moving a fairly typical 85 analog channels to digital, a cable company can free up over 500 MHz of spectrum, providing enough capacity to carry well over 200 digital HD channels. The cost of analog reclamation is estimated at approximately $30 per home passed.[139]

Finally, cable companies could go all-IP, moving away from the current spectrum allocation entirely. A 750-MHz system could provide 4.5 Gbps[140] of all-IP bandwidth, to be shared among all users and all applications. This would require a significant change not only in network architecture for cable companies, but also significant business-process redesign to figure out how to capture revenue from an all-IP network.

Impact of homes per shared node

As noted above, cable capacity is shared among all users on a given node. Where there are more users, bandwidth is shared more widely and individual users will, on average, have less capacity. By splitting nodes, cable companies can reduce the user-load per node and increase the capacity per user. Some cable companies have been splitting nodes aggressively, moving from 1,000 homes per node to 100 homes per node or fewer.[141] Cisco estimates the cost of splitting a node at approximately $1,500.[142] Assuming 300-400 homes per node puts the cost at approximately $50 per home passed.

As node-splitting continues, HFC networks will reach the point where the run of coaxial cable is quite short—short enough that there is no need for active electronics in the coaxial part of the network. These so-called passive nodes often have roughly 60 homes per node,[143] but the driver is the linear distance covered by the coaxial cable, not the number of homes. Removing active electronics from the field, however, will yield a network that is more robust and that requires less maintenance.

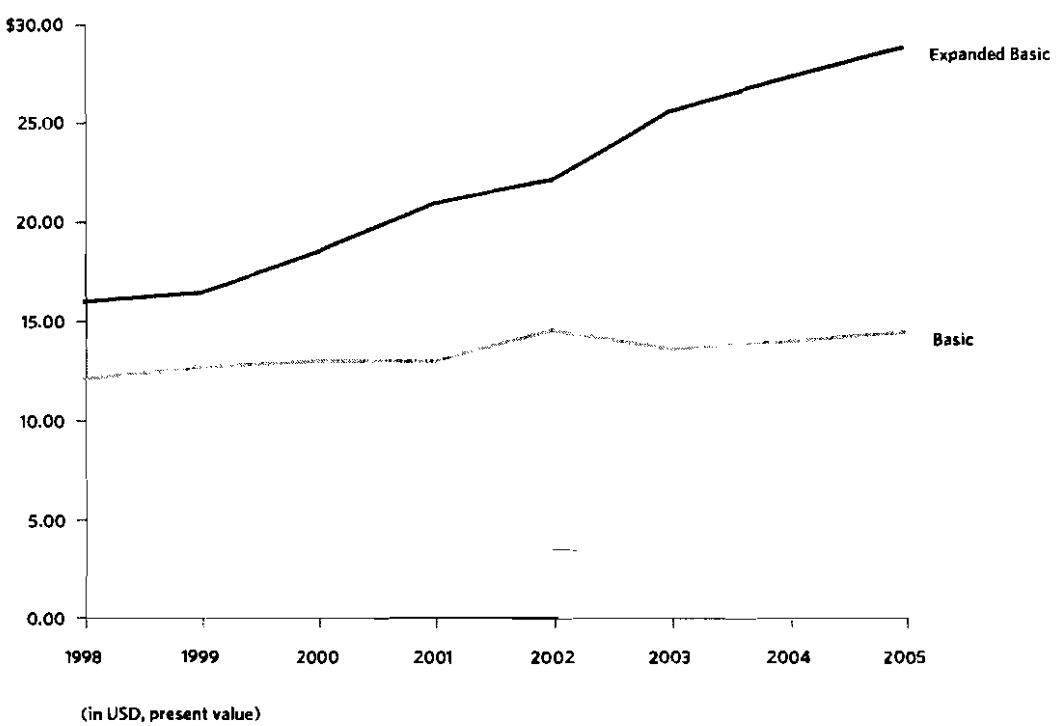
Economics

The economics of providing broadband service over cable plant are driven largely by the presence of existing network. Where networks exist, and costs are sunk, broadband economics are very attractive. In other areas, where one examines greenfield builds, the economics can be far more challenging. Since the network capabilities of an HFC network far exceed the target speed set forth in the plan, the unserved are all in greenfield areas where the investment gap of HFC is much larger than that of DSL or fixed wireless.

Existing cable deployments were funded by video

As noted earlier, cable networks were originally designed to offer video service. And, in many markets, cable companies were granted exclusive franchise agreements. As a result, the video business over

Exhibit 4-BK: Cable Video ARPU Over Time[144]—Cable Pricing



time has accounted for a large portion of cable-company revenue, providing a network on which to build the incremental broadband business. The video business, in fact, has enjoyed increasing ARPU over a long period of time (see Exhibit 4-BK), providing much of the capital for HFC investment in infrastructure. Of all subscribers who have access to these services, 88% subscribe to expanded basic and 55% subscribe to digital programming.[145]

Incremental broadband upgrades

As noted above, large investments have been made in cable systems already, principally funded by the video business. Further, as shown in Exhibit 4-BL, the incremental expense for upgrades—each aspect of which has been discussed previously—is low given the significant sunk investment already in the cable plant. As a consequence, cable systems are relatively well positioned to meet

Exhibit 4-BL: Upgrade Costs for Cable Plant

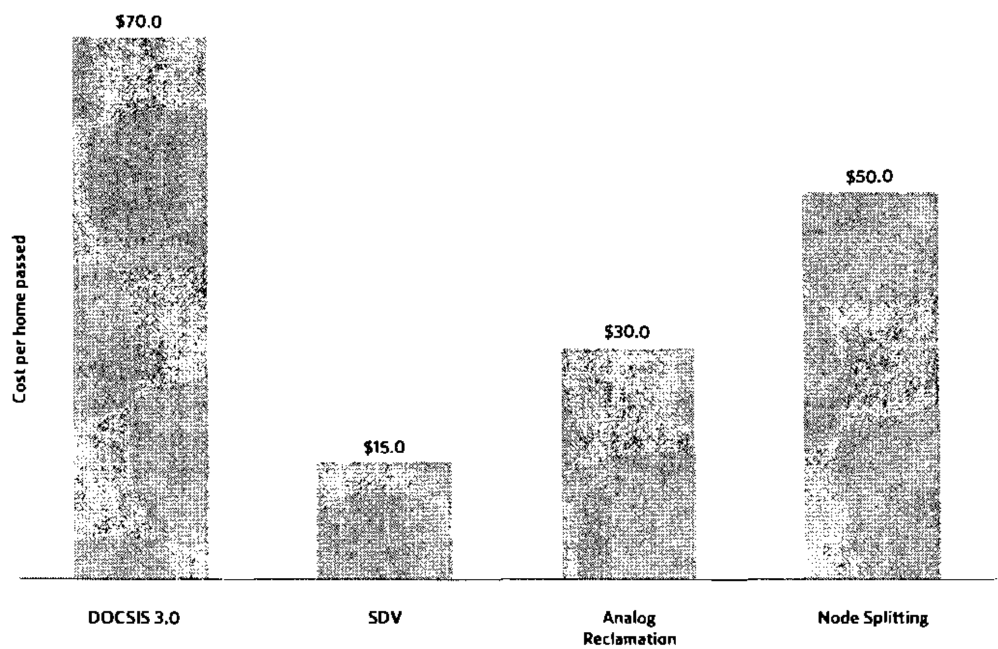
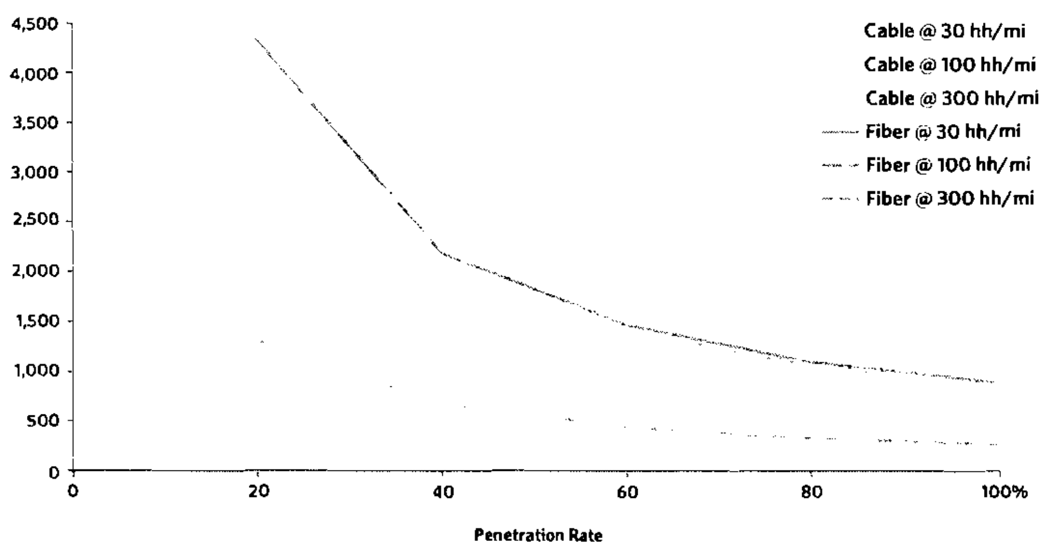


Exhibit 4-BM: Outside Plant Cost, FTTP or RFoG vs. HFC—Relative Capex Costs of Cable and Fiber, Excluding Headend Equipment[146,147]



Dollars of capex/sub/mile; penetration rate future growth in bandwidth demand.

In summary, where existing two-way cable plant exists, upgrade costs to provide high-speed service of up to 50 Mbps are low: roughly $165 per home passed.

Greenfield deployments

Building a new cable plant requires deploying a new outside plant and some form of headend to aggregate and distribute video and data content. The choice of technology for the outside plant is not an obvious one: providers can deploy a network that is a traditional hybrid fiber-coax plant, or one that is all fiber, a so-called RF over Glass (RFoG) plant.

When connecting a home for the first time—effectively adding a completely new last-mile connection—providers are likely to use the most future-proof technology possible. It would make little sense to deploy, for example, a brand-new long-loop twisted-pair network. The choice is less clear when comparing HFC and RFoG (or any other FTTP deployment). As Exhibit 4-BM shows, HFC and fiber networks have similar outside plant costs, which are mostly a function of labor costs. However, RFoG and FTTP deployments, by removing all active electronics from the outside plant, have lower ongoing expenses.

Estimates suggest these opex savings are approximately $20 per home passed per year.[148] While this may not sound large at

Exhibit 4-BN: HFC Plant Diagram—CableCo HFC Architecture

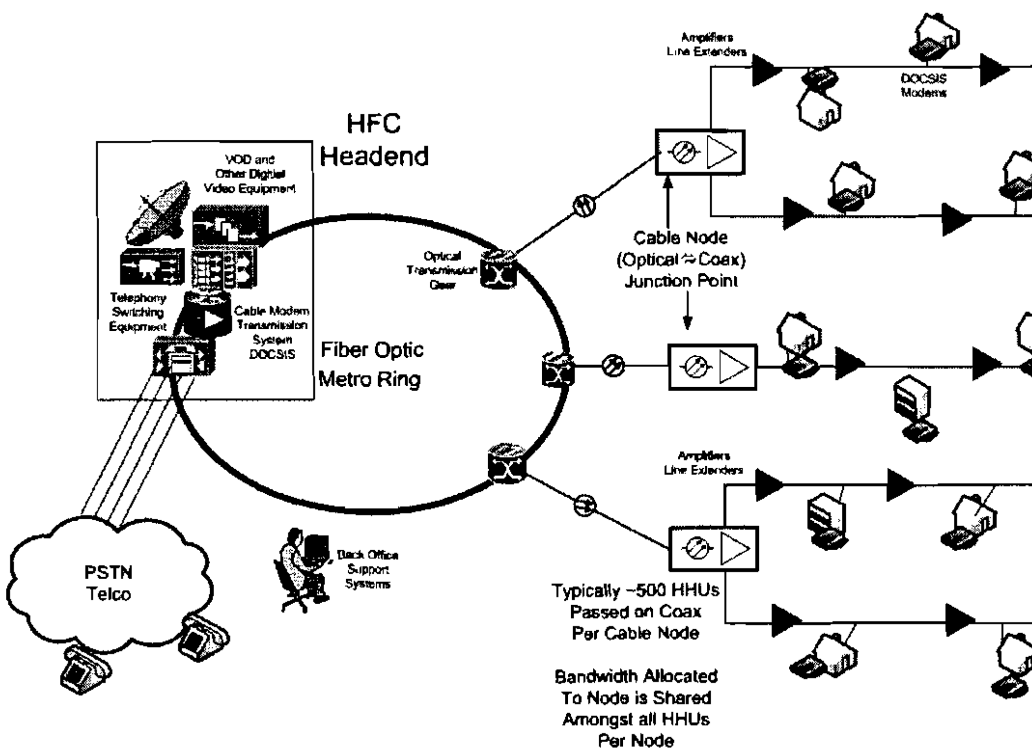


Exhibit 4-BO: Data Sources for HFC Modeling

Material Costs	Source
Splitter	Cable ONE (filed under protective order)
Fiber Node	Cable ONE (filed under protective order)
CMTS	Hiawatha (filed under protective order)
Up Stream Reciever	Hiawatha (filed under protective order)
Cable Modem	Hiawatha (filed under protective order)
Drop	Hiawatha (filed under protective order)
Tap	Cable ONE (filed under protective order)
Coaxial Cable	Cable ONE (filed under protective order)

the outset, it adds up over the life of the network. A majority of these savings come from power required for active components, system balancing and sweeping, and reverse maintenance.

The other major expense for a new network, whether HFC or RFoG, is the cost of a drop per subscriber. RFoG drops are approximately $175 more expensive than HFC drops.[149] As a consequence, the initial cost of connecting a subscriber is higher for RFoG relative to HFC.

However, the aggregate cost of a typical HFC customer will exceed, in less than 10 years, the aggregate cost of serving the same customer using RFoG. In other words, the operational savings from having an all-passive plant outstrip the initial cost savings from deploying an HFC system. It is reasonable to expect RFoG and FTTP drop costs will decline over time as deployments become increasingly mainstream and the industry attains greater scale. Accordingly, it is likely that as RFoG and FTTP deployments become cheaper, this break-even period will become even shorter. As a consequence, a greenfield developer of wireline infrastructure is more likely to choose RFoG or FTTP over HFC going forward, given both lifecycle cost and future-proofing benefits of an all-fiber network.

Modeled cost assumptions

We modeled the incremental costs of extending HFC networks into unserved areas with a high degree of granularity. Exhibit 4-BN shows the basic network elements of an HFC network and Exhibit 4-BO lists the sources for assumptions used in the model.

NETWORK DIMENSIONING

In order to ensure that the investment gap is reflective of the full costs of deployment, it is important to dimension the network to be able to deliver target broadband speeds during times of peak network demand. In particular, we need to determine that we properly model the capacity of every shared link or aggregation point in order to ensure that the network is capable of delivering required broadband speeds.

However, data flows are far more complex to characterize than voice traffic, making relatively straightforward analytical solutions of aggregated data traffic demand very challenging; this will be discussed ahead in **Complexities of data-network dimensioning**. Our approach is to describe typical usage patterns during times of peak demand, which we then use to estimate the network capacity needed to ensure a high probability of meeting end-user demand; this is discussed at the end of this chapter in **Capacity considerations in a backhaul network**.

Complexities of data-network dimensioning

Network dimensioning will not guarantee that users will always experience the advertised data rates. Note that even traditional voice networks are designed for a certain probability of being able to originate a phone call (e.g. 99% of the time in the busy hour for wireline, 95% for cellular) and a certain average sound quality. For dimensioning IP data networks, it may be useful to point out the difficulty of applying traditional voice traffic engineering principles to IP data-traffic flow. Dimensioning IP data networks is intrinsically more complex than dimensioning voice networks.

To properly dimension a traditional circuit switched voice network, it is typical to use the Erlang B formula that allows an operator to provision the number of circuits or lines needed to carry a given quantity of voice traffic. This is a fairly straightforward process mainly because the bandwidth consumed for each call is effectively static for a given voice codec in the busy hour. In fact, technology has enabled carriers to encode speech more efficiently so a voice conversation today may actually consume much less bandwidth than a voice conversation did 20 years ago. Nonetheless, the three basic variables involved are:

- Busy Hour Traffic, which specifies the number of hours of call traffic there are during the busiest hour[150]
- Blocking, or the failure of calls due to an insufficient number of lines being available and
- The number of lines or call-bearing TDM circuits needed in a trunk group

As long as the average call hold time is known and the operator specifies the percentage of call blocks it is willing to accept in the busy hour, the number of trunks is easily calculated using the Erlang B formula.

For broadband Internet access, however, there is much more uncertainty. Unlike voice telephony, Internet traffic is quite complex, multi-dimensional, and dynamic in the minute-to-minute and even millisecond-to-millisecond changes in its characteristics. Network planning and engineering for broadband Internet are more difficult with higher degrees of uncertainty because of the following principal factors:

- Each application used during an Internet access session, such as video streaming, interactive applications, voice, Web browsing, etc., has very different traffic characteristics and bandwidth requirements.
- End-user devices and applications are evolving continuously at the rate of silicon electronics, as opposed to voice (we continue to speak at the same rate of speech).
- Broadband Internet access supports many different user applications and devices, from streaming high definition video (unidirectional, very high bandwidth), to short messaging (bidirectional, very low bandwidth).
- The scientific community has not yet developed and agreed upon the best mathematical representations for modeling Internet traffic.

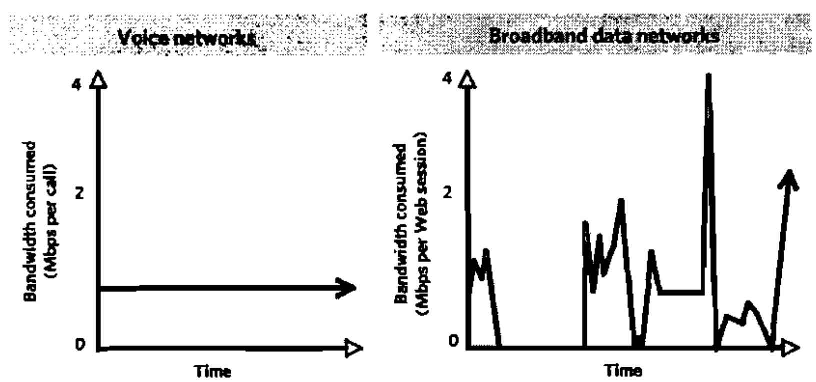
Exhibit 4-BP illustrates the additional complexities of multi-dimensional data traffic verses traditional circuit switched voice traffic. These differences introduce chaotic variables not present in the Erlang traffic model used to dimension voice networks.

Many individual Internet applications are "bursty" in nature. Consider a typical Web-surfing session, in which a user will "click" on an object, which results in a burst of information painting the computer screen followed by a lengthy period of minimal data transmission, followed by another burst of information. The instantaneous burst may occur at several Mbps to paint the screen, followed by many seconds or even many minutes with essentially no traffic, so the average transmission rate during a session may only be a small percentage of the peak rate. This type of traffic does not lend itself to modeling by the traditional mathematical models such as the Erlang formulas used for voice traffic; it can be considered fractal and chaotic in nature, as shown in Exhibit 4-BP. By contrast, the viewing of a high-definition video involves streaming content in one direction steadily at several Mbps. And a typical Skype video conference may involve a two-way continuous streaming of information but at only at around 384 kbps in each direction.[151]

Computer processing keeps improving at the rate set forth by "Moore's Law," as does the price/performance of storage. This doubling every two years enables much better performance of existing applications (e.g., very refined graphics instead of simple pictures, high definition and now even 3D-HD instead of NTSC video or standard-definition TV), as well as new applications that could not have existed several years earlier. So as long as silicon chips and electronics continue to improve, network providers may see more and more demands placed on the network by individual user applications. Moreover, behind an individual network interface, the subscriber is likely to have a local area network with several users running various applications for which traffic characteristics vary widely and with variable timescales such that the cumulative effect is a highly variable and unpredictable traffic flow into the network.

To conclude this discussion, we note that traffic engineering is based on mathematical models involving probabilities and statistics. As noted earlier, modeling voice traffic makes use of the simple inputs of average duration of call, bits-per-second used by the voice encoding scheme and number of call originations per hour. This has enabled scientists and engineers over the years to develop reliable mathematical models that correlate well with real-world experience. However, for Internet traffic, the number of variables, the magnitude of variation of these variables and the statistical nature of the variables have made it difficult for the scientific community to develop

Exhibit 4-BP: Differences Between Voice and Data Networks



Factor	Relevance to voice network dimensioning	Relevance to data network dimensioning
Number calls/data sessions	Number of calls generated in the busy hour	Number of sessions invoked by user or users during busy hour
Average call/session duration	Average duration of each call (usually in minutes)	Duration of application session (range from hours to milliseconds)
Variation in call/session duration	Almost all calls measured in minutes with little deviation	Variable session duration between applications ranging from minutes to seconds to milliseconds
Bandwidth intensity (amplitude)	N/A- bandwidth consumed for each call is static at 64 kbps	Bandwidth consumed per application session (Variable based upon active application)
Variation in bandwidth intensity	N/A (see previous)	Wide variation of bandwidth consumption for different applications
Calls Blocked / Congestion threshold during busy hour	"blocked" calls tolerated in the busy hour (typically one call block per 100 call attempts)	Minimum bandwidth at which packets are lost

a well-accepted mathematical model that can predict network traffic based on end-user demand. In fact, the underlying behavior of the traffic is still the subject of research and debate.

Consequently, it is very difficult to statistically characterize the traffic per subscriber or the aggregated traffic at each node in the network. And without such a characterization, we cannot dimension the network, *ex ante*, with the level of precision necessary to ensure subscribers will always experience the advertised data rates.

Generally speaking, Internet traffic engineers do not drive the expansion of network capacity from end-user demand models. Rather, they measure traffic on network nodes and set thresholds to increase capacity and preempt exhaust for each critical network element. Adtran remarks in its filing: "While sustainable speed can be measured in existing networks, it is nearly impossible to predict in the planning stages due to its sensitivity to traffic demand parameters."[152]

Still, we need to engineer our network model to deliver a robust broadband experience, capable of delivering burst rates of 4 Mbps in the download and 1 Mbps in the upload even without being able to measure traffic on actual network elements. The approach to do this is to provide sufficient capacity to provide a high probability of a robust user experience (as discussed in the next section). For this, we need a metric that characterizes traffic demand. One such metric that measures traffic demand is the Busy Hour Offered Load (BHOL) per subscriber.[153]

Capacity per user: busy hour offered load (BHOL)

The data received/transmitted by a subscriber during an hour represent the network capacity demanded by the subscriber during that hour. This can be expressed as a data rate when the volume of data received/transmitted is divided by the time duration. BHOL per subscriber is the network capacity demand or offered load, averaged across all subscribers on the network, during the peak utilization hours of the network.

In general, the total BHOL at each aggregation point or node of the network must be smaller than the capacity of that node in order to prevent network congestion. Alternately, the number of subscribers per aggregation node of the network must be smaller than the ratio of the capacity of the node to the average BHOL. This is the general principle we use to dimension the maximum number of subscribers at each aggregation point of the network model.

The BHOL-per-subscriber depends on a subscriber's Internet usage pattern and, as such, is a complicated overlay of the mix of Internet applications in use, the bandwidth intensity of each application and the duration of usage. But, for practical engineering purposes, the average BHOL-per-subscriber can be derived from monthly subscriber usage. Typically, 12.5% to 15% of daily usage happens during the busy hour.[154] We recognize that very high monthly usage on the same connection speeds usually results from increased hours spent online, outside of the busy hours, rather than an increased intensity of usage during the busy hours. As such, very heavy usage may not quite lead to the same proportionate increase in BHOL. However, for the purposes of our network dimensioning, we shall make the simplifying (and conservative) assumption that the effect is proportionate.

Current usage levels and corresponding BHOLs for different speed tiers are shown in Exhibit 4-BQ. Observe that the mean usage is more than five times that of the usage by the median or typical user. In fact, a small percentage of users generate an overwhelming fraction of the network traffic as shown in Exhibit 4-BR. This phenomenon is well known and is discussed in more detail in Omnibus Broadband Initiative, Broadband Performance.[155] For example, the heaviest 10% of the users generate 65% of the network traffic. So, if we were to exclude the capacity demand of these heaviest users, the BHOL of the remaining users would be far lower. For example, by excluding the heaviest 10% of the users, the BHOL by the remaining 90% is only 36-43 kbps. In Exhibit 4-BS, we show the impact on the BHOL by excluding different fractions of the heaviest users. For comparison, we also show the BHOL for the median or typical user.

Suppose we want to dimension a network that will continue to deliver 4 Mbps to all users even after the next several years of BHOL growth. In order to estimate the future BHOL, we first note that average monthly usage is doubling roughly every three years as discussed in Omnibus Broadband Initiative, Broadband Performance.[156] Next, given the significant difference between mean usage and the typical or median user's usage, it is likely that the service provider will seek to limit the BHOL on the network using reasonable network management techniques to mitigate the impact of the heaviest users on the network. For example, an Internet service provider might limit the bandwidth available to an individual consumer who is using a substantially disproportionate share of bandwidth and causing network congestion. Exhibit 4-BS shows the BHOL for possible scenarios, ranging from dimensioning for the typical user to mean usage. 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. It is also worth noting that the additional cost of adding capacity on shared links, as described throughout this paper, is low.

Capacity considerations in a backhaul network

Operators of IP broadband networks must provide a consistent, reliable broadband experience to consumers in the most cost-effective way that meets the consumer broadband requirements set forth in the Broadband Plan: 4 Mbps downstream and 1 Mbps upstream of actual speed.

An important consideration for an economical deployment of affordable broadband networks is proper sizing and dimensioning of the middle- and second-mile links. A fundamental element in the design of all modern packet-switched networks is "sharing" or "multiplexing" of traffic in some portions of the network to spread costs over as many users as possible.[157] In other words, network operators can take advantage of the network capacity unutilized by inactive applications and/or users by dynamically interleaving packets from active users and applications thus leading to a better shared utilization of the network. This is commonly known as statistical multiplexing.

This ability to dynamically multiplex data packets from multiple sources contributes to packet-switched networks being more

Exhibit 4-BQ: Monthly Usage and BHOLs by Speed Tier

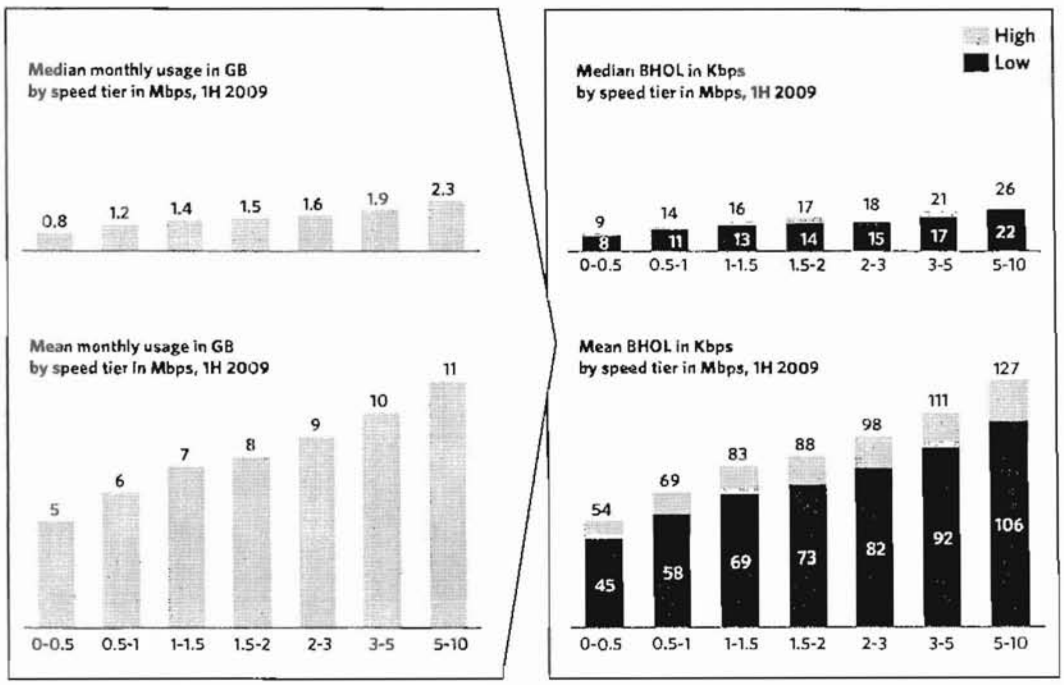
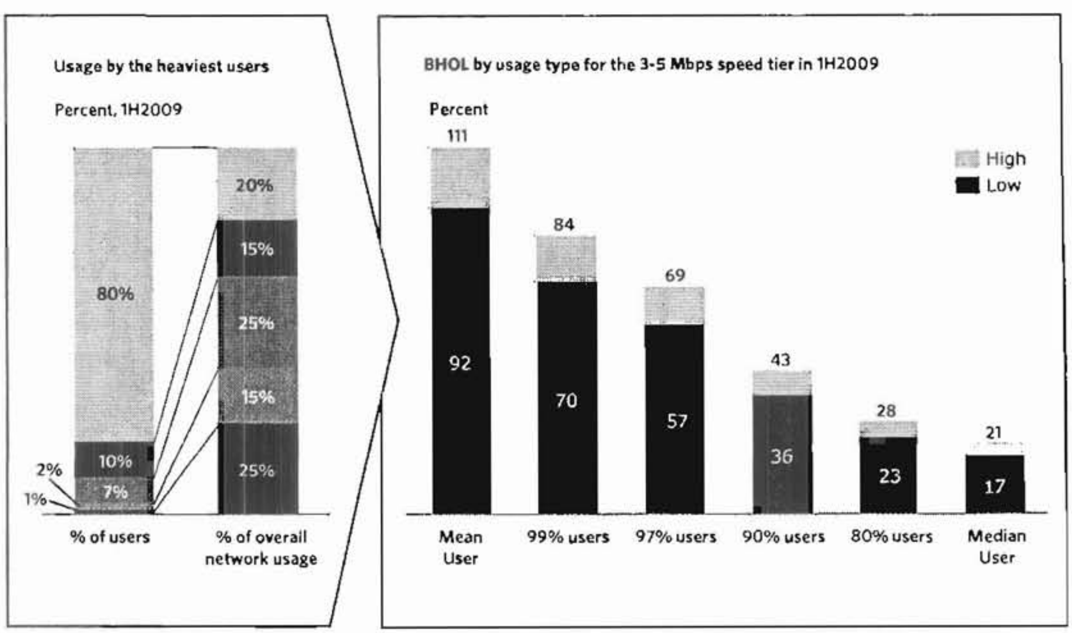


Exhibit 4-BR: Usage by Tier and BHOL



efficient and economical than circuit-switched networks. Shared network resources are the principle of network "convergence" in practice. Voice, video and data applications like Web browsing and other applications noted above are now all packetized and transmitted using the same network transmission facilities.

Of course there is a downside to shared networks, which are typically oversubscribed in order to exploit the benefits of statistical multiplexing. Oversubscription refers to the fact that the maximum aggregate demand for capacity at a shared link or node in the network can exceed the link or node capacity. Thus, there is a risk, however small, that the total traffic presented at a given time might exceed transport resources in a way that will, in turn, result in congestion, delay and packet loss.

Even though it is challenging, *a priori*, to accurately characterize the user experience on a network because of the complexity of characterizing the traffic per subscriber, we used some available analytical tools to validate the network dimensioning assumptions in our model. Specifically, in Exhibit 4-BT,

Exhibit 4-BS: Expected Future BHOL in Broadband Network Dimensioned to Deliver 4 Mbps—Expected BHOL in kbps for Different Usage Types in 2015

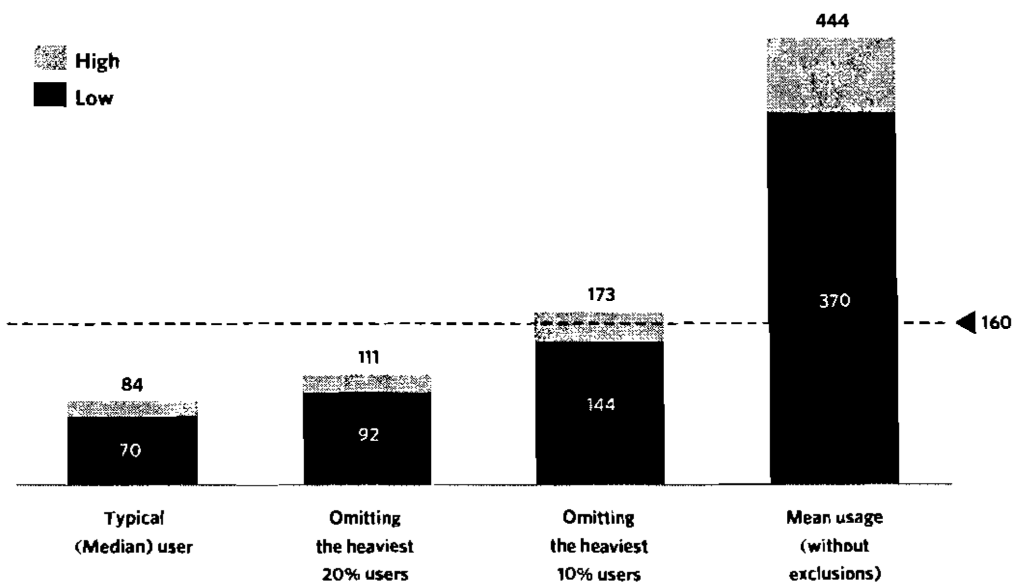
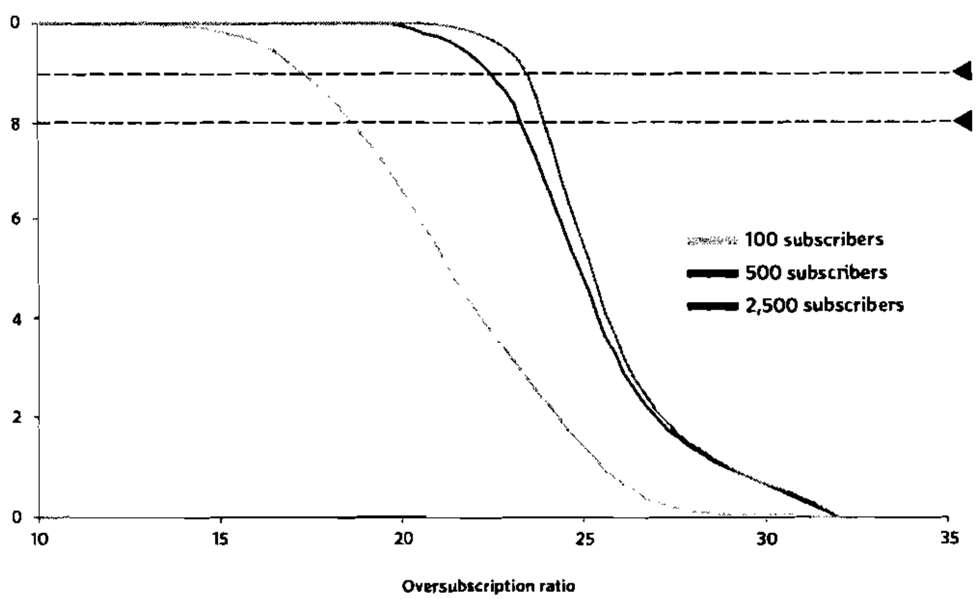


Exhibit 4-BT Likelihood of Achieving a Burst Rate Greater Than 4 Mbps at Different Oversubscription Ratios with a Varying Number of Subscribers[158]



we show the likelihood of being able to burst at rates greater than 4 Mbps on a shared *wired* or *satellite* link at different oversubscription ratios. For convenience, we shall refer to this likelihood as simply "burst likelihood."

In Exhibit 4-BT, the case with 100 subscribers is meant to represent a typical HFC node with ~100 subscribers; the 500 and 2,500 subscriber curves, on the other hand, represent a DSLAM with ~500[159] and a satellite beam with ~2,500 subscribers, respectively.

We use this chart to validate the network dimensioning assumptions in our model. For example, the chart shows that for a burst likelihood of 90%, the maximum oversubscription ratio on a link with 100 subscribers is approximately 17. Recall that oversubscription ratio of a link of capacity *C* Mbps with *N* subscribers who have an actual data rate of *R* Mbps is:

$$\text{Oversubscription ratio} = \frac{\text{(Number of subscribers) x (Actual Speed)}}{\text{(Link Capacity)}} = \frac{N x R}{C}$$

That implies that the link capacity must be greater than approximately 23.5 Mbps. Since the capacity of a DOCSIS 2.0 HFC node is about 36 Mbps, we conclude that a single DOCSIS 2.0 node, which serves about 100 subscribers can deliver our target broadband speeds with high likelihood. We can use the same approach to validate the dimensioning of shared links and aggregation points in other networks like DSL, Satellite and FTTP.[160]

We recognize that the results shown in the chart are based on certain traffic demand assumptions,[161] and that these assumptions may not hold in practice. Still, given our conservative choice of parameters in our network models, these results indicate that the network will support the required broadband speeds with very high probability. In reality, network operators may monitor traffic levels at different links within their networks and engineer their respective oversubscription ratios to ensure that capacity in the shared portions of the network is available to support offered service levels; in this case, 4 Mbps download and 1 Mbps upload in the busiest hours of the network.

One very interesting implication of the traffic simulation represented in Exhibit 4-BT is that higher oversubscription rates for the larger number of subscribers mean that capacity can grow more slowly than the number of subscribers. This is due to improved statistical multiplexing with increased number of users. For example, adding five times more subscribers, moving from 100 to 500 or from 500 to 2,500 subscribers, requires adding only roughly four times as much capacity to provide the same probability of end-user service. Thus, adding capacity linearly with the number of subscribers, as we assume in our analysis, is a conservative approach that does not account for the full benefits of statistical multiplexing.

MIDDLE-MILE ANALYSIS

Middle-mile facilities are shared assets for all types of last-mile access. As such, the cost analysis is very similar regardless of last-mile infrastructure. The local aggregation point can vary based on technology (e.g., a cable headend, LEC central office or a wireless mobile switching center (MSC)) while the Internet gateway is a common asset. Middle-mile facilities are widely deployed but can be expensive in rural areas because of the difficulties of achieving local scale, thereby increasing the investment gap. On a per-unit basis, middle-mile costs are high in rural areas due to long distances and low aggregate demand when compared to middle-mile cost economics in urban areas.

While there may be a significant affordability problem with regard to middle-mile access, it is not clear that there is a middle-mile fiber *deployment* gap. The majority of telecom central offices (approximately 95%)[162,163] and nearly all cable nodes (by definition, in a true HFC network) are fed by fiber.

Please note: terms like "backhaul," "transport," "special access" and "middle-mile" are sometimes used interchangeably, but each is distinct. To avoid confusion, "middle-mile transport" refers generally to the transport and transmission of data communications from the central office, cable headend or wireless switching station to an Internet point of presence or Internet gateway as shown in Exhibit 4-BU.

Middle-Mile Costs

The middle-mile cost analysis concludes that the initial capex contribution to serve the unserved is 4.9% of the total initial capex for the base case. That is, the modeled cost for the incumbent or lowest cost provider to build these facilities incrementally is estimated at approximately $747 million.

In order to accurately model the costs of middle-mile transport, particularly in rural, unserved areas, we examined all available data about the presence of reasonably priced and efficiently provided, middle-mile transport services. However, we recognize that broadband operators who rely on leased facilities for middle-mile transport may pay more for middle-mile than broadband providers who self-provision. This is discussed further within the subsection titled **Sensitivity: Lease vs. Build**. Thus, in a hypothetical case in which leasing facilities turns out to be four times the modeled incumbent build cost, the resulting middle-mile contribution could be estimated as high as 9.8% of the total initial capex for the base case, or approximately $1.6 billion. The following discusses the analysis done to ensure our model accurately captures the appropriate costs.

Broadband networks require high-capacity backhaul, a need that will only grow as end-user speed and effective load grow. Given the total amount of data to be transmitted, optical fiber backhaul is the required middle-mile technology in most instances. Once the transport requirement reaches 155 Mbps and above, the only effective transport mode is at optical wavelengths on a fiber optic-based transmission backbone. Plus, while the initial capital requirements of fiber optic systems are substantial, the resulting infrastructure provides long-term economies relative to other options and is easily scalable.[164] Microwave and other terrestrial wireless technologies are well suited in only some situations such as relatively short middle-mile runs of 5-25 miles. However, microwave backhaul may be a critical transport component in the second mile, primarily for wireless backhaul as discussed in detail in the wireless section.

Approach to Modeling Middle-Mile

The costs associated with providing middle-mile services are heavily dependent on the physical distances between network locations. Therefore, the approach to modeling middle-mile costs revolves around calculating realistic distance-dependent costs.

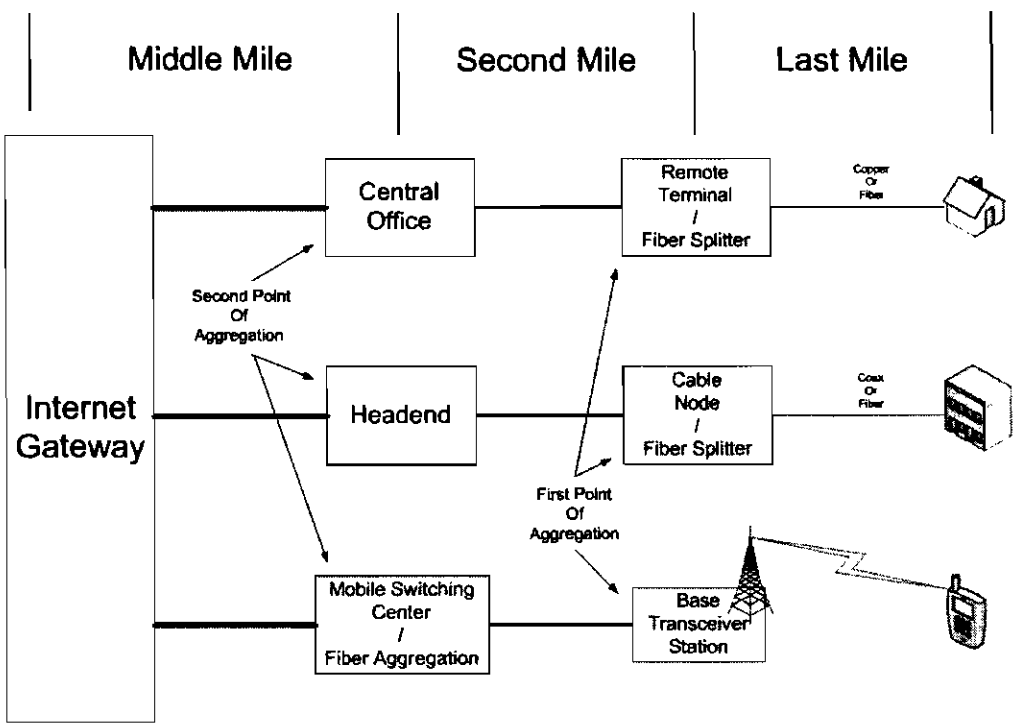
Our focus is on ILEC central offices given the availability of information on their locations. Starting with the location of ILEC central offices and the network homing topology, we estimated the distances and costs associated with providing middle-mile service. Since the cost estimate is distance-dependent, calculating the cost requires making an assumption about the routing used to connect LEC offices as will be discussed below. This same approach—mapping known fiber locations and their logical hierarchy to calculate the distances and costs for providing middle-mile service—could apply equally well to cable headends, or CAP, or IXC POPs given thorough information on their locations. However, publically available information on exact locations of cable headends, private IXC fiber POPs and other entity fiber node locations is limited; thus, the focus exclusively on ILEC fiber suggests that this analysis will significantly underestimate the presence of fiber around the country.

The following sections describe the process of collecting and processing data, along with the cost inputs and assumptions used in the model. The gap calculation assumes internal transfer pricing: i.e., the incremental cost the owner of a fiber facility would assign to the use of the fiber in order to fully cover both the cash cost and opportunity cost of capital. Importantly, as discussed below, this cost may be substantially lower than the price a competitor or other new entrant, like a wireless provider, may be charged for the same facility.

Middle-Mile Data Collection

- Identify all ILEC Central Offices (CO) and obtain each Vertical and Horizontal coordinates (analogous to latitude and longitude)

Exhibit 4-BU: Breakout of Middle, Second & Last Mile



- Identify all Regional Tandems (RT) within their respective LATA locations and determine which Central Office subtends which RT

After the middle-mile anchor node locations and hierarchical relationships between the nodes are captured, the distances between these nodes must be calculated so that the distance-dependent cost elements can be applied appropriately.

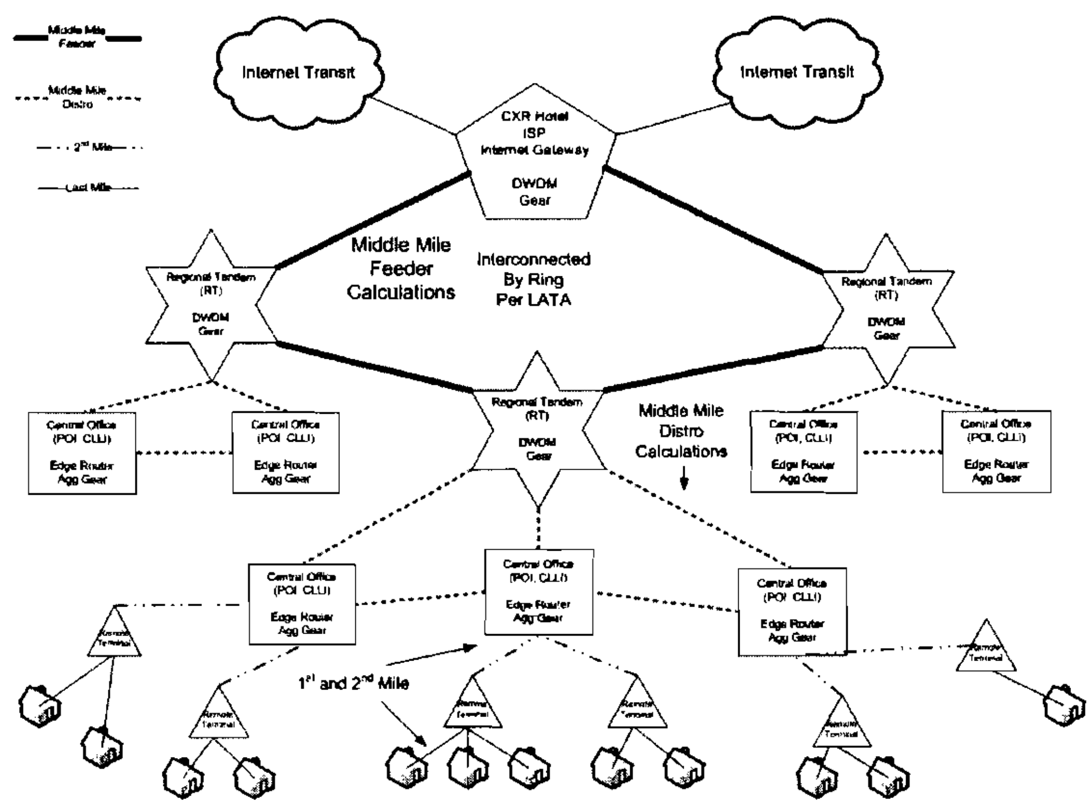
Middle-Mile Processing Steps

- Each subtending CO is assigned to its nearest RT to create the initial relation of COs to RTs.
- COs are then routed to other COs that subtend the same RT using shortest distance routing back to their respective RTs (i.e., we calculate a shortest-distance route to connect the COs to their respective RTs). To achieve this route, the process starts at the CO coordinate farthest from the appropriate RT and selects the shortest CO-to-tandem distance based on airline mileage. The CO starting point is prohibited from routing back to itself and must route toward the tandem. This approach minimizes the amount of fiber needed.
- The RTs within a given LATA are routed together in a ring.
  - The shortest ring is chosen by comparing the distances between RTs and selecting the shortest ring distance within each LATA; this distance is then used for the middle-mile feeder calculations.
  - It is assumed that the Internet gateway peering point is located on the RT ring. In this manner, all COs that are connected to the RT ring have access to the Internet.
  - Internet gateway sites are assumed to be located in regional carrier collocation facilities (known commonly as "carrier hotels"). We estimate there are some 200 of these located regionally throughout the United States.
- The middle-mile calculation is run state-by-state and stored in one central distribution and feeder table.

Tree vs. Ring architecture

- The design depicted in Exhibit 4-BV represents a hub-and-spoke hierarchy interconnected via closed rings. The model contemplates that a typical ILEC would likely interconnect end office, tandems and regional tandems in redundant-path "ring architecture."

Exhibit 4-BV: Topology Used for Middle-Mile Cost Modeling



- By assumption, the fiber link and distance calculations between COs and RTs are increased by a factor of 1.8 to account for the redundant, geographically diverse, fiber spans that would be required in ring architecture as opposed to a hub-and-spoke architecture. Note that this assumption could be fairly conservative (i.e., assuming higher than necessary costs) given degree of interconnection among the COs.

Cost Allocations on Facility

These middle-mile facilities by nature and design are engineered as shared infrastructure facilities that aggregate end-user traffic and transport traffic to regional Internet gateways. The cost of a particular middle-mile facility cannot be allocated solely to the consumer broadband users of that facility. Since that facility is shared with other provider services such as residential and enterprise voice, wholesale carrier services, enterprise data services and other management services utilized by the provider, the cost needs to be allocated appropriately.

- The model assumes that the total cost of the facility is allocated thus: 1/3 for service provider voice service, 1/3 wholesale and enterprise carrier services and 1/3 consumer broadband services. This is an estimation of the allocation of traffic within a typical ILEC transport environment, but the allocation of cost to any single product or customer group is speculative at this point.
- The model only calculates the consumer broadband services portion of the facility and assumes that BHOL doubles roughly every three years.

Nationwide Middle-Mile Fiber Estimation

Data sources about fiber routes or even the presence of fiber in a given LEC office are extremely limited. Consequently, we created our best approximation of fiber facilities available for middle-mile service; detail on that process is provided below. The overwhelming majority of telecom central offices (approximately 95%)[165 166] and nearly all cable nodes (by HFC definition) are fed by fiber.

The map shown in Exhibit 4-BW is an illustration of the paths of fiber used in our calculation to connect ILEC offices (and only ILEC offices). While it is based on as much real and calculated data as are available, we had to make a number of assumptions about the specific routes. Therefore, while we believe this map represents an accurate, if conservative, estimate of middle-mile fiber, it is not appropriate for network-planning purposes.

The diagram in Exhibit 4-BW is an estimation based on:

- Known locations of ILEC CO
- Topology based on a Gabriel Network[167] topology was considered but likely overestimated the number of links of fiber distribution. Thus, a Relative Network Neighborhood[168] distribution was chosen given the set of points representing the CO locations.
- Approximately 90% ILEC Fiber CO deployment, which is significantly lower (i.e., more conservative) than most estimates. Exhibit 4-BX, which shows the distribution of fiber-fed CO based on known services available per CO.

Exhibit 4-BW contemplates ILEC fiber only. Estimating the presence of middle-mile fiber based only on the fiber that connects LEC central offices, while excluding the fiber networks of cable companies, CAPs, CLECs and other facilities-based providers, systematically underestimates the presence of fiber. If one imagines overlaying the fiber optic facilities that have been deployed by other entities—such as Tier One IXCs/ISPs (ATT, Sprint, GX, Verizon Business, Level 3, XO, TWTC, etc.); Nationwide and regional Cable Operators (Comcast, Cox, Time Warner, Charter etc); Competitive Fiber Providers (Abovenet, Zayo, Deltacom, 360 Networks, Fiberlight, Alpheus etc.); private fiber deployments (hospitals and institutional); municipal fiber; and utility fiber—it becomes clear that the United States is generally well connected coast-to-coast.

In the limited instances where LEC fiber is not available, Windstream[169] has found that the exchanges typically have the following reasons for lack of deployment:

- The exchange is an island exchange (i.e., isolated from other exchanges in the LECs footprint) or part of a small, isolated grouping of exchanges;
- Fewer than 1,000 access lines fall within the exchange; and
- The closest point of traffic aggregation is more than 50 miles away from the CO.

The combination of a small customer base and long transport distances can make it impossible to build an economic case for fiber deployment.

However, recognizing that fiber-based middle-mile services are physically deployed does not necessarily mean that they are always economically viable in every rural area. The challenge is that access to such fiber may not be available at prices that result in affordable broadband for businesses, residents and anchor institutions, as discussed in the following section.

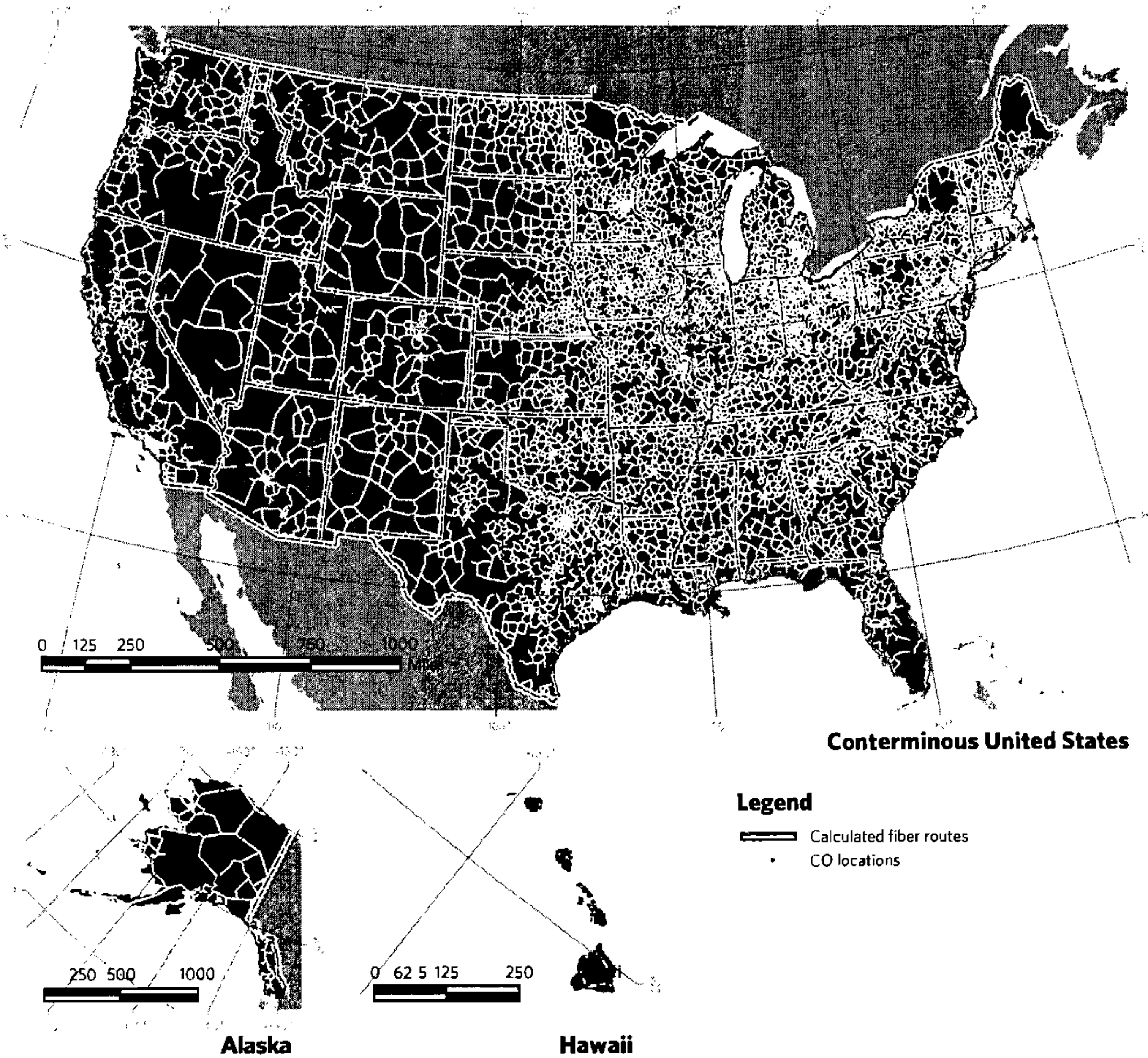
Costs Drivers for Middle-Mile Transport

Transporting data 50 miles or more from a local CO or other access point to the nearest Internet point of presence is a costly endeavor.

The costs of these facilities are proportional to their lengths. In urban or suburban areas, the cost of new fiber network construction varies widely, roughly from $4 to $35 per foot where the largest cost component is installation. The cost range depends on whether the fiber is suspended from utility poles or buried, the number of fiber strands in the cable, right-of-way costs, terrain, soil density and many other factors.[170] In the model, we assume that in rural settings, even for inter-CO transport facilities, 75% would be aerial construction. Of the 25% buried construction, the model calculates fiber burial costs that take into account local terrain, including soil composition.

Providing fiber-based service to low-density areas carries with it higher per-user costs. These costs are driven by larger distances which, even when offset by lower per-foot costs, lead

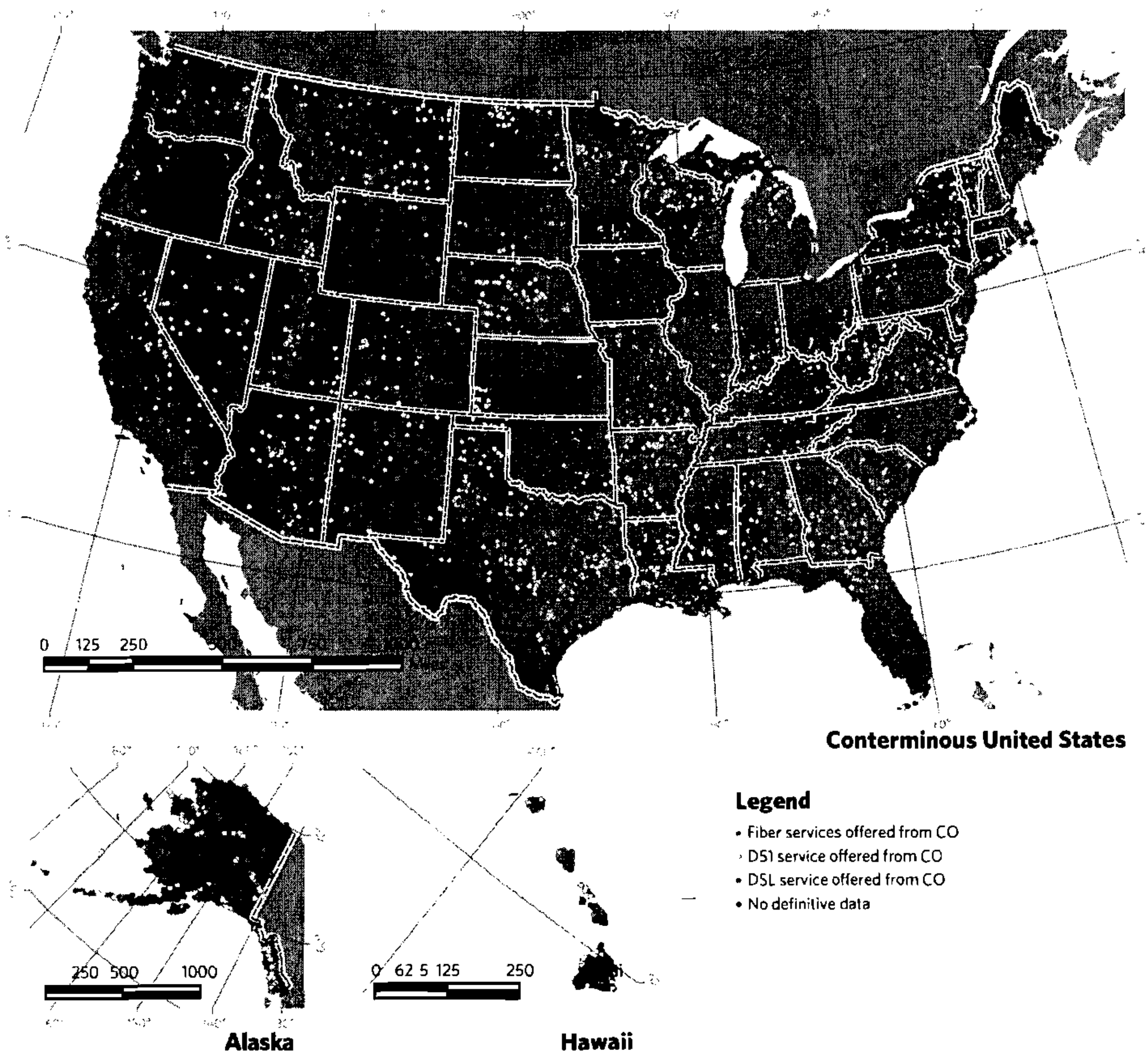
Exhibit 4-BW:
Calculated Telco Fiber Routes



to higher total cost per link. In addition, there are simply fewer users per link. Given that middle-mile links have very high fixed costs yet low costs associated with adding capacity, larger connections are more cost-effective per bit than smaller links. This is reflected in the prices shown in Exhibit 4-BY.

The low density and demand in rural areas, coupled with the volume-dependent middle-mile cost structure, mean that rural broadband operators do not benefit from the same economies of scale common among providers in denser areas. The distances at issue in unserved areas are much longer than typical

Exhibit 4-BX:
Classification of Central Offices for Creating Fiber Map



special access connections. Moreover, low population density prevents the aggregation of demand that would allow rural carriers to use lower-cost, high-capacity links.[171]

Pricing data are difficult to obtain. Tariffs are widely available but "street prices," including all contract savings and contract-term penalties, are not as readily available. Different discount structures, terms and agreements can cause great variability in middle-mile rates. As part of its COMMENTS ON NBP NOTICE #11, the NTCA provided Exhibit 4-BY that shows that while prices of middle-mile connections are indeed dependent on volume, they also vary widely across providers and geographies.[172] The highest and lowest prices vary by more than an order of magnitude for services below about 100 Mbps.

Exhibit 4-BY illustrates that on a per-unit basis, higher capacity middle-mile facilities are more economical than low-capacity facilities. According to NTCA and NECA filings, the average middle-mile cost contribution per subscriber per month is approximately $2.00 in study areas using middle-mile Ethernet connections of higher than 1,000 Mbps.[173] This can be compared to areas using middle-mile Ethernet connections of less than 10 Mbps, that resulted in monthly middle-mile costs per user of approximately $5.00 or more.[174] Again, these data are consistent with the premise that larger pipes carry lower costs per bit, suggesting the benefit for communities in smaller and less-dense areas to aggregate demand for homes and businesses as much as possible and that long-term commitments to utilize these facilities be in place.

Sensitivity: Lease vs. Build

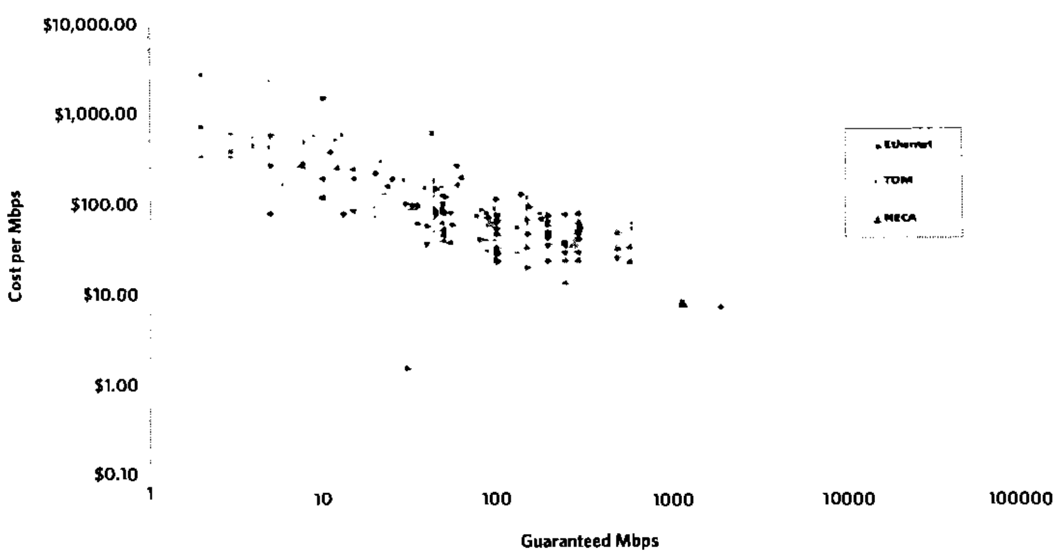
The base case assumes that operators in unserved areas have access to middle-mile transport at economic pricing—cost plus a rate of return. To the extent that middle-mile transport prices exceed this cost-plus pricing model, middle-mile costs can be higher for carriers leasing capacity. The broadband team models the cost to incrementally build middle-mile fiber facilities from scratch to a) understand the overall middle-mile cost contribution for the unserved and b) to establish a baseline middle-mile cost with which to compare to leased middle-mile costs.

The analysis in Exhibit 4-BZ compares middle-mile facility connections of different distances, connection sizes and methods to highlight the lease vs. build decision. Leasing facilities from an incumbent carrier, when properly sized for capacity demand, carries higher costs than the modeled cost for the incumbent provider to build these facilities incrementally. Thus broadband operators who rely on leased facilities for middle-mile may pay more for middle-mile costs than incumbent broadband providers.

To arrive at these estimates, we examine randomly chosen regional routes as shown in Exhibit 4-BZ. Separate "city-pair" routes were selected specifically in rural areas that are homed back to regional carrier collocation facilities (CCF) or "carrier hotels." These particular towns and CCF pairs were selected based upon known locations of CCFs to avoid Tier One MSA access points to best represent rural middle-mile connections. For each route, we calculate the applied tariff rate for the appropriate connection, applying a 30% discount rate for each connection. We recognize, however, that discount levels can range from 10-70% from "rack rates" and that a particular provider in an area may pay more or less than modeled.

NECA Tariff #5 was used as these tariffs are published, and we believe NECA carriers are likely to provide these rural

Exhibit 4-BY: Middle-Mile Cost Dependency on Capacity



Cost per Mbps by Guaranteed Mbps per Connection middle-mile connections. The towns were selected such that they are likely to be in the high-cost study group in accordance with NECA rate band blends.[175] In its comments, NECA suggests that on average, 1 Mbps is required in the shared portions of the network for every 14.5 users for a typical consumer best-effort DSL service.[176] We use this ratio in the analysis and size middle-mile capacity to provide 1 Mbps for every 14.5 users. For example, in the Exhibit 4-BZ for Flasher, ND, the middle-mile capacity required to support 351 HUs is 24 Mbps. In order to provide middle-mile support in Flasher ND, the lowest-cost facility likely available for lease large enough to carry the required 24 Mbps is a DS-3, which has a capacity of 45 Mbps. This need to "overbuy" capacity is repeated as demand requires the lease of larger facility tiers from DS3 to OC3 to OC12, etc. This illustrates the importance of demand aggregation and capacity utilization in the middle mile.

We also estimate the incremental cost that the owner of existing fiber facilities would assign to the use of these facilities in order to fully cover both the cash cost and opportunity cost of capital along these routes. The cost of the build includes the fiber deployment costs (labor, plowing, trenching, pole attachments, ROW, etc.) and the fiber optic electronics (DWDM transport nodes, regenerators, aggregation electronics, etc.). The capacity of the middle-mile network was modeled as 40 Gbps between interoffice nodes. While we believe that the modeled electronics are very high capacity and represent future scalability, it should be understood that included in this cost model is the fiber itself, which is virtually unlimited in capacity as electronics are upgraded. While we make assumptions about the allocation of cost to the modeled services as discussed in the previous section entitled "Approach to Middle-Mile Model," we also estimate the full cost of providing service along these routes as a price ceiling. The results of the analysis are summarized in Exhibit 4-BZ.

Exhibit 4-BZ suggests that on a per-unit basis, it is cheaper to build than to lease. However, that does not necessarily imply that for a given (small) user base and limited capacity demand that the lowest cost option is to build. Cost-per-unit for fiber builds is highly sensitive to scale and utilization. Consequently, it is possible that cost-per-unit for a build is actually higher than lease when demand and utilization are subscale. There is still a question regarding the extent to which leased facility pricing in rural areas is reflective of high deployment costs—long distances driving high-cost deployments that can be amortized over only a small base of end users—or of rent-seeking by facilities owners. The Federal Communications Commission is currently undertaking a proceeding to address special access pricing generally, not only with regard to interoffice transport in rural areas.[177] That proceeding will delve in greater depth into the question of costs and pricing.

In order to connect some rural areas, providers must deploy

Exhibit 4-BZ: Middle-Mile Build vs. Lease Comparison

From City	To City	# of unserved HU	Airline miles between	Circuit size	Build cost per HU per month	Lease cost per HU per month	Lease Premium
Nenana, Alaska	Juneau, Alaska	315	648.96	DS3	$26.99	$302.44	1020%
Bagdad, Ariz.	Phoenix, Ariz.	206	100.32	DS3	$36.49	$93.34	156%
Irwinton, Ga.	Macon, Ga.	934	26.95	OC3	$3.46	$10.10	192%
Libby, Mont.	Missoula, Mont.	2,372	127.95	OC12	$10.89	$12.93	19%
Fort Sumner, N.M.	Ruidoso, N.M.	701	113.87	OC3	$28.22	$31.86	13%
Flasher, N.D.	Bismark, N.D.	351	32.66	DS3	$16.73	$28.06	68%
Lindsay, Okla.	New Castle, Okla.	834	29.46	OC3	$4.87	$11.76	141%
Glide, Ore.	Eugene, Ore.	759	51.76	OC3	$11.19	$17.28	54%
Denver City, Texas	Brownfield, Texas	455	35.24	DS3	$17.98	$22.44	25%
Eureka, Utah	Provo, Utah	578	31.02	DS3	$3.61	$16.65	361%
Rock River, Wyo.	Cheyenne, Wyo.	30	73.32	DS3	$155.63	$516.23	232%
Sheffield, Ala.	Huntsville, Ala.	3,570	58.88	OC12	$1.93	$5.00	159%
Hope, Ark.	Fouke, Ark.	3,465	32.65	OC12	$2.40	$3.75	56%
Buena Vista, Colo.	Colorado Springs, Colo.	2,592	70.96	OC12	$5.29	$7.75	47%
Ketchum, Idaho	Boise, Idaho	1,532	92.00	OC3	$2.92	$12.46	326%
Monticello, Miss.	Hattiesburg, Miss.	2,746	50.59	OC12	$2.09	$5.94	184%
Winchester, Tenn.	Chattanooga, Tenn.	5,145	46.77	OC12	$1.46	$3.03	107%
Pomeroy, Wash.	Walla Walla, Wash.	893	45.15	OC3	$9.99	$13.59	36%
Fayetteville, W. Va.	Beckley, W. Va.	2,780	24.30	OC12	$0.86	$4.11	381%

middle-mile facilities over considerable distances at significant cost. These challenges are further compounded by the fact that these areas often do not have the population density necessary to generate the type of demand that justifies the large investment needed to construct these facilities.[178] The list below summarizes the basic conclusions based upon the middle-mile analysis:

- The distances at issue in unserved areas are much longer than typical special access connections and the low housing-unit or population density results in demand that is insufficient for lower cost high-capacity links.[179]
- As Internet demand increases, the total middle-mile cost for all providers will rise.
- Rural broadband operators do not benefit from the economies of scale on middle-mile facility cost in comparison to urban providers.

CHAPTER 4 ENDNOTES

1 *See* Section 5, Wireless Technology, for a discussion of wireless second mile backhaul

2 While we realize that a typical fully configured DSLAM would likely support no more than ~350 subscribers, we used 550 to show maximum subscribers that can be achieved at a DSLAM aggregation point (RT or CO) using Fast Ethernet backhaul.

3 Note that the number of simultaneous video streams is driven by capacity of the cell site, not the coverage which is limited by upstream signal strength as discussed below

4 Simultaneous streams assume non-real-time streams/videos with sufficient buffers at the receiver. Capacity with real-time traffic requirements, such as is required with video-conferencing applications, will be lower. The 480Kbps and 700Kbps video streams here are typical Hulu video streams. *See* Hulu typical video streaming requirements, http://www.hulu.com/support/technical_faq, February 2010. The 1Mbps video stream corresponds to a high-def Skype video conference

5 UBS Investment Research, "US Wireless 411," August 14, 2009.

6 A paired 2x20MHz of spectrum refers to a spectrum allocation where downlink and uplink transmissions occur on two separate 20MHz bands.

7 Enhanced technologies, such as multiple antenna technologies (aka MIMO), can also help. *See* Wireless Technology section below for more detail.

8 In the bands below 3.7GHz, 547MHz is currently licensed as flexible use spectrum that can be used for mobile broadband. The NBP recommends an additional 300MHz be made available within the next five years.

9 Yankee Group, "North America Mobile Carrier Monitor," December, 2009.

10 Theoretical peak rate inside a cell, does not take into account many real world deployment issues or cell-edge average rate.

11 The CDMA family of standards has its own 4G evolution called UMB. However, UMB is no longer in development and most worldwide CDMA operators have already announced plans to adopt either WiMAX or LTE for when they upgrade to 4G. In the United States, for example, Verizon has chosen LTE while Sprint is planning to deploy WiMAX.

12 Includes total cost of network plus success based capital for subscribers.

13 Based on American Roamer mobile coverage data, August 2009.

14 In 2G systems, by contrast, the signals were transmitted over 200kHz and 1.25MHz.

15 For a more detailed exposition on these multiple access techniques, *see*, for example, "Fundamentals of Wireless Communication," David Tse and Pramod Viswanath, as well as references therein.

16 Letter from Dean R. Brenner, Vice Pres., Gov't Aff., Qualcomm Inc., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 09-51 (Dec. 9, 2009) Attach. A at 2. Figure shows downlink capacities calculated for 2x10MHz spectrum availability. Estimates of spectral efficiency calculated for each technology with the following antenna configuration: WCDMA, 1x1 and 1x2; HSPDA, Rel.5, 1x1; HSPA Rel. 6, 1x2; HSPA, Rel. 7, 1x1 and 1x2; LTE, 1x1 and 1x2.

17 *See*, for example, "Fundamentals of Wireless Communications," David Tse and Pramod Viswanath, for details on Shannon theory as well as multi-user scheduling.

18 Our estimate of the limit is based on a simplified evaluation of the "single-user" Shannon capacity of a cell site using the signal quality distribution for a cell site provided in Alcatel Lucent's Ex Parte Presentation, GN Docket 09-51, February 23, 2010, and then adjusting for multi-user scheduling gains. Our analysis also assumes 43% loss in capacity due to overhead; *see*, for example, *"LTE for UMTS - OFDMA and SC-FDMA Based Radio Access,"* Harri Holma and Antti Toskala (Eds). *See*, for example, *"Fundamentals of Wireless Communications." See*, for example, Section 7.7 in *"The Mobile Broadband Evolution: 3G Release 8 and Beyond, HSPA+, SAE/LTE and LTE-Advanced,"* 3G Americas.

19 *See*, for example, Section 7.7 in "The Mobile Broadband Evolution. 3G Release 8 and Beyond, HSPA+, SAE/LTE and LTE-Advanced," 3G Americas.

20 *See*, for example, "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access," Harri Holma and Antti Toskala (Eds).

21 *See*, for example, "The performance of TCP/IP for networks with high bandwidth-delay products and random loss," T. V. Lakshman and U. Madhow, IEEE/ACM Transactions on Networking, June 1997.

22 CDMA operators can choose either LTE or WiMAX for their 4G evolution. LTE currently supports handoffs from CDMA systems.

23 Spectral efficiencies calculated for a (paired) 2x10MHz spectrum allocation for all technologies. Downlink spectral efficiency for WCDMA performance based on 1x1 and 1x2 antenna configurations; HSDPA Rel 5 and HSPA Rel 6 results based on 1x1 and 1x2 configurations, respectively; HSPA Rel 7 performance assumes 1x2 and 2x2 configurations while LTE result assumes 2x2. Uplink spectral efficiencies for WCDMA, HSPA and LTE capacities evaluated for 1x2 antenna configurations. Performance of (3G) EV-DO, which is not shown in the chart, is comparable to (3G) HSPA.

24 CITI BROADBAND REPORT AT 25-28.

25 CITI BROADBAND REPORT AT 8.

26 "HSPA to LTE-Advanced: 3GPP Broadband Evolution to IMT-Advanced (4G)," Rysavy Research/3G Americas, September 2009.

27 Round-trip latencies do not include public Internet latencies. Illustrative latencies for 2G/3G/4G networks; latencies for two networks using the same technology can vary depending on network configuration, infrastructure vendor optimizations, etc.

28 CITI BROADBAND REPORT AT 8.

29 *See*, for example, Figure 9.12 in "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access," Harri Holma and Antti Toskala (Eds); and "LS on LTE performance verification work" at http://www.3gpp.org/FTP/tsg_ran/WG1_RL1/TSGR1_49/Docs/ R1-072580.zip

30 In terms of cell radius, this gain translates to nearly a three-fold improvement in coverage.

31 *See* also Clearwire Ex-Parte filing, "Mobile broadband link budget example – for FCC", GN Docket No. 09-51 (Nov. 13, 2009) and link budget templates in http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_45/Documents/RP-090740.zip. Both documents perform downlink and uplink link budget analyses for a number of data rates and show that the limiting link budget in each scenario is the uplink.

32 Okumura-Hata is a RF propagation model. *See*, for example, *"Introduction to RF propagation,"* by John Seybold.

33 Using the Okumura-Hata model, we obtain the maximum cell-size at 700MHz to be 12 miles or higher

34 We chose to classify CTs instead of counties or Census Block Groups (CBG) because counties can be very large and CBGs too small—especially when compared with a typical cell size. Studying the variation over too large an area can lead to picking up terrain effects that are well outside of the cell-coverage area. On the other hand, looking at variations over an area that is too small compared with the desired cell size can lead us to overlooking significant terrain variations that are within the cell coverage area

35 Based on data provided in Qualcomm Ex-Parte filing, "Mobile broadband Coverage by Technology," GN Docket No. 09-51 (Feb. 22, 2010); Clearwire Ex-Parte filing, "Mobile broadband link budget example – for FCC," GN Docket No. 09-51 (Nov. 13, 2009); "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access," Harri Holma and Antti Toskala (Eds); and link budget templates in http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_45/Documents/RP-090740.zip.

36 Maximum transmit power: fixed CPEs can have higher transmit powers and higher antenna gains through the use of directional antennas and can avoid body losses. Receiver noise figure assumes the use of low-noise amplifiers. Effective noise power is calculated as: Total noise density + 10log10 (Occupied bandwidth), where total noise density = thermal noise density + receiver noise figure = -172dBm/Hz. Required SINR assumes the use of two receive antennas at the base station. Penetration losses can be reduced by fixed CPEs by placing the antennas in ideal locations within the house or outside. MAPL without shadow fading margin is appropriate when using RF planning tools because these tools enable shadowing and diffraction losses due to terrain. Shadow fading margin is required for 90% coverage reliability. MAPL with shadow fading margin is appropriate when using propagation loss models, such as the Okumura-Hata model.

37 RF planning tools by EDX Wireless, see http://www.edx.com/index.html

38 Propagation loss analysis using RF planning tools takes into account shadowing and diffraction effects due to terrain. So, it is not necessary to include a shadowing margin in the MAPL.

39 Propagation losses due to foliage are ~2-7dB at 700MHz.

40 "PL" denotes propagation loss.

41 Signal quality is the ratio of the received signal strength to the sum of the aggregated interference from other cell sites and thermal noise. This ratio is often called SINR or Signal to Interference and Noise Ratio.

CHAPTER 4 ENDNOTES

42 A *serving* cell site is the cell site that is transmitting the desired data to the end-user. All other cell sites are, then, interfering cell sites.

43 Based on data and analysis provided in: Alcatel Lucent in Ex Parte Presentation, GN Docket 09-51, February 23, 2010; Ericsson in Ex Parte filing, GN Docket 09-51, February 17, 2010; *"The LTE Radio Interface - Key Characteristics and Performance,"* Anders Furuskar, Tomas Jonsson, and Magnus Lundevall, Ericsson Research; "LTE-Advanced – Evolving LTE towards IMT-Advanced," Stefan Parkvall, et al, Ericsson Research; "LTE and HSPA+: Revolutionary and Evolutionary Solutions for Global Mobile Broadband," Anil Rao, et al, in Bell Labs Technical Journal 13(4), (2009); "LS on LTE performance verification work," at http://www.3gpp.org/FTP/tsg_ran/WG1_RL1/TSGR1_49/Docs/ R1-072580.zip, 3GPP RAN-1 submission by QUALCOMM Europe, Ericsson, Nokia and Nokia Siemens Networks in 3GPP TSG-RAN WG1 in "Text proposal for TR on system simulation results," http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_53/Docs/R1-082141.zip.

44 *See*, for example: Ericsson in Ex Parte filing, GN Docket 09-51, February 17, 2010; 3GPP RAN-1 submission by QUALCOMM Europe, Ericsson, Nokia and Nokia Siemens Networks in 3GPP TSG-RAN WG1 in "Text proposal for TR on system simulation results," http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_53/Docs/R1-082141.zip; "The LTE Radio Interface - Key Characteristics and Performance," Anders Furuskar, Tomas Jonsson, and Magnus Lundevall, Ericsson Research; "LTE-Advanced – Evolving LTE towards IMT-Advanced," Stefan Parkvall, et al, Ericsson Research; "LS on LTE performance verification work," at http://www.3gpp.org/FTP/tsg_ran/WG1_RL1/TSGR1_49/Docs/ R1-072580.zip.

45 Based on signal quality distribution data provided by Alcatel Lucent in Ex Parte Presentation, GN Docket 09-51, February 23, 2010. We then determine spectral efficiency for mobile and FWA networks by mapping signal quality to data rates using the method and results published in "LTE Capacity compared to the Shannon Bound," by *Morgensen, et al*, in IEEE 65th Vehicular Technology Conference, 2007.

46 A paired 2x20MHz of spectrum refers to a spectrum allocation where downlink and uplink transmissions occur on two separate 20MHz bands. This is also referred to as Frequency Division Duplex, or FDD, allocation. Note that the total spectrum allocation in this example is 40MHz. Similarly, the total allocation in a paired 2x10MHz of spectrum is 20MHz.

47 When SINR is 0 dB, the power of the signal is equal to the sum of the powers of the interfering signals and noise

48 MIMO techniques use multiple antennas at the transmitter and receiver to improve spectral efficiency of communication. *See*, for example, "Fundamentals of Wireless Communications," David Tse and Pramod Viswanath, for a detailed exposition.

49 In a system with 2x2 MIMO downlink, both the transmitter (base station) and the receiver (CPE) are equipped with two antennas.

50 For the rest of this section, we shall refer to a "paired 2x10MHz" carrier as simply a 2x10MHz carrier. Thus, for example, a 2x20MHz carrier will imply a "paired 2x20MHz" carrier.

51 Based on results published by QUALCOMM Europe, Ericsson, Nokia and Nokia Siemens Networks in 3GPP TSG-RAN WG1 in *"Text proposal for TR on system simulation results,"* http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_53/Docs/R1-082141.zip.

52 *See* "WCDMA 6-sector Deployment - Case Study of a Real Installed UMTS-FDD Network," by Ericsson Research and Vodafone Group R&D, in IEEE Vehicular Technology Conference, Spring 2006; "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access," Harri Holma and Antti Toskala (Eds); "Higher Capacity through Multiple Beams using Asymmetric Azimuth Array," by TenXc wireless, April 2006. The last two references show that 6-sector cells result in an 80% to 90% capacity improvement per cell site.

53 Based on signal quality distribution data provided by Alcatel Lucent in Ex Parte Presentation, GN Docket 09-51, February 23, 2010, and "LTE Capacity compared to the Shannon Bound," by *Morgensen, et al*, in IEEE 65th Vehicular Technology Conference, 2007.

54 "Downlink user data rate" refers to burst rate in a fully utilized network.

55 *See* American Roamer Advanced Services database (accessed Aug. 2009) (aggregating service coverage boundaries provided by mobile network operators) (on file with the FCC) (American Roamer database); see also Geolytics Block Estimates and Block Estimates Professional databases (2009) (accessed Nov. 2009) (projecting census populations by year to 2014 by census block) (on file with the FCC) (Geolytics databases).

56 "Mobile Backhaul: Will the Levees Hold?", Yankee Group, June 2009.

57 Sprint Nextel in Ex Parte Presentation, GN Docket 09-51, January 13, 2010

58 Level(3) Communications, Notice of Ex Parte Presentation, GN Docket 09-51, November 19, 2009; the filing notes that gigabit links are also available, albeit with limited range; see also "Microwave, Leased Lines, and Fiber Backhaul Deployments: Business Case Analysis."

59 Dragonwave, "Achieving the Lowest Total Cost of Ownership for 4G Backhaul," and "Microwave, Leased Lines, and Fiber Backhaul Deployments: Business Case Analysis."

60 Fiber-to-the-Home Council (FTTH Council), Notice of Ex Parte Presentation, GN Docket 09-51,October 14, 2009, Response to September 22, 2009, FCC Inquiry regarding Broadband Deployment Costs.

61 Dragonwave, "Achieving the Lowest Total Cost of Ownership for 4G Backhaul."

62 Clearwire Ex Parte Presentation, GN Docket 09-51, November 12, 2009 at 12.

63 Ancillary equipment here refers to communication cables, antennas, etc.

64 Average HU density in mountainous and hilly areas is 3 POPs/square mile and 7.4 POPs/square mile, respectively, while in flat areas it is 308 POPs/square mile.

65 Cost and gap shown for counties that have a negative NPV. Recall that the rural cell radius in the 700MHz band can be as much as 57% greater than that at 1900MHz. We chose the cell radius in mountainous areas to be 2 miles as well. In these areas, terrain rather than propagation losses dominate the determination of cell radius; so, it is unlikely that cell sizes will get much smaller than 2 miles.

66 This exhibit supports information and conclusions found in Exhibit 4-Z: Sensitivity of Buildout Cost and Investment Gap to Terrain Classifications.

67 *See* Tower Maps database (Accessed August, 2009) (on file with the Commission).

68 Mobile Satellite Ventures Subsidiary, LLC, Comments, in PS Docket 06-229 at 50 (June 20, 2008). They show that 30% of the sites required to cover 95th percentile of the population in the rural United States are "greenfield;" that number grows to 75% for the 99th percentile. We assume in our model that the number of greenfield sites required is 52.5%, which is the average of those two numbers.

69 Other network costs include those incurred in the Core (Node-0) network as well as on CPE (Node-4) subsidies

70 IDC, United States Consumer Communications Services QView Update, 3Q09, pg. 5, December 2009

71 United States Telecom Association, Telecom statistics, http://www.ustelecom.org/Learn/TelecomStatistics.html (last visited Feb. 3, 2010). It should be noted that these 1,311 operating companies comprise fewer than 850 holding companies.

72 IDC, United States Consumer Communications Services QView Update, 3Q09, pg. 5, December 2009

73 *See* Network Dimensioning section below.

74 Adtran -"Defining Broadband Speeds. Estimating Capacity in Access Network Architectures" Submissions for the Record -- GN Docket No. 09-51, (January 4, 2010) at 8.

75 Adtran -"Defining Broadband Speeds: Estimating Capacity in Access Network Architectures." Submissions for the Record -- GN Docket No. 09-51, (January 4, 2010) at 8.

76 Zhone Applications, http://www.zhone.com/solutions/ethernet/. (last visited Nov. 17, 2009).

77 Level 2 Dynamic Spectrum Management (DSM-2) is currently available and aids in the management of power and begins to cancel some crosstalk. Level 3 Dynamic Spectrum Management (DSM-3), also known as vectoring, is currently being tested in the laboratory and in field trials. Vectoring is discussed in greater detail in the 3-5 kft section of the appendix because, although possible on ADSL2+, the technique is most beneficial on line lengths below 4,000 feet; Broadband Forum Jan. 19, 2010 Notice of *Ex Parte* Communication – Addendum at 5.

78 Letter from Robin Mersh, Chief Operating Officer, Broadband Forum, to Marlene H. Dortch, Secretary, FCC (Jan. 19, 2010) ("Broadband Forum Jan. 19, 2010 Notice of *Ex Parte* Communication – Addendum") at 4.

79 Adtran -"Defining Broadband Speeds: Estimating Capacity in Access Network Architectures." Submissions for the Record -- GN Docket No. 09-51 (January 4, 2010).

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80 Broadband Forum Jan. 19, 2010 Notice of *Ex Parte* Communication – Addendum at 10.

81 Comments of National Exchange Carrier Association (NECA) at Table 1, Impact of Middle and Second Mile Access on Broadband Availability and Deployment, GN Docket #s 09-47,09-51,09-137 (filed November 4, 2009).

82 "Current backhaul dimensioning" is based on comments from NECA that on average ~1Mbps is required in the shared portions of the network for every 14.5 users.

83 Comments of National Exchange Carrier Association (NECA) at Table 1, Impact of Middle and Second Mile Access on Broadband Availability and Deployment, GN Docket #s 09-47,09-51,09-137 (filed November 4, 2009).

84 Load coils, which are in-line inductors used as low-pass filters to balance response for voice frequency transmission, effectively block xDSL signals. Load coils generally exist on loops exceeding 18,000 feet.

85 Bridged taps, lengths of unterminated wire typically formed when changes are made to the loop and unneeded cable is left attached to the loop, can cause some service degradation, especially for data services.

86 TCP acceleration is the consolidation of requests for and acknowledgement of data to minimize the number of serial transmissions over communications links. TCP fast-start is the disabling of slow-start, which entails error checking before the link is brought to full speed, in order to provide full link bandwidth from the outset of the session. TCP pre-fetch is the use of the predictive caching of Web content and DNS look-ups.

87 Letter from John P. Janka on behalf of ViaSat, Inc. to Marlene H. Dortch, Secretary, FCC (Jun. 24, 2009) ("ViaSat Jun 24, 2009 *Ex Parte*") at 6.

88 Max Engel, Satellite Today, http://www.satellitetoday.com/via/satellitegetspersonal/Why-ViaSat-Acquired-WildBlue-and-Why-WildBlue-Needed-It_32911.html (last visited Jan. 12, 2010).

89 Peter B. de Selding, Space News, http://www.spacenews.com/satellite_telecom/with-wildblue-acquisition-via-sat-doubles-bet-satellite-broadband.html (last visited Jan.12, 2010)

90 CITI BROADBAND REPORT AT 57.

91 ViaSat Comments at 3.

92 BHOL is the average demand for network capacity across all subscribers on the network during the busiest hours of the network. BHOL is discussed later in the Network Dimensioning section.

93 *See* OBI, Broadband Performance.

94 ViaSat Jan. 5, 2010 *Ex Parte* at 2.

95 Hughes Oct. 26, 2009 *Ex Parte* at 6.

96 See OBI, Broadband Performance.

97 ViaSat Comments in re A National Broadband Plan for Our Future, GN Docket No. 09-51, Notice of Inquiry, 24 FCC Rcd 4342, (2009) at 13.

98 ViaSat Comments in re National Broadband Plan NOI, at 13.

99 ViaSat Comments in re National Broadband Plan NOI, at 3.

100 We assume a growth rate that doubles exactly every three years, i.e. 26.5%, for this analysis.

101 It is unclear what the effect of the Plan will be for satellite broadband providers' subscriber churn due to the build-outs in areas that are currently served only by satellite.

102 ViaSat 2009 Annual Report at 17.

103 ViaSat 2009 Annual Report at 4.

104 Note that the investment gap calculation does *not* exclude NPV-positive counties as the base case does, which explains why the revenue number differs from the $8.9 billion in the base case.

105 Hughes, High-speed Internet Service Plans and Pricing, http://consumer.hughesnet.com/plans.cfm (last visited Mar. 8, 2010).

106 Operational savings are offered by the Point to Point (P2P) and Passive Optical Network (PON) varieties of FTTP, not by the Active Ethernet variety.

107 RVA LLC, FIBER TO THE HOME: NORTH AMERICAN HISTORY (2001-2008) AND FIVE YEAR FORECAST (2009-2013), 7 (2009), *available* at http://www.rvallc.com/FTTP_subpage7.aspx.

108 CISCO SYSTEMS, FIBER TO THE HOME ARCHITECTURES, 4 (2007), *available* at http://www.ist-bread.org/pdf/FTTP%20Architectures.pdf.

109 Dave Russell, Solutions Marketing Director, CALIX, Remarks at FCC Future Fiber Architectures and Local Deployment Choices Workshop 31 (Nov. 19, 2009).

110 National Exchange Carrier Association Comments in re PN#11 filed (Nov. 4, 2009) at 10.

111 See OBI, Broadband Performance.

112 Dave Russell, Solutions Marketing Director, CALIX, Remarks at FCC Future Fiber Architectures and Local Deployment Choices Workshop 31 (Nov. 19, 2009).

113 Letter from Thomas Cohen, Counsel for Hiawatha Broadband Communications, to Marlene H. Dortch, Secretary, FCC (November 10, 2009) ("Hiawatha Broadband November 10, 2009 *Ex Parte*") at 7.

114 Letter from Thomas Cohen, Counsel for the Fiber to the Home Council, to Marlene H. Dortch, Secretary, FCC (October 14, 2009) ("Fiber to the Home Council October 14, 2009 *Ex Parte*") at 9-10.

115 This equation was derived from fitting a curve to the data, and as such averages over the type of outside plant (aerial or buried). This curve fit may underestimate costs in very high-density areas or other areas with a greater mix of buried infrastructure. The r2 for the curve fit is 0.992 and the R2 adjusted is 0.990.

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118 Letter from Thomas J. Navin, Counsel for Corning, to Marlene H. Dortch, Secretary, FCC (October 13, 2009) ("Corning October 13, 2009 *Ex Parte*") at 17.

119 RVA LLC, FIBER TO THE HOME: NORTH AMERICAN HISTORY (2001-2008) AND FIVE YEAR FORECAST (2009-2013), 7 (2009), http://www rvallc.com/FTTP_subpage7.aspx.

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124 Broadband Forum Jan. 19, 2010 Notice of *Ex Parte* Communication – Addendum") at 7.

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128 National Cable & Telecommunications Association, Industry Data, http://www.ncta.com/StatsGroup/Availability.aspx (last visited Feb. 3, 2009) and ROBERT C. ATKINSON & IVY E. SCHULTZ, COLUMBIA INSTITUTE FOR TELE-INFORMATION, BROADBAND IN AMERICA: WHERE IT IS AND WHERE IT IS GOING (ACCORDING TO BROADBAND SERVICE PROVIDERS) at 20 (2009) ("CITI BROADBAND REPORT"), *available* at http://www4.gsb.columbia.edu/citi/.

129 National Cable & Telecommunications Association, Industry Data, http://www.ncta.com/StatsGroup/Investments.aspx (last visited Feb. 3, 2009).

130 David Reed, Chief Strategy Officer, CableLabs, Remarks at FCC Future Fiber Architectures and Local Deployment Choices Workshop 31 (Nov. 19, 2009).

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132 This does not mean that every cable operator will offer packages at these speeds, nor that every subscriber will have service at these speeds; instead this is a comment on the capability of the access network for typical user loads. Localized heavy use, e.g., from heavy use of peer-to-peer programs could load the network more than is typical and lead to lower realized speeds.

133 FCC, US spectrum allocation (http://www.fcc.gov/mb/engineering/usallochrt.pdf), (last visited Feb. 19, 2010).

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144 Report on Cable Industry Prices, MM Docket No. 92-266, ATTACHMENT 4 (2009).

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147 Penetration rate denotes attach rate of homes passed for digital TV, high-speed data and voice; cost does not include CPE cost.

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155 *See* OBI, Broadband Performance.

156 *See* OBI, Broadband Performance.

157 Consumer-oriented broadband today is provided as a best-effort service whereby the transport network elements are shared among many users. However, business-oriented broadband networks often are sold with service level guarantees that provide performance assurances. As such, last mile as well as the backhaul network elements must be engineered with higher capacity to assure that bandwidth is always available to the subscribers at all times, regardless of network conditions. This adds cost to the transport portions of the networks, which are reflected in much higher prices to the end-users. Business class "dedicated" Internet services have a pricing structure that can be many times more expensive on a cost-per-bit basis.

158 Adtran Ex-Parte Filing; *A National Broadband Plan for Our Future*, GN Docket No. 09-51, (FCC filed 23 February, 2010)

159 While we realize that a typical fully configured DSLAM would likely support no more than ~350 subscribers, we used 500 per the availability of the simulation tool. Assuming that fast Ethernet backhaul is still used for a ~350 subscriber DSLAM would result in an even better oversubscription ratio and even greater probability performance.

160 The results of this analysis do not easily apply to wireless networks. Unlike in other networks, the signal quality or data rate in a wireless network is strongly dependent on the location of the user relative to the cell site. We need to account for this non-uniformity in signal quality to dimension the wireless network [See Wireless Section above.] Still, we note that the spectral efficiency of a Fixed Wireless Access (FWA) network is ~2.35–2.7 b/s/Hz. So, the oversubscription ratio of a 3-sector cell site with 2x20 MHz spectrum allocation and 650 subscribers is ~16–18.5. Therefore, at first blush, this figure indicates that a FWA network should be able to deliver 4 Mbps in the download with high likelihood. And, as we show in more detail in the Wireless Section above, the FWA network can indeed support this subscriber capacity.

161 The analysis is based on a simulation of N subscribers on a link with capacity C. Specifically, the simulation determines the burst likelihood for the Nth subscriber on the link when the remaining subscribers generate traffic according to a Pareto distribution of mean 160 kbps. Note that the mean of this distribution corresponds to our BHOL assumption of 160 kbps. For more details, *see* Adtran, *Defining Broadband Speeds: Deriving Required Capacity in Access Networks*, at 22, GN Docket No. 09-51, January 4, 2010.

162 Centurylink Ex-Parte filing; *A National Broadband Plan for Our Future*, GN Docket No. 09-51; *International Comparison and Consumer Survey Requirements in the Broadband Data Improvement Act*, GN Docket No. 09-47; *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, GN Docket No. 09-137(FCC filed January 22, 2010)

163 Windstream Ex-Parte Filing; *A National Broadband Plan for Our Future*, GN Docket No. 09-51; *International Comparison and Consumer Survey Requirements in the Broadband Data Improvement Act*, GN Docket No. 09-47; *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, GN Docket No. 09-137 (FCC filed January 13, 2010).

164 Comments of Kodiak-Kenai Cable Company, LLC. at 5, *A National Broadband Plan for Our Future*, GN Docket # 09-51, PN #11 (FCC filed November 4, 2009).

165 Centurylink Ex-Parte filing; *A National Broadband Plan for Our Future*, GN Docket No. 09-51; *International Comparison and Consumer Survey Requirements in the Broadband Data Improvement Act*, GN Docket No 09-47; *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, GN Docket No. 09-137(FCC filed January 22, 2010).

166 Windstream Ex-Parte Filing; *A National Broadband Plan for Our Future*, GN Docket No. 09-51; *International Comparison and Consumer Survey Requirements in the Broadband Data Improvement Act*, GN Docket No. 09-47; *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, and Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996, as Amended by the Broadband Data Improvement Act*, GN Docket No. 09-137 (FCC filed January 13, 2010).

167 The Gabriel network for a point set is created by adding edges between pairs of points in the source set if there are no other points from the set contained within a circle whose diameter passes through the two points, introduced as one means of uniquely defining contiguity for a point set such that no other point could be regarded as lying 'between' connected pairs; *available* at. http://www.spatialanalysisonline.com/output/html/Gabrielnetwork.html.

168 A subset of the Gabriel network in which the additional constraint is applied that no other points may lie within the area of intersection defined by circles placed at each Gabriel network node with radius equal to the inter-node separation: *available* at: *http://www.spatialanalysisonline.com/output/html/Gabrielnetwork.html*.

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LIST OF COMMON ABBREVIATIONS

3G .... Third generation

4G .... Fourth generation

ADSL .... Asymmetric Digital Subscriber Line

AMPS .... Advanced Mobile Phone Service

ARPU .... Average Revenue per User

AWG .... American Wire Gauge

BHOL .... Busy Hour Offered Load

BPON .... Broadband Passive Optical Network

CAP .... Competitive Access Provider

Capex .... Capital Expenditures

CDMA .... Code-Division Multiple Access

CLEC .... Competitive Local Exchange Carrier

CO .... Central Office

CPE .... Customer Premises Equipment

DOCSIS .... Data Over Cable Service Interface Specification

DSL .... Digital Subscriber Line

DSLAM .... Digital Subscriber Line Access Multiplexer

EBITDA .... Earnings Before Interest, Taxes, Depreciation and Amortization

EPON .... Ethernet Passive Optical Network

EV-DO .... Evolution-Data Optimized

FTTN .... Fiber to the Node or Fiber to the Neighborhood

FTTP .... Fiber-to-the-Premise

FW .... Fixed Wireless

Gbps .... Gigabits per second

GHz .... Gigahertz (1 billion Hertz)

GPON .... Gigabit Passive Optical Network

GSM .... Global System for Mobile communication

HFC .... Hybrid Fiber Coaxial

HFM .... Hybrid Fiber Microwave

HSDPA .... High Speed Downlink Packet Access

HSUPA .... High Speed Uplink Packet Access

HSPA .... High Speed Packet Access

HU .... Housing Units

Hz .... Hertz

iDEN .... Integrated Digital Enhanced Network

ISP .... Internet Service Provider

kft .... Kilo-feet (1,000 feet)

ILEC .... Incumbent Local Exchange Carrier

IXC .... Interexchange Carrier

kbps .... Kilobits per second

kHz .... Kilohertz (1 thousand Hertz)

LATA .... Local Access and Transport Area

LTE .... Long-Term Evolution

Mbps .... Megabits per second (1 million bits per second)

MHz .... Megahertz (1 million Hertz)

MIMO .... Multiple Input, Multiple Output

MSC .... Mobile Switching Center

MSO .... Multiple System Operator

NBP .... National Broadband Plan

NIU .... Network Interface Unit

NPV .... Net Present Value

OECD .... Organization for Economic Co-operation and Development

Opex .... Operating Expenses

OTT .... Over-the-top

POP .... Point of Presence

PON.................. Passive Optical Network

POTS................. Plain Old Telephone Service

PSTN................. Public Switched Telephone Network

PV .... Present Value

QAM................. Quadrature Amplitude Modulation

QOS.................. Quality of Service

RBOC................ Regional Bell Operation Company

RFoG................. Radio Frequency Over Glass

RT....................... Regional Tandem

SG&A................ Selling, General and Administrative expenses

SINR .... Signal to Interference plus Noise Ratio

TDMA............... Time Division Multiple Access

UMTS .... Universal Mobile Telecommunications System

VDSL................. Very high bit rate Digital Subscriber Line

VOIP .... Voice Over Internet Protocol

WCDMA........... Wideband Code Division Multiple Access

WISP................. Wireless ISP

GLOSSARY

4G—Abbreviation for fourth-generation wireless, the stage of broadband mobile communications that will supersede the third generation (3G). Specifies a mobile broadband standard offering both mobility and very high bandwidth. Usually refers to LTE and WiMax technology. For the purposes of analysis in this paper, areas where carriers have announced plans to deliver 4G service are treated as 4G areas; all other areas are treated as non-4G areas.

Access Network—Combination of Last and Second Mile portions of a broadband network. See Last Mile and Second Mile.

Actual Speed—Refers to the data throughput delivered between the network interface unit (NIU) located at the end-user's premises and the service provider Internet gateway that is the shortest administrative distance from that NIU. In the future, the technical definition of "actual speed" should be crafted by the FCC, with input from consumer groups, industry and other technical experts, as is proposed in Chapter 4 of the National Broadband Plan. The technical definition should include precisely defined metrics to promote clarity and shared understanding among stakeholders. For example, "actual download speeds of at least 4 Mbps" may require certain achievable download speeds over a given time period. Acceptable quality of service should be defined by the FCC.

Advanced Mobile Phone Service (AMPS)—A standard system for analog signal cellular telephone service in the United States and elsewhere. It is based on the initial electromagnetic radiation spectrum allocation for cellular service by the FCC in 1970 and first introduced by AT&T in 1983.

American Wire Gauge (AWG)—A U.S. measurement standard of the diameter of non-ferrous wire, which includes copper and aluminum—the smaller the number, the thicker the wire. In general, the thicker the wire, the greater the current-carrying capacity and the longer the distance it can span.

Analog reclamation—In a cable system, refers to repurposing spectrum previously used to carry analog channels for other uses, either digital channels or high-speed data.

Asymmetric Digital Subscriber Line (ADSL)—A technology that transmits a data signal over twisted-pair copper, often over facilities deployed originally to provide voice telephony. Downstream rates are higher than upstream rates—i.e., are asymmetric. ADSL technology enables data transmission over existing copper wiring at data rates several hundred times faster than analog modems using an ANSI standard.

Average Revenue Per User (ARPU)—A metric used by investors and financial analysts to measure the financial performance of telecommunications service providers. ARPU is the average amount of revenue a company collects from each user per month.

Availability Gap—See Broadband Availability Gap and Investment Gap.

Base Case—The basic set of assumptions that leads to the $23.5 billion Investment Gap. The base case in the model compares the most economical technologies: 12,000-foot-loop DSL and Fixed Wireless. For the 12k-foot-loop DSL, the main assumption is that there is one competing provider in areas that are assumed to receive 4G service, and zero competing technologies in non-4G areas. For Fixed Wireless, costs are allocated to mobile infrastructure in 4G areas; in non-4G areas, all costs are allocated to fixed service, but the carrier is assumed to earn incremental revenue from mobile operations.

Broadband—For the purposes of determining the Investment Gap, 4 Mbps actual download and 1 Mbps actual upload; see also the National Broadband Availability Target.

Broadband Availability Gap—The amount of funding necessary to upgrade or extend existing infrastructure up to the level necessary to support the National Broadband Availability Target. Because this is a financial metric, and to avoid confusion with measures of whether local networks are capable of supporting a given level of broadband service, the Broadband Availability Gap is referred to as the *Investment Gap* throughout this paper.

Broadband Passive Optical Network (BPON)—A type of PON standardized by the ITU-T, offering downstream capacities of up to 622 Mbps and upstream capacities of up to 155 Mbps, shared among a limited number of end users.

[1] The authors provide this glossary as a reader aid. These definitions do not necessarily represent the views of the FCC or the United States Government on past, present or future technology, policy or law and thus have no interpretive or precedential value.

Brownfield—A network in which a carrier already has infrastructure in the area that can be used to deliver service going forward.

Burst Rate—The maximum rate or "speed" which a network is capable of delivering within a short timeframe, typically seconds or minutes. This is usually expressed as a rate in Mbps.

Busy Hour Offered Load (BHOL)—BHOL (per subscriber) is the network capacity required by each user, averaged across all subscribers on the network, during the peak utilization hours of the network. Network capacity required is the data received/transmitted by a subscriber during an hour; this can be expressed as a data rate (like kbps) when the volume of data received/transmitted is divided by the time duration.

Capacity—Ability of telecommunications infrastructure to carry information. The measurement unit depends on the facility. A data line's capacity might be measured in bits per second, while the capacity of a piece of equipment might be measured in numbers of ports.

Capital Expenditures (Capex)—Business expense to acquire or upgrade physical assets such as buildings, machinery and in this case telecommunications equipment; also called capital spending or capital expense.

Census Block—The smallest level of geography designated by the U.S. Census Bureau, which may approximate actual city street blocks in urban areas. In rural districts, census blocks may span larger geographical areas to cover a more dispersed population.

Central Office (CO)—A telephone company facility in a locality to which subscriber home and business lines are connected on what is called a local loop. The central office has switching equipment that can switch calls locally or to long-distance carrier phone offices. In other countries, the term *public exchange* is often used.

Churn—The number of subscribers who leave a service provider over a given period of time, usually expressed as a percentage of total customers.

Code-Division Multiple Access (CDMA)—Any of several protocols used in so-called second-generation (2G) and third-generation (3G) wireless communications. As the term implies, CDMA is a form of multiplexing, which allows numerous signals to occupy a single transmission channel, optimizing the use of available bandwidth. The technology is used in ultra-high-frequency (UHF) cellular telephone systems in the 800-MHz and 1.9-GHz bands.

Competitive Access Provider (CAP)—Facilities-based competitive local exchange carriers (CLECs).

Competitive Local Exchange Carrier (CLEC)—The term and concept coined by the Telecommunications Act of 1996 for any new local phone company that was formed to compete with the ILEC (Incumbent Local Exchange Carrier).

Coverage—In wireless communications, refers to the geographic area in which one can obtain service.

Customer Premises Equipment (CPE)—Equipment which resides on the customer's premise. Examples include set top boxes, cable modems, wireless routers, optical network terminals, integrated access devices, etc.

Data Over Cable Service Interface Specification (DOCSIS)—A cable modem standard from the CableLabs research consortium (www.cablelabs.com), which provides equipment certification for interoperability. DOCSIS supports IP traffic (Internet traffic) over digital cable TV channels, and most cable modems are DOCSIS compliant. Some cable companies are currently deploying third-generation (DOCSIS 3.0) equipment. Originally formed by four major cable operators and managed by Multimedia Cable Network System, the project was later turned over to CableLabs.

Digital signal 1 (DS-1)—Also known as T1; a T-carrier signaling scheme devised by Bell Labs. DS-1 is a widely used standard in telecommunications in North America and Japan to transmit voice and data between devices. DS-1 is the logical bit pattern used over a physical T1 line; however, the terms DS-1 and T1 are often used interchangeably. Carries approximately 1.544 Mbps.

Digital Subscriber Line (DSL)—A generic name for a group of enhanced speed digital services generally provided by telephone service providers. DSL services run on twisted-pair copper wires, which can carry both voice and data signals.