. The opinions in this report are my personal ones, not reflecting any official position of the MINTS project or of the University of Minnesota.

growth continue, I do not foresee any urgent need for greatly increased investment in the telecom infrastructure, nor for intrusive traffic interference.

[6] Historically, over the last decade and a half, there have been several waves of concern that various disruptive innovations would swamp the Internet and require the introduction of intrusive control mechanisms on customer usage. One such wave came with the arrival of the graphics-rich Web browsing. Another came with the appearance of Napster, the first P2P program, which caused a surge in music traffic. Yet in all cases, the actual rise in demand was far more modest than had been feared, and was accommodated largely through deployment of improved technologies, supplemented sometimes with some simple and neutral traffic throttling mechanisms. And this was in an environment where traffic was still growing at 100% per year. Today, growth rates are considerably lower and rapid technological progress is continuing. Some careful experiments (such as those on the Internet2 research network[2]) showed that simple networks are preferable, not just in terms of stimulating innovation, but also of keeping down costs.

Part 1 Internet Traffic Growth

[7] In CRTC Telecom PN 2008-19, the Commission asks in Question 1 a):

> How has Internet traffic grown in the past three years and what are the predictions for its growth in the future? What has been the impact on Canadian ISP networks?

[8] The Commission goes on to ask in Question 1 b):

> How has average end-user bandwidth consumption changed in the past three years and what are the predictions for future changes in Canada?

[9] Worldwide wireline Internet traffic growth over the past three years appears to have been in the 50-60% per year range. That is estimate of the MINTS project, as well as of the Cisco Visual Networking Index project,[3] and of TeleGeography (a market research firm).[4] Of those three, the only one that explicitly predicts future trends (as opposed to estimating past and current growth based on collected data) is the Cisco study, which predicts 46% annual growth through 2012. This prediction is accepted widely in the industry (for example, in the supplemental filing by Shaw in these proceedings[5]). The statistics provided by the 7 carriers in these proceedings that were released to the public show that in Canada, the growth rate has declined from 53% between 2005 and 2006 to 32% between 2007 and 2008.[6] (All these estimates concern total traffic, so that observed

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[2] Testimony of Gary R. Bachula, Vice President, Internet2, before the U.S. Senate Committee on Commerce, Science and Transportation, hearing on net neutrality, Feb. 7, 2006, http://commerce.senate.gov/pdf/bachula-020706.pdf

[3] http://newsroom.cisco.com/dlls/2008/prod_061608b.html

[4] http://www.telegeography.com/cu/article.php?article_id=24888

[5] Shaw response to interrogatories, ***1-Abridged-2***

[6] "ITMP - Disclosure of Aggregated Data", p. 1 of attachment, simple arithmetic average of growth rates for the 7 carriers gives 53% for 2005-6, 44% for 2006-7, and 32% for 2007-8.

and estimated growth is a function both of increase in the number of broadband customers and increased usage per customer.)

[10] There do exist other Internet traffic estimates and projections, both lower and higher. For example, Larry Roberts, who played a key role in developing the ARPANET, the predecessor of the Internet, and is a founder of a company that provides tools for shaping traffic, claimed in October 2007 that Internet traffic was growing at 100% per year.[7] Also, Nemertes Research has published white papers that claim Internet traffic is currently growing at about 100% per year and will continue to do so for the next half a dozen years.[8] On the other hand, Peter Poll, CTO of Qwest, estimated at a conference in Feb. 2008 that Internet traffic would only grow from 9 PB/day in 2007 to 21 PB/day in 2012, which would correspond to CAGR of only 18.5%.[9] None of the claims from Larry Roberts, Nemertes, and Peter Poll, provided any evidence for their estimates.

[11] The three studies that appear to be most credible, those from Cisco, MINTS, and TeleGeography, all rely on a variety of sources, most confidential, and are thus hard to validate. (The core of the MINTS project is a collection of traffic data from around a hundred sites around the world that make their traffic statistics publicly available, but those account for far less than half of total world traffic, so that even MINTS relies on confidential information for its conclusions about global traffic trends.) There are just three sources of publicly available data that cover entire countries or regions, and appear to be completely trustworthy. (References for all three are available on the MINTS site.) Two are governments, those of Australia and Hong Kong. The third one is a cooperative association of Japanese ISPs that have about a 40% market share in Japan, so their detailed studies can be scaled up for the entire country by multiplying their raw traffic figures by 2.5. What those sources show is a variety of trends:

(i) In Japan, growth rates over the last three years have been close to 30% per year. (Traffic volumes per subscriber are perhaps only twice those of Canada, if we accept the TELUS data as typical for Canada, in spite of the far higher access speeds in Japan, where almost half of the broadband customers have fiber to the home.)

(ii) Australian Internet traffic grew at about 100% per year until about two years ago, but then the growth rate decelerated suddenly, with the latest available statistics showing actually a tiny decline in total volumes in the first half of 2007. Traffic volumes are lower than those for TELUS customers, with residential customers in Australia downloading about half as much as TELUS subscribers.

(iii) Hong Kong traffic grew extremely rapidly in the early years of this decade, as broadband access was deployed on a massive scale, in some years at over

[7] Larry Roberts, "Routing economics threaten the Internet," October 2007, http://www.internetevolution.com/author.asp?section_id=499&doc_id=136705.
[8] http://www.nemertes.com/internet_interrupted_why_architectural_limitations_will_fracture_net
[9] http://www.ofcnfoec.org/Materials/08_Plenary_Poll.pdf

400%, but then decelerated. Growth over the three years to November 2008 came to 20% CAGR, with just 12% growth over the preceding 12 months. The average download per residential customer is about 60 GB/month, or 10 times as high as the figure for TELUS.

[12] The bottom line is that there is great variation in traffic growth rates around the world. The reasons have not been explicated. They presumably depend on intricate combinations of culture, available applications, technology deployment, pricing, as well as copyright enforcement and other government policy decisions.

[13] However, generally wireline Internet traffic growth rates have been declining. That is visible practically everywhere, and in particular in the three places listed above (Japan also had higher growth rates early in this decade, although that is not well documented as the decline for Australia and Hong Kong). And it is very visible in the Canadian data provided to the Commission, with the average growth rate falling from 53% between 2005 to 2006, down to 32% between 2007 and 2008. The precise reasons for these declines have also not been explicated. Traffic interference by service providers, lack of exciting new applications, and so on all undoubtedly had some roles in this development. And it is not just traffic interference by service providers that is responsible. If we consider the TELUS data supplied to the Commission,[10] although it does not show traffic of average users, the slow growth in average usage over all clients suggests strongly such users are not ramping up their utilizations very rapidly.

[14] Given the relatively low (as compared to half a dozen years ago, say) and declining growth rates for wireline traffic, the claim in the supplemental filing by Bell Mobility that "Internet demand growth over the last few years greatly surpassed industry projections"[11], is astounding. It can be true only if the industry used some extremely low projections, such as those cited above from Qwest. There was certainly no good reason for adopting such projections.

[15] Telecommunications networks are complicated, and vary in their architectures, so it is hard to come up with a single cost index that would apply fairly to all. However, there are many estimates from equipment suppliers, as well as from ISPs, such as the 2008 projections from CarPhone Warehouse, an ISP in the UK[12] about costs of building its own facilities network, which suggest that growth rates of 50% per year in traffic can be accommodated without increases in capital expenditures. (A 33% increase in technological efficiency almost exactly offsets a 50% growth in volume. Suppose you start out a year at some traffic level, call it 100, which might cost $100 to handle. During that year, 50% growth in traffic will lead to year-end traffic level of 150. But if the unit costs decline during the year by 33%, the cost of handling that traffic will be just $150*0.67 = $100.50. The claims of humongous capital expenditures that will

[10] RELUS(CRTC)4Dec09-2, Page 3 of 6, ABRIDGED.
[11] Bell Mobility, document The Companies(CRTC)4Dec08-9 PN 2008-19 Abridged Supplemental, p. 5.
[12] CarPhone Warehouse, April 15, 2008 Annual Strategy Day presentation, http://library.corporate-ir.net/library/12/123/123964/items/287985/Analyst_Day_150408_Pres.pdf

supposedly be required to accommodate demand, such as the claim made by Bell in[13], are based on the projections of the Nemertes studies, which assume traffic will grow at 100% per year.)

[16] The conclusion is that the claim in the Bell Mobility filing referred to above that:

> [w]hile continued investments in network capacity must remain at the core of the carrier's network management solution this type of incremental investment will not be sustainable without changes to existing revenue models and the introduction of new business models…

appears very questionable, at least for wireline broadband services. And over the last three years, with growth rates at about the current levels around the world (although recently lower in Canada), service providers have been able to provide connectivity that has been, if anything, increasing in terms of user experience. There has not been any substantial evidence of growing congestion.

[17] There is certainly potential for much faster growth. There is far more broadcast and cable video than there is traffic on the Internet, and also far more data on the hard drives of personal computers than ever shows up on the Internet.

[18] So with the right business models and technology, one could potentially see a sudden spurt of growth. (And the data from Hong Kong shows that even with currently available off-the-shelf technology, one can obtain traffic volumes 10 times those observed in Canada. But to attain Hong Kong levels in Canada would require additional investments.) But so far there is no sign of any such acceleration of wireline traffic growth.

[19] The comments above apply only for wireline Internet services. For wireless Internet access, the situation is different. There is not much historical information in this area, since until recently wireless data volumes were extremely small. They are still small compared to wireline Internet access, but are growing much more rapidly. The statistics provided by TELUS in their response to the CRTC interrogatory show growth rate of 130% per year (for total traffic, sum of inbound and outbound) from May 2007 to December 2008.

[20] Such growth rates, and in some cases even higher ones, have also been reported elsewhere around the world. Moreover, industry is projecting growth rates of close to 100% for the next 5 to 10 years. That can be seen in the presentation by Hank Kafka, Vice President, Network Architecture, AT&T, at a January 27, 2009 briefing.[14] There is also the prediction of the Jan. 2009 Cisco Global Mobile Data Traffic Forecast Update.[15] While wireless technology is advancing, as shown by some of the cost projections in the

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[13] Bell claim reference in David Fewer's comment, DAF2.
[14] Slide #4 of http://www.3gamericas.org/documents/03_Hank%20Kafka.pdf
[15] http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

Hank Kafka deck, it is not improving to the point of being able to accommodate growth rates of close to 100% per year. This suggests that either revenue per customer for data services will have to grow substantially, or else traffic will have to be managed in some way. Just expanding capacity at current capex levels is not likely to be feasible, and so in wireless the Bell Mobility statement cited above is likely to be correct.

[21] Wireline traffic, on the other hand, presents a different picture. As discussed above, it is growing fast, but it is growing at rates that can be accommodated through capacity expansion.

Part 2 Congestion and Application Bandwidth Requirements

[22] In CRTC Telecom PN 2008-19, the Commission asks in Question 1 d):

Are there applications or services that are more likely to cause congestion, and if so, what are they?

[23] The Commission goes on to ask in Question 1 e):

What are the relative bandwidth requirements for different types of Internet applications?

[24] The first question that should be asked is what applications or services are sensitive to even low levels of congestion. There are some, but not that many, primarily voice telephony and video telephony (including videoconferencing) and online gaming, where real-time human interaction is involved. Many applications (control of power plants, nuclear or conventional, for example, or various emergency services) should not be on the public Internet at all, since in the current and foreseeable state of technology there is no way to assure their safe operations when mixed with general (and thus possibly maliciously crafted) traffic. Almost all video, on the other hand, can be handled successfully on the public Internet, and is surprisingly resistant to congestion. This can be done by using progressive downloads, as is used by YouTube and many other video delivery services, and avoiding real-time streaming.[16]

[25] Right now video dominates in terms of volume of traffic, and this video is delivered over either peer-to-peer (P2P) software, or by content delivery networks (CDNs) like Akamai, or directly from various servers. Thus video is the most likely form of traffic to cause congestion. P2P video is especially likely to do so, since it can potentially fill any size link, and it uses the uplink from residential customers, which usually operates at lower speeds than the downlink. However, in principle any transmission can cause congestion. A web page with rich graphics can be just as serious a contributor to congestion as a movie (although usually for a much shorter period). The main question, though, is not what is the worst that can happen, but what actually happens. Banks do not hold enough cash to satisfy the demand that would arise if all depositors asked for their

[16] For a detailed discussion of this issue, see my paper ""The delusions of net neutrality," presented at the 2008 Telecommunications Policy Research Conference, http://www.dtc.umn.edu/~odlyzko/doc/net.neutrality.delusions.pdf

money, nor do grocery stores prepare for everybody doing their shopping on Saturday, while leaving the rest of the week free. And on the Internet, various neutral control mechanisms operate (such as the TCP congestion control scheme), and P2P system designers have an interest in keeping their programs from being disruptive, as that would limit their spread. Hence we observe BitTorrent developers participating in IETF working groups on providing ways to avoid congestion. And overall, there is a lack of evidence of any serious congestion problems. Traffic growth at the current or in most cases even higher rates was accommodated quite well for many years, and technological progress has shown no signs of stopping.

[26] In thinking about networks, it helps to consider how they are used. Consider the TELUS access plans.[17] If we consider the mid-tier "High Speed Enhanced" service, and assume that the "Up to 3.0 Mbps" for the download does deliver 3 Mbps, then over a full month, it could in principle deliver about 300 GB. However, from TELUS response[18], we see that on average, TELUS customers download under 6 GB per month. Unfortunately the data made available by TELUS does not tell us what the average is for the customers who opt for the "High Speed Enhanced" service, but if we assume their usage pattern is similar (as this is the mid-tier service) we see that the link is used at only 2% of its capacity (average over the full month). And utilizations in countries like Japan and Hong Kong, which offer higher speeds, are even lower. The main utility of data networks is in providing fast response rates, and that calls for high bandwidth networks that will be lightly used.

[27] Now if one has, as an example, a TELUS "High Speed Enhanced" service, even one that delivers the full 3 Mbps, then one cannot download a movie in HDTV format in real time, as they require 6-10 Mbps. One would have to prefetch it for watching, possibly overnight. And just a few such movies would exhaust the 60 GB/month limit that TELUS sets. And downloading such a movie would fully saturate the link, and so would interfere with the activities of that customer (such as web surfing, or emailing), and could easily contribute to congestion in the network. However, resolutions of movies and video clips are not likely to grow very rapidly, due to limitations on display technologies. On the other hand, transmission speeds should grow. 100 Mbps is already routinely available in Japan and South Korea, and South Korea has recently announced a national goal to make 1 Gbps available almost universally in a few years. In an environment where such high speeds are available, access links will likely be very lightly utilized, and congestion will arise from coincidence of rare events. P2P will be one contributor to congestion, but just one, and may very well not be the main one.

[28] Voice telephony can be carried in compressed form, with some loss of fidelity, as is done currently in the commercial wireless sectors, at rates on the order of 10 Kbps. However, to assure high quality with minimal latency, many VoIP services encode it as the basic 64 Kbps rate of PSTN or even somewhat higher. However, even addition of stereo and quality higher than the "toll quality" of PSTN is unlikely to require more than 20 Kbps.

[17] TELUS interrogatory response, file #15.
[18] TELUS interrogatory response, file #2a.

[29] Video telephony, as well as its extension to video conferencing, can be done successfully at a few hundreds of kilobits per second. However, good user experience requires on the order of 1 Mbps, and high-end video conferencing systems can take over 10 Mbps.

[30] Gaming has low overall traffic with most processing done locally, and much of the data required for generating video images stored locally ahead of time. However, the transmissions that occur come in bursts, and extremely low latency, considerably lower than with voice or video, is demanded, and this is accommodated by providing large capacities.