Satellite Service Can Help to Effectively Close the Broadband Gap

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"The optimal role could be in . . . ensuring that satellite can function as a ubiquitous bidder in a range of auctions."

OBI Technical Paper No. 1 at 40.

The author thanks ViaSat for its support of this study.

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Executive Summary

The Federal Communications Commission (FCC) has identified a broadband gap— seven million or more housing units that are home to at least fourteen million people that are unlikely to get broadband Internet access without some form of subsidy. The FCC established an Omnibus Broadband Initiative (OBI) to study this problem and to identify the most efficient way to close this gap. OBI Technical Paper No. 1 concluded that using satellites to serve only a small fraction of the currently unserved housing units would cut the cost of closing the broadband gap by more than half. However, OBI Technical Paper No. 1 did not propose any additional role for satellite in closing the broadband gap. The FCC appears to have relied on the analysis in OBI Technical Paper No. 1 in developing the National Broadband Plan and in developing the proposed rules for the Connect America Fund (CAF).

But, the analysis in OBI Technical Paper No. 1 of the potential role of satellites is flawed in at least four respects. OBI Technical Paper No. 1 made three serious errors when analyzing satellite broadband services.

First, it estimated the cost of satellite broadband service by extrapolating from market prices *today*. This extrapolation did not take into account either the current or future historical reduction of the "cost per bit" of satellite technology or the fact that the launch of new satellites will solve the current congestion on satellite broadband systems. This was quite different from the OBI analysis of the cost of terrestrial technologies such as wireless and ADSL where future expected costs of those technologies were considered, without regard to the state of network congestion today. In determining the cost of using terrestrial technologies to provide broadband access in currently unserved areas, OBI Technical Paper No. 1 developed a complex cost model that identified the costs of building and supporting new telecommunications plant to provide service. The need for subsidies was based on those future costs.

Second, it made no allowance for continuing technological progress in satellite communications—a field that has seen enormous progress in the past.

Third, OBI Technical Paper No. 1 failed to provide for any growth in satellite capacity beyond the launch of the next two broadband spacecraft, including that which necessarily would flow from the launch of additional spacecraft.

Fourth, a less distorting error was to calculate the cost of closing the gap with satellite broadband services as if every unserved housing unit would subscribe rather than adjusting for the expected rate of adoption by unserved housing units. A large portion of the projected cost of providing satellite service relates to actually connecting the end user.

These omissions caused the analysis in OBI Technical Paper No. 1 to overstate the cost and understate the capabilities of the satellite broadband alternative. The cost of providing satellite-based broadband access should be calculated and compared with the assumed revenue from broadband services. If technological progress continues into the future at its historical rates, then satellite capacity in 2015 should cost about half what it costs today.

Moreover, accounting for the type of capacity growth that has naturally occurred in the satellite industry significantly increases the number of housing units that satellite could serve in the near term—realistically—providing the capacity to serve about 6.6 million broadband subscribers by 2020, even with the FCC's predicted increase in bandwidth demands.

Taking all of these factors into account, this paper demonstrates that satellite is the least expensive way to serve at least 3 million additional housing units – a total of at least 47% of the broadband gap, for about $1.8 billion in subsidy. In contrast, serving these same housing units by terrestrial technologies would require support of $23 billion, based on the Commission's data.

Consequently, no decision should be based on OBI Technical Paper No. 1's conclusions regarding the suitability of a limited role for satellites. A sound analysis indicates that satellite service can provide an economically attractive alternative to close much of the broadband gap.

Introduction

The Commission has identified a broadband gap—the seven million housing units and fourteen million people to which it estimates broadband access cannot be extended without some form of economic support. The Commission has also created an ambitious National Broadband Plan designed to ensure that every American has access to broadband capability. The National Broadband Plan determined that closing the broadband gap using terrestrial technologies would cost $23.5 billion.[1] However, the National Broadband Plan also determined that using satellite services for only the 250,000 housing units that are most expensive to serve would drop the cost of closing the gap by more than half.[2]

This study examines the current and likely future performance and cost of satellite services in helping close the broadband gap. It confirms the analysis in the National Broadband Plan that satellite is by far the least expensive way to serve the 250,000 most-costly-to-serve housing units, but also demonstrates that satellite also is the least expensive way to serve at least 3 million additional housing units---a total of least 47%percent of the broadband gap, for about $1.8 billion in subsidy. In contrast, serving these same housing units by terrestrial technologies would require support of $23 billion, based on the Commission's data.[3] This report presents the results of analyzing the cost and performance of satellite broadband under a variety of assumptions. It first replicates the analysis that was used in developing the FCC's National Broadband Plan and that was relied on in the CAF NPRM. It then considers a variety of modifications to the assumptions used by the FCC in its analysis and shows how varying those assumptions results in projections of increased ability of satellite broadband systems to help close the broadband gap. The differences in assumptions are clearly identified, and the rationale for each difference is explained. The analysis is structured so that readers can apply their own judgments to the appropriateness of the various assumptions and see the implications of their judgments regarding the role of satellite.

This report begins with some background. It first reviews the various estimates of satellite capacity that FCC staff recently developed and employed in its policy analysis. Next, it looks at satellite technology—how it has developed over time and the nature of expected advances in the capacity of satellite systems providing two-way services to residences. It then discusses the process of funding, procuring, launching, and putting into orbit a new satellite. Finally, the report turns to the capacity analysis described above.

Satellite Capabilities Envisioned by the FCC

Over the last year, the FCC has expressed its view that, although satellites have an essential role in the National Broadband Plan—use of satellites cuts the cost of closing the broadband gap by more than half—satellites should not be expected to otherwise be counted on to play a significant

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[1] Notice of Proposed Rulemaking In the Matter of Connect America Fund, WC-Docket 10-90, Federal Communications Commission, Feb. 9, 2011, (herein after CAF NPRM), at footnote 597.

[2] *CAF NPRM,* at para. 424.

[3] *National Broadband Plan,* at p. 138. Throughout this report, as in the OBI analysis, subsidies are generally referred to in net present value terms with costs and revenues being discounted at 11.25% annually.

role in closing the broadband gap and satellite broadband providers should be ineligible to participate directly in at least Phase I of the Connect America Fund.

These views are set forth in three different documents—Technical Paper No. 1 of the Omnibus Broadband Initiative, the National Broadband Plan, and the CAF NPRM. These three documents are consistent in their treatment of the role of satellites, and all appear to be derived from the same analysis, which is reported in the most detail in OBI Technical Paper No. 1.

The key tool that the FCC seeks to employ in closing the broadband gap is to subsidize firms to provide broadband Internet access in areas where it would be uneconomic to otherwise provide such service. The CAF NPRM proposes that a reverse auction be held to determine which firm would be granted the right to provide subsidized broadband Internet access in a service area. Under Phase I, wireless and wireline companies would be permitted to bid for subsidies and to subcontract with satellite firms; satellite firms, even if they were willing to subcontract with wireless and wireline firms, would be ineligible to bid. Winners of such reverse auctions would be required to build out systems to cover their service areas in three years, and they would have an obligation to continue serving for some as yet undefined time afterwards.

Current and Future Satellite Technology

In the United States, the first commercial communications satellite went into service in 1974. That first satellite, Westar 1, had 12 transponders, and the earth stations used with it had antennas 15 meters in diameter. It is hard to calculate a proper comparison between that technology and modern satellites that use much smaller antennas. But, assuming that each transponder could transmit at 12 megabits per second, Westar 1 had a total capacity of 144 megabits per second.[4] Current state-of-the-art satellites, designed for residential Internet access, have a capacity of 130 gigabits per second.[5] This is an increase by a factor of about one thousand.[6] This corresponds to an improvement of 20% per year—not quite matching Moore's Law, but an enormous rate of progress.[7]

This improvement came from many different innovations in satellite and communications—not least those made possible by the progress in semiconductors described by Moore's Law. These innovations included the use of dual polarization (doubling capacities), higher frequencies (facilitating the use of smaller antennas), much larger satellite antennas (permitting the use of spot beams and more intensive frequency reuse), larger spacecraft (supporting the use of higher powers and permitting the use of larger antennas), improved modulation and signal design (made possible by Moore's Law), and improved system design. This improvement also came from access to additional radiofrequency spectrum.

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[4] This data rate could not be achieved if one used a typical home satellite antenna about 0.7 meters in diameter with about 0.2% of the area of a 15 meter dish

[5] OBI Technical Paper No. 1 at p. 90.

[6] The more exact number for the improvement factor is 903.

[7] If we had assumed that Westar 1 supported a higher data rate, say 500 megabits per second or one bit-per-second per Hertz (ignoring issues of transponder bandwidth and the comparison with small antennas), that would imply that the rate of growth was a still respectable 16% per year.

This progress was relatively even over time—it did not all happen one day due to a single brilliant insight. Table 1 compares some historical milestones in satellite development with the capacity that would have occurred following a simple 20% per year improvement rate.

Table 1. Satellite Capacity—Actual versus Predicted

Date	U.S. Capacity of a Single Satellite (Mbps)	Predicted Capacity (assuming 20%/year improvement rate)	Comment
1974	144	144	Westar 1
1982	288	619	Westar4 (24 Transponders)
1993	1,000	4,601	Ku-band satellites, 1 Gbps
1998	10,000	11,448	First-generation Ka-band satellite with spot beams, 10 Gbps
2011	130,000	122,481	ViaSat-1, Ka-band with many spot beams, 130 Gbps

There is no reason to think that progress in satellite technology has yet stalled. A wide variety of things are understood today that offer the promise of improved capacity—such as smaller spot beams, higher power, more complex signal processing, improved protocols, and use of additional radiofrequency spectrum. Consequently, any analysis of the utility of satellites in meeting the broadband gap should assume that the progress in satellite technology will continue in the future as it has done in the past. Not doing so would be like assuming that personal computing devices and smartphones in 2020 would be no better than they are today.[8]

The state-of-the-art in satellite broadband is exemplified by ViaSat-1 (due to be launched this summer) and the similar KA-SAT (launched last December and currently in geostationary orbit).[9] These satellites operate in the Ka-band (around 20/30 GHz—more than 10 times higher in the spectrum than the PCS and cellular bands) and use many spot beams (82 spot beams on KA-SAT, 80 on ViaSat) to deliver far more capacity per second than any of the hundreds of

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[8] At some point, the capacity of the orbital arc comes into play. The need for angular separation between satellites along the orbital arc implies a limit of perhaps 30 or 40 satellites serving the United States in any single satellite band. Even so, only about 10 of such locations are being or soon will be used in the Ka-band. Moreover, other parts of the Ka-band remain unmined, the "reverse DBS" band at 18 GHz remains largely unused, and the 40/50 GHz range remains an untapped resource.

[9] *Eutelsat's KA-SAT Satellite Successfully on Station at 9° East and Undergoing in-Orbit Tests*, Eutelsat Press Release, 13 January 2011. Available at http://www.eutelsat.com/news/compress/en/2011/pdf/PR%200211%20KA%20SAT%20leop.pdf.

other spacecraft that have been launched to date (70 Gbps on KA-SAT, 130 Gbps on ViaSat).[10] Hughes plans to launch its Jupiter satellite next year, which it estimates will have more than 100 Gbps of capacity.[11]

The cost of communications satellites is dominated by the costs of the satellite bus and payload (the communications capabilities, the station-keeping and power-generating functions of the bus) and of its launch. Later-generation satellites cost about the same as earlier-generation satellites—but they do much, much more. Thus, progress in satellite performance has led to enormous decreases in the cost per unit of capacity in orbit (i.e., $/Mbps) and will continue to do so.

It is generally accepted that, under normal conditions, it takes about three years from the decision to build a satellite to the satellite becoming operational.[12]

The FCC's Analysis of Satellite Costs and Capacity

OBI Technical Paper No. 1 describes the model that the FCC developed to predict the cost of closing the broadband gap using a variety of technologies. It does not directly incorporate satellite technology into that model. Rather the authors conducted a separate analysis of satellites. That satellite analysis was based on a few basic assumptions:

- Satellite performance was that of the current (2010) state-of-the-art;
- Data usage would increase over time;
- User fees could be determined by considering current satellite service prices; and
- Satellite capacity would be limited to that already under construction.

Under these assumptions, OBI Technical Paper No. 1 concludes the following:

- A single satellite could serve about 440,000 housing units in 2015;
- User fees would be in the range of $70 to $120 per month; and
- Capital investment per user for the satellite service would be $700, $1,400, or $3,050, depending on assumed usage (low, medium, high).[13]

FCC staff calculated that a subsidy buy-down of satellite service—the payment necessary to close the gap between the user fees that it projected satellite firms would charge and the acceptably affordable level of $35 per month—would range between $35 and $85 per month.

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[10] ViaSat actually has 92 beams and a capacity of over 140 Gbps but some of the beams and capacity are owned by a third party and cover Canada.

[11] See http://defense.hughes.com/solutions-and-services/transformational-satcom-systems/jupiter.

[12] See OBI Technical Paper No. 1 at p. 92. Note also that the description of its Jupiter satellite by Hughes stated that development was begun in 2009 and that launch is scheduled for 2012.

[13] OBI Technical Paper No. 1 at Exhibit 4-AR.

This subsidy is assumed to continue for 20 years and is discounted to the present to yield a net present value (NPV) of the subsidy as $800 million for 250,000 housing units.

An Alternate Analysis

OBI Technical Paper No. 1 contains some unsound assumptions about unserved housing units, continuing technological developments in satellite communications, and the cost structure of the satellite industry. In this section, the implications of substituting more realistic assumptions are explored. Table 2 presents an analysis that parallels the analysis of OBI Technical Paper No. 1. This table was developed in order to provide a benchmark against which to compare the implications of varying some assumptions implicit in the FCC staff's model about extending broadband service to unserved housing units.

Specifically, like the OBI Technical Paper No. 1, Table 2 assumes that a modern satellite has 130 gigabits per second of capacity, that the capacity is split 60/40 between downlink and uplink, that 10% of the capacity is lost due to imperfect fill on some spot beams, and that user downlink demand follows either the medium- or high-usage scenario. The table shows that, under these assumptions, two ViaSat-1-like satellites could serve 870,000 housing units, or 435,000 each. OBI Technical Paper No. 1 calculated a capacity of 440,000 housing units per satellite.

Table 2. Reproduction of the FCC OBI Technical Paper 1 Analysis [14]

Scenario description: Medium-subscriber usage, no new satellites beyond ViaSat-1 and Jupiter, no technological progress. 35 Gbps of pre-existing capacity Per-sub usage growth rate = 27% Per-satellite investment = $400 million Includes capacity existing prior to 2011 Uplink/downlink traffic split = 60% downlink					
Variable	2011	2012	2013	2014	2015
Total downlink satellite capacity	99	177	177	177	177
Adjusted capacity for imperfect fill (90%)	89	159	159	159	159
Total satellite investment	400	800	800	800	800
Per-sub capacity required (kbps)	62	79	100	126	160
Housing units that can be served (millions)	1.45	2.02	1.59	1.26	1.00

The numbers shown in Table 2 match those in text and Exhibits on pages 90–91 of OBI Technical Paper No. 1. We can also calculate the cost of two state-of-the art satellites, one launching in 2011 and another in 2012, on a per subscriber basis. That is done in Table 3, which shows the capital investment per subscriber under the assumptions of Table 2 (but without factoring in preexisting satellite capacity) for two state-of-the-art satellites costing $400 million each.

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[14] A more complete version of this table, showing all the intermediate calculations, is Attachment A to this report.

Table 3. Satellite Capital Expenditure Analysis

	2011	2012	2013	2014	2015
Total Satellite Capital Investment (millions)	$400	$800	$800	$800	$800
Satellite CapEX/subscriber (Medium Usage Scenario)	$351	$450	$570	$718	$912
Satellite CapEX/effective housing unit passed 83% take rate	$292	$374	$473	$596	$757
Satellite CapEX/effective housing unit passed 67% take rate	$235	$302	$382	$481	$611
Satellite CapEX/subscriber (High Usage Scenario)	$1,014	$1,009	$1,624	$2,051	$2,593
Satellite CapEX/effective housing unit passed 83% take rate	$842	$837	$1,348	$1,703	$2,152
Satellite CapEX/effective housing unit passed 67% take rate	$680	$676	$1,088	$1,374	$1,737

However, the calculations of per-user capital expenditure do not match the capital expenditure shown in OBI Technical Paper No. 1 at Exhibit 4-AR. That figure shows satellite capital expenditure per subscriber of $1,400 in 2015 in the medium-usage case and of $3,100 in the high-usage case.[15] Table 3 shows a capital expenditure of $912 in the medium-demand case and $2,593 in the high-demand case for 2015. The reason for the difference is that the capital expenditure shown in OBI Technical Paper No. 1 at Exhibit 4-AR may also include the costs of gateways and equipment at the user's location, and factor in the costs of preexisting satellite capacity. If we assume for purposes of this comparison that those investments total $500 per subscriber, then there is close match between the capital expenditure in Table 3 and that in OBI Technical Paper No. 1 ($1,412 vs. 1,400 and $3,093 vs. $3,050). Thus, this reproduction of the OBI Technical Paper No. 1 analysis yielded very similar results. Note that below, when we model those costs we use a significantly higher number—$715 in 2011 and declining by $5 per year thereafter.

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[15] We can check these values. The downlink capacity of a satellite under the OBI assumptions is 0.6*130 0.9 = 70.2 Gbps. Exhibit 4-AN shows medium usage of 160 kbps and high usage of 445 kbps in 2015. Now, 70.2 Gbps / 160 kbps = 487,500 users. And $400 / 487,500 = $912. Similarly, 70.2 Gbps / 455 kbps = 154,000 users, and $400 / 154,000 = $2592.

Projected Rural Broadband Subscribers

The first problem with the analysis in OBI Technical Paper No. 1 is that it does not take into account a less than a 100% adoption rate. Table 3 shows two other numbers for capital expenditure—measured against the effective number of housing units passed based on different adoption rates. Consider the 250,000 most expensive to serve housing units. Even with a generous subsidy, it is highly unlikely that the people living in every housing unit would subscribe to broadband Internet access. Some people are not interested in Internet services, others may be unwilling or unable to pay even the subsidized price, and still others may get adequate Internet access at work. Some housing units are occupied only part-time, and a part-time usage plan or portable access device may meet the needs at those housing units. A study prepared for the FCC's Omnibus Broadband Initiative estimated that today only 67% of households have broadband Internet access.[16]

One of the goals of the National Broadband Plan is to spur further adoption of broadband. An entire chapter is devoted to this challenge.[17] OBI Technical Paper No. 1 devotes several pages to analyzing the appropriate take-rate for broadband Internet access and develops a complex model that is used to predict the take-rate separately for each census block based on several demographic factors.[18] Exhibit 3-S to OBI Technical Paper No. 1 shows the forecast adoption rates for several different demographic groups, as well as an adoption rate labeled *overall.* The overall adoption rate reaches a maximum of about 83% after 10 years.[19] A more appropriate way to calculate the subsidies needed to buy down the cost of satellite service may be to incorporate the same take-rate analysis as was used for other technologies.

Table 3 shows how capital costs per effective home passed would decline if adoption were assumed to be only 83% or 67%. A similar reduction should be applied to the capital expenditures identified by the FCC staff. However, it does not appear to have been done. Thus, FCC staff estimates of the cost of closing the gap with satellite service for the last 250,000 unserved units appear to be inflated by a factor of 1.0/0.83, or 20%.[20]

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[16] See the discussion below at footnote 19.

[17] See Chapter 9 of the National Broadband Plan.

[18] See OBI Technical Paper No. 1 at pp. 45–48.

[19] That diagram displays much information and is hard to read. In particular, there are two lines drawn with the color used for the overall take-rate. We used the higher of the two lines to get the 83% number. If we had used the other line, the peak adoption would have been about 75%. It is possible that we have read the diagram too conservatively and that the relative economics of satellite are even more favorable than this analysis indicates. We also note that Exhibit 3-U does a sensitivity analysis by increasing the take rate by 15%. That implies that the average take rate used in the analysis in OBI Technical Paper No. 1 is no more than 85%. It is unclear to us whether the adoption rate is calculated for households are housing units. We have made the conservative assumption that it refers to housing units.

[20] It might seem that, if the take rate is at most 83%, then the relevant inflation factor would be 17%. But, the proper calculation is to ask by what factor must one multiply the costs of serving 83% to obtain the cost of serving 100%? Well, 83%*1.2 = 100% — a 20% increase is required.

Technological Progress

A second, perhaps more important problem with the FCC analysis of the cost of satellite service is its implicit assumption that there will be no technological progress in satellite communications. More specifically, the analysis in OBI Technical Paper No. 1 assumes that the price of satellite capacity (per megabit per second) will stay constant for the next 20 years and discounts the required constant subsidy for 20 years at 11.25%.[21] The historical experience with satellite capacity has been quite different—at the historical rate of improvement of 20% per year, the cost of satellite Internet access would decline by a factor of 40 over 20 years.

If one assumes that the cost of satellite capacity were to decline at the historical rate of 20% per year, then the net present value of the required satellite capacity would fall by a factor of 2.45. Combining this factor with the adoption factor discussed above means that the cost of the satellite capacity required to serve the unserved in the fifth year should be decreased by a factor of 2.45/0.83, or 2.95. This is almost a factor of 3! The attractiveness of the satellite alternative in unserved areas must be considerably higher than the analysis in OBI Technical Paper No. 1 indicates if, as this analysis concludes, the satellite cost has been overestimated by a factor of 2.95.

Forecasting Usage

One important aspect of modeling the cost of broadband access is projecting the average user demand in the future. The cost of the satellite capacity consumed by a user grows directly proportionally to the busy hour usage. Similarly, some of the costs of 4G wireless and ADSL systems vary with usage so forecasting their costs also requires a forecast of usage. The method and forecasts of usage in OBI Technical Paper No. 1 appear reasonable and are adopted for use in this report. Using the same traffic levels as OBI used in their forecasts also ensures that our comparisons with their results is as apple-to-apple as possible.

But, some words of background and explanation may be helpful. OBI Technical Paper No. 1, in a section labeled network dimensioning, contains an extensive discussion of the problem of properly modeling user demand. They conclude that the appropriate average load in the busy hour (the busy-hour offered load [BHOL]) is 160 kbps in 2015.[22] That number, 160 kbps, was calculated by considering the usage of the median user in 2009 and assuming that usage grows 27% per year until 2015 when it reaches 160 kbps. That is an increase of a factor of 4 over the actual median average user load of 39 kbps in 2009.[23] And, OBI used that average usage of 160 kbps to calculate the costs of extending 4G wireless and ADSL systems.[24] Similarly, in

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[21] OBI Technical Paper No. 1 at p. 94.

[22] Specifically, at page 111 OBI Technical Paper No. 1 states "For our network dimensioning purposes, we shall use a BHOL of 160 kbps to represent usage in the future. Thus, this network will not only support the traffic of the typical user, but it will also support the traffic of the overwhelming majority of all user types, including the effect of demand growth over time."

[23] See OBI Technical Paper No. 1 at Exhibit 4-AN.

[24] At page 61, OBI Technical Paper No. 1 states "All of the technology comparisons in this chapter are based on network builds that can meet the target, with an effective busy hour load assumption of 160 kbps (see later section on Network Dimensioning). A fundamental tenet is that the networks have been modeled such

analyzing the subsidies needed to provide satellite broadband service to the 250,000 housing units that are most expensive to serve terrestrially, OBI Technical Paper No. 1 uses 160 kbps as the busy-hour average user load.[25]

Our model of satellite costs assumes that average user demand follows the same scenario as was used by OBI to estimate the costs of other technologies. Specifically, we assume that usage grows as shown in Exhibit 4-AN reaching 160 kbps in 2015. However, we also assume that usage continues to grow until it reaches 260 kbps in 2018. We do this because 260 kbps appears to be the actual average capacity of the ADSL system modeled in OBI Technical Paper No. 1. (Examining Exhibit 4-AJ one can calculate that the ADSL system modeled by OBI had a capacity of 260 kbps per user when fully loaded.[26])

This assumption of continued growth to 260 kbps makes the conclusions reached in this report about future satellite capacity more conservative than one based simply on 160 kbps. This conservative assumption makes for a closer comparison between satellite and ADSL by analyzing a satellite system that matches the actual capacity of the ADSL system.

Understanding the Cost of Satellite Service

One must also consider whether the specific level of the price of satellite service used in the FCC analysis was appropriate, even ignoring issues of take rate and technological improvement. The analysis of the cost of satellite broadband service in OBI Technical Paper No. 1 differs substantially from the analysis applied to other technologies. The analysis of ADSL or 4G wireless identifies the costs of providing building out ADSL and 4G wireless service, including a reasonable return on investment, and uses that cost to determine the gap (or subsidy) associated with that technology. The required subsidy is the difference between the estimated cost and the assumed revenue. In contrast, in OBI Technical Paper No. 1, future satellite service prices are not estimated by considering costs and the necessary returns to capital, but rather by considering today's prices for satellite service and adjusting them to reflect higher traffic levels. But, we know that broadband satellites today are capacity constrained.[27] In a capacity-constrained environment, one would not expect cost-based pricing. Rather, we expect congestion-based pricing, and economic theory teaches that congestion-based pricing would lead to consumer welfare gains.[28] Consequently, using today's capacity-constrained prices to predict future pricing is flawed—it is like using the price of corn during a drought to estimate the price of corn during a banner year for produce. The use of predicted satellite prices in OBI Technical Paper

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that users will receive an equivalent level of service and performance whether they are serviced by the fixed wireless 4G access network or a 12 kft DSL architecture." See also p. 71 and p. 88 for specific statements regarding the use of 160 kbps to estimate the cost of 4G and ADSL networks.

[25] See OBI Technical Paper No. 1 at Exhibit 4-AP and at pp. 91-94.

[26] Exhibit 4-AJ shows that the modeled ADSL system can only support 26% of its users with 1 Mbps streaming service. This is an average downstream usage of 260 kbps. Because capacity in telecommunications systems often comes in discrete lumps, building an ADSL system to have an average capacity of 160 kbps results in building one with somewhat more capacity.

[27] See OBI Technical Paper No. 1 at p. 90.

[28] See, for example, http://ops.fhwa.dot.gov/publications/congestionpricing/index.htm.

No. 1 based on today's congestion means that the OBI analysis was not apples-to-apples with terrestrial technologies.

In OBI Technical Paper No. 1, the cost of ADSL service is calculated by considering capital expenditures, operating costs, and revenues. Operating costs and revenues are converted to net present values by discounting at 11.25%. This process is described in OBI Technical Paper No. 1 as ". . . we equivalently set the internal rate of return (IRR) of these incremental broadband buildouts to 11.25%."[29] The broadband gap associated with ADSL service is calculated by comparing the costs of providing ADSL service with the expected (subsidy-free) revenues.

The analysis in OBI Technical Paper No. 1 assumes that the appropriate subsidy-free price for Internet access alone such as is provided by satellite service is $35 per month.[30] A constant stream of monthly payments of $35 for 20 years discounted to the present at 11.25% annual rate (0.8924% per month) has a net present value of $3,457.[31] This is the subsidy-free cost of broadband Internet access. That is, a broadband Internet access alternative with net present value of costs of $3,457 is assumed to require no subsidy, but alternatives with any higher cost would require subsidy.

Analysis of Satellite Costs

Table 4 presents an alternate analysis of satellite costs and capacities. The analysis was done in the same fashion as that in Table 2, which reproduced the analysis of OBI Technical Paper No. 1. However, the following assumptions were changed:

- The performance of new satellites is assumed to improve at the long-term average rate of 20% per year; and
- The satellite broadband industry is assumed to launch a new satellite every year, starting in 2014.

These two assumptions are significant differences because they predict the capacity growth that has naturally occurred in the satellite industry[32]. They also significantly increase the number of housing units that satellite broadband could serve in the near term—realistically providing the capacity to serve about 6.6 million broadband subscribers (medium-demand scenario) by 2020, even with the FCC's predicted increase in bandwidth demands.

The changed assumptions in Table 4 are in bold and italics for emphasis.

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[29] OBI Technical Paper No. 1 at p. 33.

[30] OBI Technical Paper No. 1 at p. 93.

[31] The annual discount factor of 1.1125 is here converted to a monthly discount factor of $1.1125^{1/12}$, or 1.008924. This results in the discount factor for a 12-month period being 1.008924^{12}, or 1.1125.

[32] By way of analogy, since its inception in the mid-1990s, the satellite TV industry has launched over two dozen DBS satellites. *See* DIRECTV 2010 10-K at 7 (noting that DIRECTV "currently ha[s] a fleet of twelve geosynchronous satellites . . . ."); DISH Network 2010 10-K at F-18 ("We currently utilize 13 satellites in geostationary orbit . . . .").

Table 4. Satellite Capacity Assuming Technological Progress[33]

Scenario description: Medium-subscriber usage, ***one new satellite per year after 2014***, as well as ViaSat-1 and Jupiter, ***20% per year technological progress***. State-of-the-art in 2011 is 130 Gbps. Considering only the capacity of satellites launched in 2011 and later. Per-sub capacity growth rate = 27% Per-satellite investment = $400 million Does not factor in capacity existing prior to 2011(we lack the data to do the capital analysis) Uplink/downlink traffic split = 60% downlink					
Year	**2011**		**2015**		**2020**
Total downlink satellite capacity	78		453		1897
Adjusted capacity for imperfect fill (90%)	70		407		1707
Total satellite investment (millions)	$400		1,600		3,600
Per-user capacity need (kbps)	62		160		260
Housing units that can be served (millions)	1.14		2.55		6.57

We can also look at the satellite investment required per supportable housing unit and per housing unit actually served. Those numbers are shown in Table 5 below. Note that in 2011 in the medium-usage scenario, the per subscriber satellite capital investment is only $351.

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[33] A more complete version of this table, showing all the intermediate calculations, is Attachment B to this report.

Table 5. Satellite Capital Expenditure Analysis Assuming Technological Progress and Continued Satellite Deployment (Not Including Customer Equipment)

Capital Expenditure	2011	2015	2020
Total satellite capital investment (millions)	$400	$1,600	$3,600
Satellite CapEX/housing unit subscribing (medium-usage scenario)	$351	$629	$548
Satellite CapEX/effective housing units served, 83% take-rate	$292	$522	$455
Satellite CapEX/effective housing unit served, 67% take-rate	$235	$421	$367
Satellite CapEX/housing unit subscribing (high-usage scenario)	$1,014	$1,787	$1,548
Satellite CapEX/effective housing unit served, 83% take-rate	$842	$1,483	$1,285
Satellite CapEX/effective housing unit served, 67% take-rate	$680	$1,197	$1,037

Although the changes made to the assumptions are relatively small—the most important change being the assumption of continuing technological progress in the satellite industry—the resulting conclusions are markedly different. In particular, the satellite capital investment per subscriber in the medium-usage scenario in 2015 has fallen to $629, and the investment per effective home served (assuming an 83% take rate) has fallen to $522. If we use the $500 per-subscriber allowance for non-satellite capital costs from OBI Technical Paper No. 1,[34] then we get a total investment per subscriber of $1,129 for the medium-usage scenario in 2015. This is a small fraction of the present value of the income stream associated with a subscriber. OBI Technical Paper No. 1 assumes that a data-only subscriber will pay $36 per month.[35] At a discount rate of 11.25% annually for 20 years, this stream of payments has a net present value of $3,556. Subtracting the $1,129 initial capital costs from this leaves $2,427 as an allowance for operating expenses and other costs. The cost models in OBI Technical Paper No. 1 consistently show operating expenses as having a net present value of about the same magnitude as the initial capital investment.[36] Thus, under these assumptions, and before factoring in the cost of customer equipment, it appears quite reasonable to conclude that by 2015, satellite systems would need relatively little subsidy to serve a large fraction of the broadband gap in the medium-usage scenario. OBI Technical Paper No. 1 states that "Operating costs for a satellite broadband operator are typically lower than for a wired network provider."

The analysis of the satellite cost per subscriber is straightforward. However, the analysis of other capital costs and of operating expenses is more complex. As explained above, OBI

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[34] At p. 92.

[35] See OBI Technical Paper No. 1 at Exhibit 3-V. Note that OBI Technical Paper No. 1 also considers a data service price of $43 per month for wireless in some areas and used a $35 per month figure when estimating the cost of subsidizing satellite service.

[36] See, for example, OBI Technical Paper No. 1 Exhibit I-A at p. 5.

Technical Paper No. 1 appears to be based on an assumption that other capital costs, mostly gateways and customer equipment, will total $500. ViaSat informs me that reasonable values to use for the upfront investment needed to put a customer in service total $715 in 2011 and are expected to decline at about $5 per year due to decreases in the cost of the electronics at the customer premises. ViaSat also informs me that a reasonable value for the monthly operating expense per user is $24.

We also added a calculation of the tax effects following the approach used in OBI Technical Paper No. 1 at Exhibit 4-AX.

We can combine all these numbers to generate an estimate of the subsidy required for satellite broadband in exactly the same manner as OBI Technical Paper No. 1 does for ADSL and 4G wireless. Doing so we get the results shown in Table 6. Because technology is changing and traffic is growing, the required subsidy varies depending upon which year one does the calculation. However, the required subsidies are relatively small. In the medium usage case, the maximum subsidy of $649 occurs in 2017.

It bears emphasis that these calculations are provided to demonstrate the cost-effectiveness of satellite broadband, when compared with terrestrial technologies on the same terms. Of course, the amount that an individual bidder in an auction would require may depend on a variety of factors not considered by OBI Technical Paper No. 1, such as less than 100% adoption in a given area, subscriber churn, and actual or potential competition from other providers. A full analysis of those factors is beyond the scope of this paper.

Table 6. The Apples-to-Apples Cost and Subsidy for Broadband Satellite (Medium Usage, Continued Satellite Deployment, 100% Adoption)

Quantity	2011	2015	2020
Satellite CapEx/subcriber (medium usage scenario)	$351	$629	$548
Other Upfront Investments	$715	$695	$670
Present Value of Operating Expense	$2,371	$2,371	$2,371
Present Value of All Investment and Costs (medium usage)	$3,437	$3,694	$3,589
Present Value of Revenue	$3,556	$3,556	$3,556
Taxes[37]	$267	$331	$305
Subsidy Required	$148	$469	$338

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[37] Calculated as in OBI Technical Paper 1 Exhibit 4-AX.

Examining the Gap

Exhibit 3-H of OBI Technical Paper No. 1 and the essentially identical Exhibit 8-C of the National Broadband Plan show the cumulative distribution of the subsidies required to close the broadband gap versus the percentage of housing units served. Exhibit 3-H is reproduced below. The least expensive housing units require relatively little subsidy, the last 25 or 30% of housing units require substantial subsidies.

Examining Exhibit 3-H allows calculation of the distribution of the required subsidies by percentile. Attachment C describes how this was done, based on the data available to us at this point in time. The resulting distribution is not completely in line with Exhibit 3-H, but various checks show that it must be quite close to the distribution underlying Exhibit 3-H.

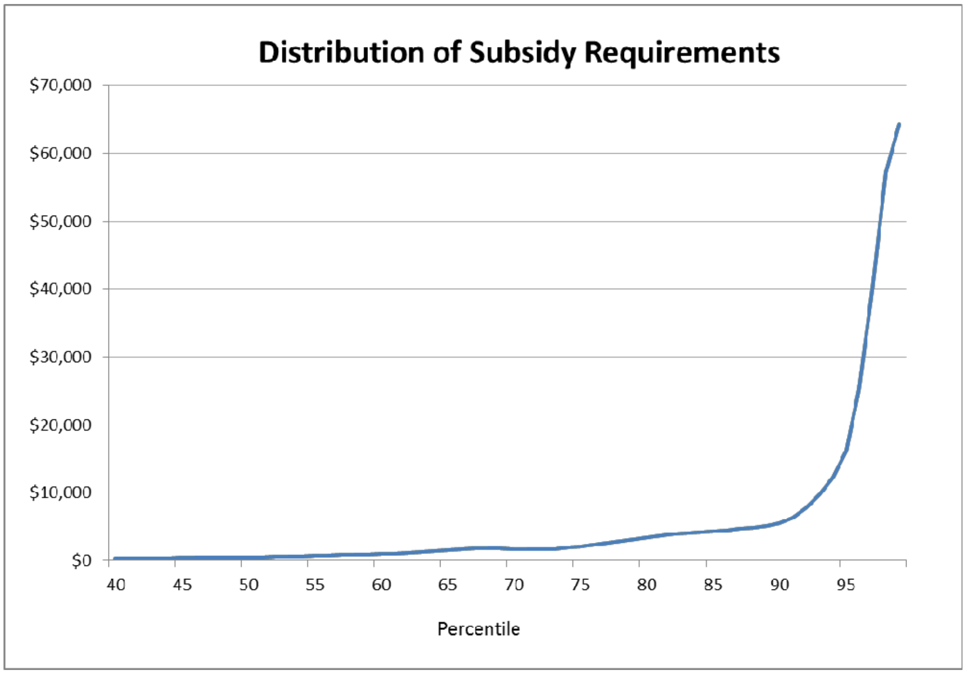

Figure 1. Distribution of Subsidies Needed to Close the Broadband Gap

Several interesting features can be seen from this figure. First, the subsidies required for the first 40 percent of housing units are quite low. Second, recall that OBI Technical Paper No. at page 94 calculated that the subsidy needed to use satellite to serve the 250,000 most expensive to serve housing units would require a total subsidy of $800 million. That works out to $3,200 per housing unit. If we adjusted for the fact that not all housing units will be subscribers then the actual cost to close that part of the gap would fall. Assuming only 83% of housing units subscribe, the actual cost required to close that part of the gap would be $664 million. Examining Figure 1 shows that about 20% of the housing units in the gap require a subsidy of more than $3,200. So, even using the flawed analysis of satellites in OBI Technical Paper No. 1 satellite is the most cost-effective technology for serving 20% of the gap or 1.4 million housing units! OBI Technical Paper No. 1 offered an alternate estimate, based on a satellite price of $120 per month, or $2 billion in present value to subsidize the last 250,000 housing units.[38] This works out to $8,000 per housing unit. About 8% of the housing units in the gap, or more than 500,000, require a subsidy larger than that. Thus, using its own data (and putting aside the analytical flaws identified above), one must question the conclusion in OBI Technical Paper No. 1 that satellite should be used only to serve the last 250,000 housing units.

Above, the necessary subsidies were calculated on the apples-to-apples basis and the highest subsidy under the medium-usage scenario was $649 in 2017 (Note, the column for 2017 was not shown in order to keep the table compact, but is shown in Attachment B). At that subsidy level, satellite is the most cost-effective technology for about 47% of the gap, or 3.3 million housing units. The cost to close that 47% of the gap would be ($649 per housing unit) times (3.3 million housing units) times (83% take rate) or $1.8 billion. In contrast, Exhibit 3-H of OBI Technical Paper No. 1 shows that closing the last 47% of the gap would cost about $23 billion—about 13 times more (note that at a take-rate of 83%, only 2.7 million subscribers need to be served.) Looking at the spreadsheet underlying Table 6 (and available in Attachment B), assuming the launch of one new broadband satellite per year starting in 2014 would provide the capacity needed to do this by 2016. If one considers the maximum subsidy required in the high-usage case, $2,453 in 2017 (again this number appears in Attachment B), it is still the case that satellite broadband is the most cost-effective technology for about 23% of the gap. The cost to close that 23% of the gap would be ($2,453 per housing unit) times (1.61 million housing units) times (83% take rate) or $3.2 billion. In contrast, Exhibit 3-H of OBI Technical Paper No. 1 shows that closing the last 23% of the gap would cost more than $20 billion—about six times more. As detailed in Attachment B, assuming the launch of one new broadband satellite per year starting in 2014 would provide the capacity needed (for 1.3 million subscribers, or 1.61 million times an 83% take rate) to do this by 2018. (Recall that this is not an apples-to-apples comparison as the high-capacity demand in 2019 is about three times the design maximum of ADSL systems considered in OBI Technical Paper No. 1.)

Implications of the Assumptions

Table 7 below summarizes the implications of varying only one of the assumptions in the OBI analysis. That is, if one redoes the analysis of satellites as was done in OBI Technical Paper No. 1 after changing a single assumption, the conclusions are changed as described in the right-hand column.

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[38] Again, adjusting for 83% fill, the 2 billion falls to $1.66 billion.

Table 7. Consequences of Varying the Assumptions

Assumption	Implication for Satellite Competitiveness
Analyze the required subsidy for satellites using the same, cost-based approach that OBI uses in its analysis of other technologies.	The required subsidy shrinks enormously. Satellite becomes the technology requiring the least subsidy in a substantial fraction of the broadband gap.
Factor in the expected effects of technological progress in satellite communications.	Satellite becomes far more cost-effective in future years than would otherwise be predicted.
Calculate required subsidies by assuming, as OBI does in its analysis of other technologies, that only a portion of housing units, one growing over time, will subscribe to broadband access.	Some of the satellite subsidy requirements calculated in OBI Technical Paper No. 1, such as the subsidy needed for the last 250,000 housing units, shrink significantly (i.e., service to fewer housing units must be subsidized).

Conclusions

OBI Technical Paper No. 1 concludes that using satellites to serve only a small fraction of the currently unserved housing units could cut the cost of closing the broadband gap by more than half. The analysis in OBI Technical Paper No. 1 substantially underestimates the role of satellites could play in closing the broadband gap, because it suffers from at least four flaws.

First, it estimated the cost of satellite service by extrapolating from market prices today. This extrapolation took into account neither current or future satellite technology nor the fact that new satellites will solve the current congestion on satellite broadband systems. This was quite different from the OBI analysis of the cost of other technologies such as wireless and ADSL where future expected costs of those technologies were considered without regard to the state of network congestion today. In determining the cost of using those technologies to provide broadband access in currently unserved areas, OBI developed a complex cost model that identified the costs of building and supporting new telecommunications plant to provide service. The need for subsidies was based on those future costs.

Second, it made no allowance for continuing technological progress in satellite communications—a field that has seen enormous progress in the past.

Third, OBI failed to provide for any growth in satellite capacity beyond the launch of the next two broadband spacecraft, including that which necessarily would flow from the launch of additional spacecraft.

Fourth, a less distorting error was to calculate the subsidies required for satellite broadband services as if every unserved housing unit would subscribe rather than adjusting for the expected rate of adoption by unserved housing units.

Each of these errors caused the analysis in OBI Technical Paper No. 1 to overstate, sometimes dramatically, the cost and understate the capabilities of the satellite alternative. The cost of providing satellite-based broadband should be calculated and compared with the assumed revenue from service to end users. If technical progress continues into the future at its historical rates, then satellite capacity should cost half what it costs today.

OBI Technical Paper No. 1 also indicates that the time required to build a satellite makes the use of satellites problematic, claiming, "Timing may be an issue if satellite broadband were deployed as the only means of reaching the unserved, as a next-generation satellite takes approximately three years to build."[39] The CAF NPRM proposes that winners of reverse auctions have three years to deploy their systems. If a satellite service provider has a satellite scheduled for deployment or has taken the initial steps towards procuring a new satellite before the reverse auction is held at some undetermined point in the future, or otherwise has capacity available, then it should be able to meet such a deadline.

About the Author

Dr. Charles L. Jackson is an electrical engineer who has worked extensively in communications and wireless. He has been both a digital designer and a system programmer. He works as a consultant and as an adjunct professor at George Washington University, where he has taught graduate courses on computer security, networking and the Internet, mobile communications, and wireless networks. Dr. Jackson consults on technology issues—primarily wireless and telecommunications. Dr. Jackson served three terms on the FCC's Technological Advisory Council. He previously worked at both the FCC and the House Commerce Committee. He holds two U.S. patents. Dr. Jackson received his PhD from MIT.

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[39] OBI Technical Paper No. 1 at p. 92.

Attachment A

Reproduce FCC OBI Technical Paper 1 Analysis in Exhibit 4-AX scenario use FCC parameters

Per Sub Capacity Growth Rate (note, growth is capped in 2017)	27%		Fraction of satellite capcity lost to incomplete fill	10%	
Sat Cap Growth Rate	0%		Medium capacity usage in 2011	62	kbps
Per Satellite Investment (millions)	$400		High capacity usage in 2011	178	kbps
State-of-the Art Satellite Capacity 2011	130	Gbps	Effective Tax Rate	20%	
Capacity Existing Prior to 2011	35	Gbps			
Capacity Used on Downlink	60%				

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Expected Capacity of Additional Satellite - Downstream (Gbps)	78	78	78	78	78	78	78	78	78	78
ViaSat Satellite Capacity										
New Satellites Launched	1	-	-							
Added Capacity in Orbit (Gbps)	78	-	-	-	-	-	-	-	-	-
Cummulative Capacity in Orbit (Gbps)	78	78	78	78	78	78	78	78	78	78
Other Satellite Industry Capacity										
New Satellites Launched	-	1	-							
Added Capacity in Orbit (Gbps)	-	78	-	-	-	-	-	-	-	-
Cummulative Capacity in Orbit (Gbps)	-	78	78	78	78	78	78	78	78	78
Satellites In Orbit	1	2	2	2	2	2	2	2	2	2
Total Downlink Satellite Capacity	99	177	177	177	177	177	177	177	177	177
Adjust Total for Imperfect Fill (90%)	89	159	159	159	159	159	159	159	159	159
Capacity Needed (OBI TP 1 Medium Usage Scenario)										
Per Sub Capacity Required (kbps)	62	79	100	126	160	203	258	328	416	529
Housing units that can be served (Millions)	1.445	2.016	1.593	1.264	0.996	0.784	0.617	0.486	0.383	0.301
Capacity Needed (OBI TP 1 High Usage Scenario)										
Per Sub Capacity Required (kbps)	178	225	285	360	455	578	734	932	1,184	1,503
Housing units that can be served (Millions)	0.501	0.708	0.559	0.443	0.350	0.276	0.217	0.171	0.135	0.106
Satellite Capital Expenditure Analysis										
Total Satellite Capital Investment (millions)	$400	$800	$800	$800	$800	$800	$800	$800	$800	$800
Satellite CapEX/subscriber (Medium Usage Scenario)	$277	$397	$502	$633	$804	$1,020	$1,296	$1,646	$2,090	$2,655
Satellite CapEX/effective housing unit passed 83% take rate	$230	$329	$417	$525	$667	$847	$1,076	$1,366	$1,735	$2,203
Satellite CapEX/effective housing unit passed 67% take rate	$185	$266	$336	$424	$538	$684	$868	$1,103	$1,401	$1,779
Satellite CapEX/subscriber (High Usage Scenario)	$799	$1,130	$1,431	$1,808	$2,285	$2,902	$3,685	$4,681	$5,944	$7,549
Satellite CapEX/effective housing unit passed 83% take rate	$663	$938	$1,188	$1,501	$1,897	$2,409	$3,059	$3,885	$4,934	$6,266
Satellite CapEX/effective housing unit passed 67% take rate	$535	$757	$959	$1,211	$1,531	$1,944	$2,469	$3,136	$3,983	$5,058

The independent variables in this spreadsheet are those in the lightly shaded region and the 83% and 67% take rates. All other values are calculated from those values.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Satellite CapEx/subcriber (medium usage scenario)	$277	$397	$502	$633	$804	$1,020	$1,296	$1,646	$2,090	$2,655
Other Upfront Investments	$715	$710	$705	$700	$695	$690	$685	$680	$675	$670
Present Value Factor	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Operating Expense	$24	$24	$24	$24	$24	$24	$24	$24	$24	$24
Present Value of Operating Expense	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371
Present Value of All Investment and Costs(medium usage)	$3,362	$3,477	$3,578	$3,703	$3,869	$4,081	$4,352	$4,696	$5,136	$5,695
Monthly Average Revenue per User	$36	$36	$36	$36	$36	$36	$36	$36	$36	$36
Present Value of Revenue	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556
Taxes	$248	$277	$302	$333	$375	$428	$495	$581	$691	$831
Subsidy Required	$55	$198	$324	$481	$688	$953	$1,291	$1,722	$2,271	$2,971
Satellite CapEx/subcriber (high usage scenario)	$799	$1,130	$1,431	$1,808	$2,285	$2,902	$3,685	$4,681	$5,944	$7,549
Other Upfront Investments	$715	$710	$705	$700	$695	$690	$685	$680	$675	$670
Present Value Factor	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Operating Expense	$24	$24	$24	$24	$24	$24	$24	$24	$24	$24
Present Value of Operating Expense	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371
Present Value of All Investment and Costs(medium usage)	$3,885	$4,211	$4,507	$4,878	$5,351	$5,962	$6,741	$7,731	$8,990	$10,590
Monthly Average Revenue per User	$36	$36	$36	$36	$36	$36	$36	$36	$36	$36
Present Value of Revenue	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556
Taxes	$379	$460	$534	$627	$745	$898	$1,093	$1,340	$1,655	$2,055
Subsidy Required	$707	$1,115	$1,485	$1,950	$2,540	$3,305	$4,278	$5,515	$7,089	$9,089

Attachment B

Reproduce FCC OBI Technical Paper 1 Analysis in Exhibit 4-AX

scenario Description: Medium and high subscriber usage, technical progress, one new satellite per year from 2014 on, no consideration of capacity existing prior to 2011.

Per Sub Capacity Growth Rate (note, growth is capped in 2017)	27%		Fraction of satellite capcity lost to incomplete fil	10%	
Sat Cap Growth Rate	20%		Medium capacity usage in 2011	62	kbps
Per Satellite Investment (millions)	$400		High capacity usage in 2011	178	kbps
State-of-the Art Satellite Capacity 2011	130	Gbps	Effective Tax Rate	20%	
Capacity Existing Prior to 2011	-	Gbps	(omitted because we lack the data to do the capital analysis)		
Capacity Used on Downlink	60%				

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Expected Capacity of Additional Satellite - Downstream (Gbps)	78	94	112	135	162	194	233	279	335	402
ViaSat Satellite Capacity										
New Satellites Launched	1	-	-	1	-	1	-	1	-	1
Added Capacity in Orbit (Gbps)	78	-	-	135	-	194	-	279	-	402
Cummulative Capacity in Orbit (Gbps)	78	78	78	213	213	407	407	686	686	1,089
Other Satellite Industry Capacity										
New Satellites Launched		1	-	-	1	-	1	-	1	-
Added Capacity in Orbit (Gbps)	-	78	-	-	162	-	233	-	335	-
Cummulative Capacity in Orbit (Gbps)	-	78	78	78	240	240	473	473	808	808
Satellites In Orbit	1	2	2	3	4	5	6	7	8	9
Total Downlink Satellite Capacity	78	156	156	291	453	647	880	1,159	1,494	1,897
Adjust Total for Imperfect Fill (90%)	70	140	140	262	407	582	792	1,043	1,345	1,707
Capacity Needed (OBI TP 1 Medium Usage Scenario)										
Per Sub Capacity Required (kbps)	62	79	100	126	160	203	258	260	260	260
Housing units that can be served (Millions)	1.138	1.777	1.399	2.077	2.545	2.864	3.067	4.012	5.173	6.566
Capacity Needed (OBI TP 1 High Usage Scenario)										
Per Sub Capacity Required (kbps)	178	225	285	360	455	578	734	734	734	734
Housing units that can be served (Millions)	0.394	0.624	0.493	0.728	0.895	1.007	1.078	1.421	1.832	2.326
Satellite Capital Expenditure Analysis										
Total Satellite Capital Investment (millions)	$400	$800	$800	$1,200	$1,600	$2,000	$2,400	$2,800	$3,200	$3,600
Satellite CapEX/subscriber (Medium Usage Scenario)	$351	$450	$572	$578	$629	$698	$782	$698	$619	$548
Satellite CapEX/effective housing unit passed 83% take rate	$292	$374	$474	$480	$522	$580	$649	$579	$513	$455
Satellite CapEX/effective housing unit passed 67% take rate	$235	$302	$383	$387	$421	$468	$524	$468	$414	$367
Satellite CapEX/subscriber (High Usage Scenario)	$1,014	$1,282	$1,623	$1,649	$1,787	$1,985	$2,225	$1,970	$1,746	$1,548
Satellite CapEX/effective housing unit passed 83% take rate	$842	$1,064	$1,347	$1,369	$1,483	$1,648	$1,847	$1,635	$1,449	$1,285
Satellite CapEX/effective housing unit passed 67% take rate	$680	$859	$1,087	$1,105	$1,197	$1,330	$1,491	$1,320	$1,170	$1,037

The independent variables in this spreadsheet are those in the lightly shaded region and the 83% and 67% take rates. All other values are calculated from those values.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Satellite CapEx/subcriber (medium usage scenario)	$351	$450	$572	$578	$629	$698	$782	$698	$619	$548
Other Upfront Investments	$715	$710	$705	$700	$695	$690	$685	$680	$675	$670
Present Value Factor	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Operating Expense	$24	$24	$24	$24	$24	$24	$24	$24	$24	$24
Present Value of Operating Expense	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371
Present Value of All Investment and Costs(medium usage)	$3,437	$3,531	$3,647	$3,648	$3,694	$3,759	$3,838	$3,748	$3,664	$3,589
Monthly Average Revenue per User	$36	$36	$36	$36	$36	$36	$36	$36	$36	$36
Present Value of Revenue	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556
Taxes	$267	$290	$319	$319	$331	$347	$367	$344	$323	$305
Subsidy Required	$148	$265	$411	$412	$469	$550	$649	$537	$432	$338
Satellite CapEx/subcriber (high usage scenario)	$1,014	$1,282	$1,623	$1,649	$1,787	$1,985	$2,225	$1,970	$1,746	$1,548
Other Upfront Investments	$715	$710	$705	$700	$695	$690	$685	$680	$675	$670
Present Value Factor	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Operating Expense	$24	$24	$24	$24	$24	$24	$24	$24	$24	$24
Present Value of Operating Expense	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371	$2,371
Present Value of All Investment and Costs(medium usage)	$4,100	$4,363	$4,698	$4,720	$4,852	$5,046	$5,281	$5,021	$4,792	$4,588
Monthly Average Revenue per User	$36	$36	$36	$36	$36	$36	$36	$36	$36	$36
Present Value of Revenue	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556	$3,556
Taxes	$432	$498	$582	$587	$620	$669	$728	$663	$605	$554
Subsidy Required	$976	$1,305	$1,725	$1,752	$1,917	$2,159	$2,453	$2,128	$1,841	$1,587

Attachment C

Derivation of the Distribution of Subsidy Requirements

Exhibit 3-H of OBI Technical Paper No. 1 and the essentially identical Exhibit 8-C of the National Broadband Plan show the cumulative distribution of the subsidies required to close the broadband gap versus the percentage of housing units served. Exhibit 3-H is reproduced below. The least expensive housing units require relatively little subsidy, the last 25 or 30% of housing units require substantial subsidies.

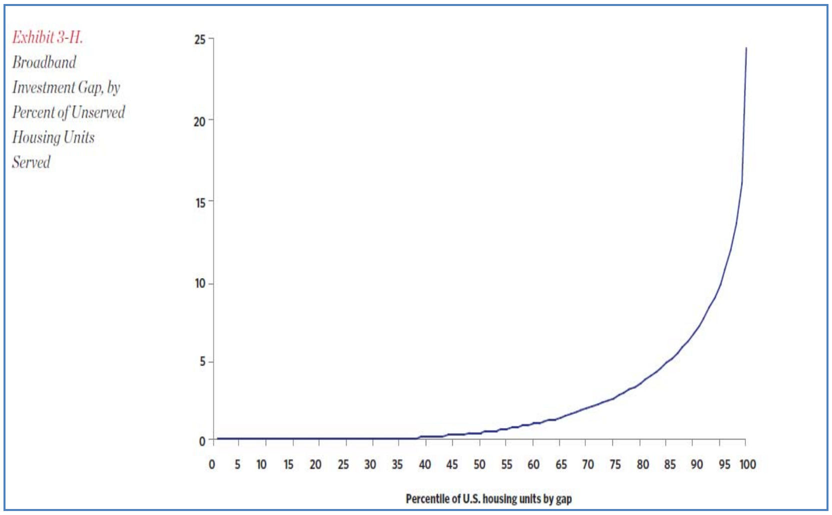

Figure C-2. Exhibit 3-H from OBI Technical Paper No. 1 "Cumulative Distribution of the Broadband Gap"

This graph does not allow one to see directly how much subsidy is required by a particular group of households. That information may be in the supporting materials released by OBI but we did not find it. However, one can find that information from the figure. We did that by reading off the values of the cumulative distribution at the 40th percentile, the 45th percentile, the 50th percentile, and so on all the way to the 100th percentile. To do this with some accuracy the figure was imported into Adobe Illustrator and a grid was overlaid on the figure so that values could be read more exactly. So, for example, the investment gap for the first 95% of housing units is approximately $9.3 billion. According to Exhibit 1-A of OBI Technical Paper No. 1, the investment gap for the full 100% is $23.5 billion so we used that value for the 100-percentile value.

If those readings from the figure are correct then the 5% of housing units lying between the 95th and the 100th percentile must require a total subsidy of 23.5-9.3 = $14.2 billion. We know that there are 7 million housing units in the gap so 5% of 7 million is 350,000. Dividing $14.2 billion by 350,000 gives $40,571—the average cost per housing unit of closing the last 5% of the broadband gap is $40,571.

However, we wanted finer resolution than we could easily get by reading the figure. So, we fit a cubic spline to the data points we had read off and interpolated for the values of the cumulative cost curve at every 1% point between 40% and 100%. Doing so indicated that the 1% of housing units (a total of 70,000 units) between the 80th and the 81st percentiles were calculated to need a total subsidy of $247 million or a subsidy of $3,525 each. This process is not perfect but, in the absence of access to the underlying data, does generate a reasonable estimate of the average per housing unit costs in each percentile.

As a check we used our derived costs to generate a cumulative cost distribution like the one in OBI Technical Paper No. 1 Exhibit 3-H and graphed the distribution. We then overlaid a plot of our distribution on Exhibit 3-H. That overlay is shown in Figure 2. As one can see our cumulative distribution matches quite closely the cumulative distribution in Exhibit 3-H except for the region between the 95th and the 100th percentile where our distribution rises more quickly in the range from about the 95th to the 98th percentile but then rises more slowly for the rest of the way. Nevertheless, this plot gives one great confidence that our derived cost distribution closely matches the cost distribution used by OBI to generate Exhibit 3-H. The dark blue line is the curve from OBI Technical Paper 1, the light blue line is the reproduction from our data.

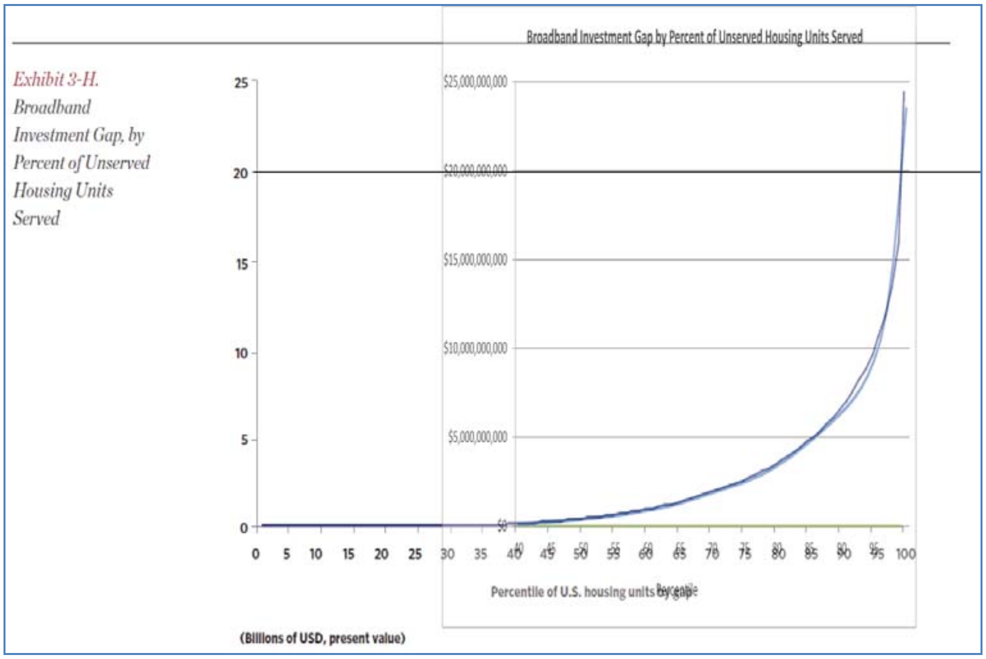

Figure C-3. Overlay of Derived Cumulative Distribution on Exhibit 3-H

Figure C-3 plots the required per household subsidy in one-percent steps from the 40th percentile on up. Table C-1 below shows our derived values for the average subsidy needed for all the single percent intervals from 40-41 to 99-100. As another check, we can calculate using the numbers in the table below that the average subsidy needed for most expensive three percent of unserved housing units or the most expensive 210,000 housing units is ($39,994 + $57,143 + $64,286) / 3 = $53,807. OBI Technical Paper No. 1 states that “the highest-gap 250,000 housing units account for $13.4 billion of the total $23.5 billion investment gap."[40] This is an average cost of $13.4 billon / 250,000 = $53,600. That is the average cost for the most expensive 250,000 housing units is almost the same as our estimated cost for the most expensive 21,000 units—but is actually slightly lower as would be expected.

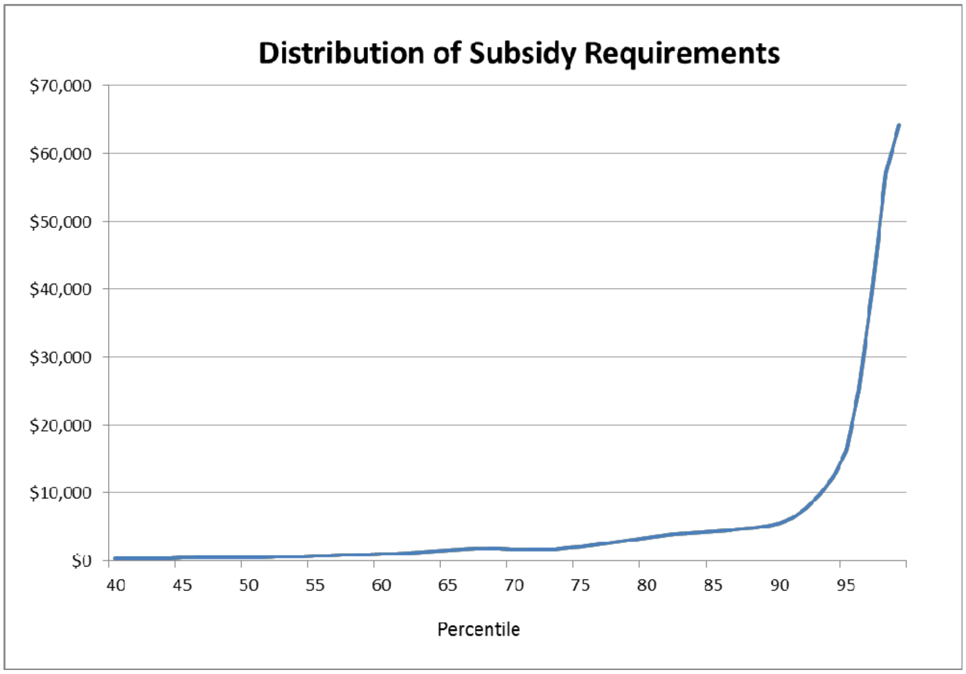

Figure C-4. Distribution of Per-Housing Unit Subsidy Requirements

Table C-1. Subsidy Requirements Per Housing Unit

Interval Lower Boundary Percentile	Average Subsidy per Housing Unit
40	$389
41	$391
42	$397
43	$406
44	$417
45	$431
46	$445
47	$458
48	$470
49	$482

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[40] OBI Technical Paper No. 1 at p. 5.

Interval Lower Boundary Percentile	Average Subsidy per Housing Unit
50	$495
51	$520
52	$558
53	$609
54	$674
55	$749
56	$815
57	$869
58	$911
59	$942
60	$968
61	$1,021
62	$1,108
63	$1,230
64	$1,387
65	$1,564
66	$1,697
67	$1,772
68	$1,790
69	$1,748
70	$1,669
71	$1,631
72	$1,653
73	$1,737
74	$1,882
75	$2,080
76	$2,306
77	$2,551
78	$2,817
79	$3,103
80	$3,398
81	$3,666
82	$3,895
83	$4,087
84	$4,240
85	$4,366
86	$4,511
87	$4,685

Interval Lower Boundary Percentile	Average Subsidy per Housing Unit
88	$4,888
89	$5,121
90	$5,474
91	$6,309
92	$7,714
93	$9,691
94	$12,240
95	$16,238
96	$25,197
97	$39,994
98	$57,143
99	$64,286