# The Internet is a Series of Tubes

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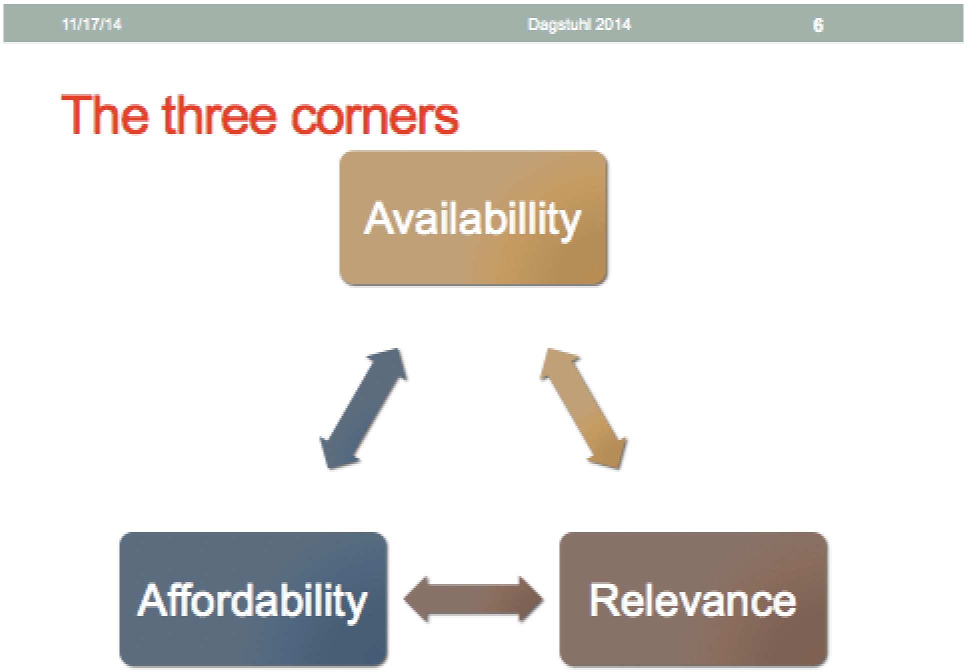
## Availability, Affordability and Relevance



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The three corners

Availabillity

Affordability

Relevance

Internet adoption tends to progress in phases: early rapid adoption in urban areas and by relatively well-educated and higher-income households, then transitioning to a slower pace once between 70 and 85% of households subscribe. For example, in a 2013 survey, the Pew Research Internet Project found that approximately 15% of the adult population does not use the Internet; those least likely to use the Internet include “senior citizens, adults with less than a high-school education and those living in households earning less than $30,000 per year.”[1]

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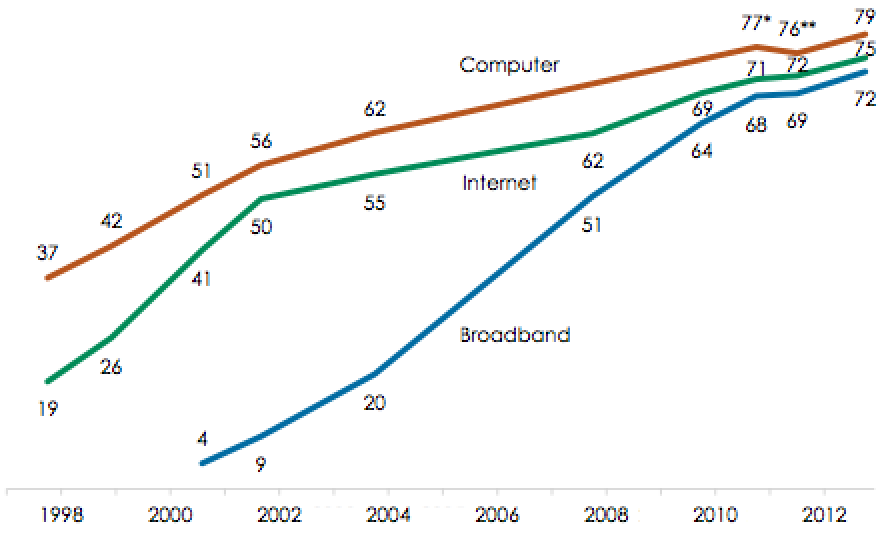
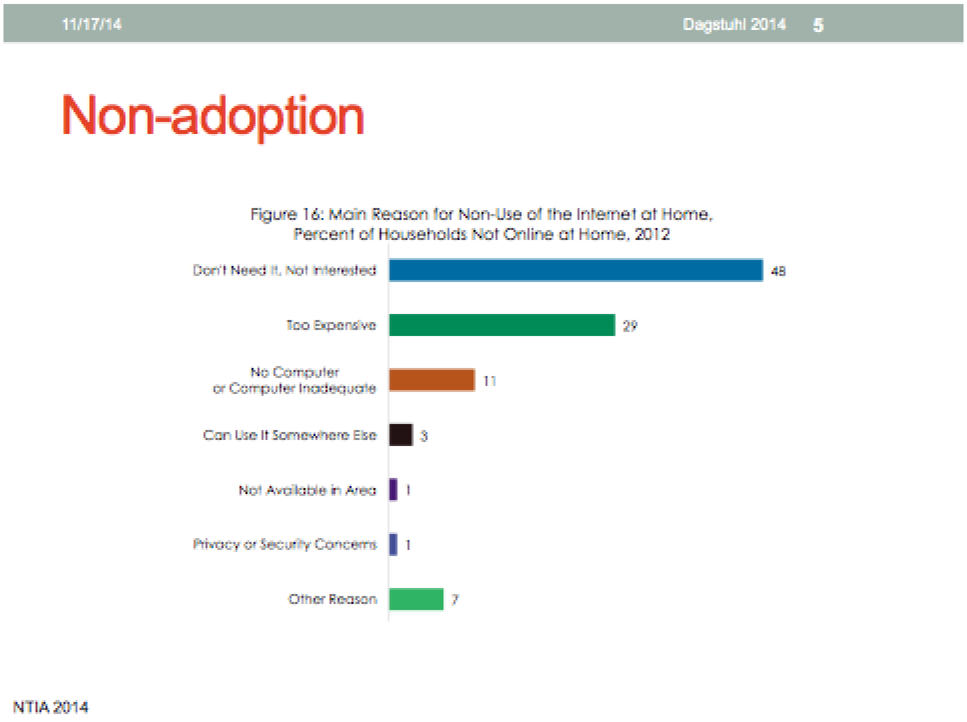
[1] http://www.pewinternet.org/fact-sheets/broadband-technology-fact-sheet/

Figure 1: Overview of Household Adoption Rates by Technology, Percent of U.S. Households, 1997-2012



NTIA 2014

Non-adoption has multiple reasons that vary in each country, and, within each country, by demographics. These reasons are often grouped, somewhat crudely, as availability, affordability and relevance. For the United States, a 2014 NTIA survey identified 48% as stating “Don’t need. Not interested.”, often summarized as “relevance”, as the main reason for not using the Internet at home, followed by “too expensive” (29%), “no computer or computer inadequate” (11%). Only 1% each claimed that there was no Internet access available or that privacy or security concerns dominated. A small percentage (3%) use the Internet somewhere else, e.g., at work, in coffee shops or a library. It is likely that many individuals will have multiple reasons and some non-users increasingly use functions on smartphones that may require Internet access, e.g., for maps or games, that may not be appear to the user as such.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Non-adoption

Figure 16: Main Reason for Non-Use of the Internet at Home, Percent of Households Not Online at Home, 2012

NTIA 2014

While the emphasis is often on private use, either at home or mobile, availability, affordability and relevance play a role for use by community anchor institutions such as schools, libraries, health care facilities and local government offices, as well as for small businesses, whether retail, hospitality or small manufacturing. For example, a recent report "finds significant gaps in the availability of high speed broadband among traditionally underserved students and their more affluent, suburban, and White peers"[2].

Availability, affordability and relevance are in turn influenced by a number of external factors, such as industry structure, the regulatory environment, consumer behavior overall, and available technologies and speed tiers. For example, the level of competition is likely to influence both the price consumers pay for access, i.e., affordability, and the investment made in new high-speed access and middle-mile technologies. In turn, the regulatory environment strongly influences industry structure. Consumer behavior, such as the shift from landline to mobile phones or from linear video to streaming video-on-demand, creates opportunities for existing and new entrants.

## What Kind of Internet?

When we discuss Internet access, it is helpful to distinguish multiple tiers, with very different capabilities. For example, basic messaging, whether via SMS or low-bandwidth IP-based technologies, can already satisfy key information and transaction needs, whether for electronic payments (M-PESA), person-to-person communication or for information retrieval

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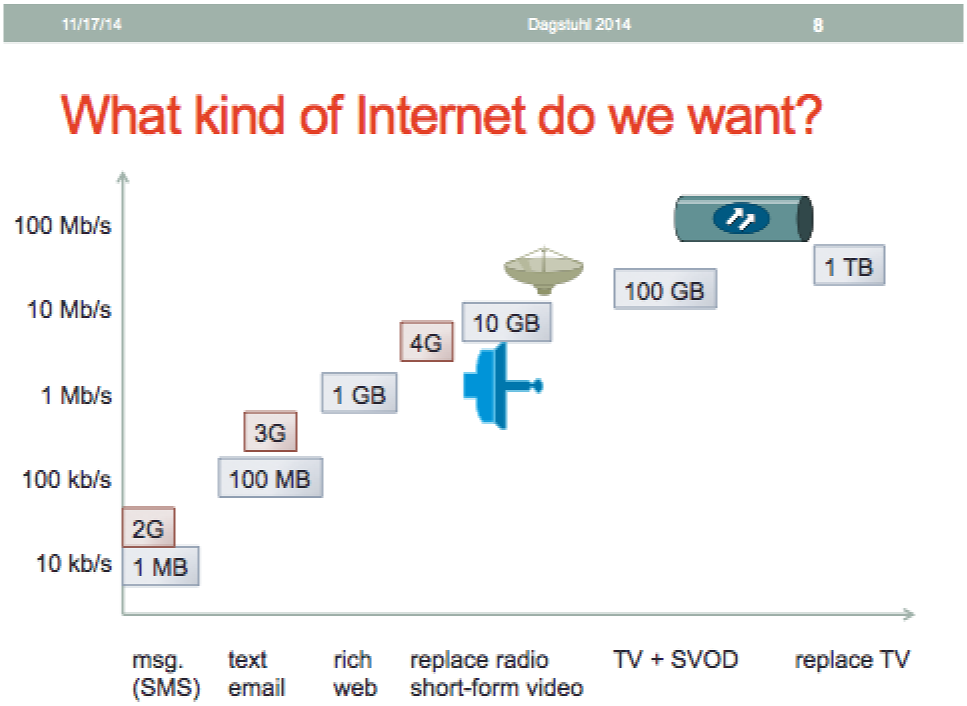
[2] http://99in5.org/resources-news/equity/

about weather or medical information. Such services may only require access bandwidths of the order of 10 kb/s, such as those enabled by 2G wireless or dial-up, and are likely to consume at most a few MB of data a month. The next step up enables text-heavy web content as well as text email, and is easily achievable through (reliable) 3G coverage or basic ADSL. With bandwidths of a few Mb/s and monthly bandwidth-allowances of around 1 GB, users can access most main-stream web sites, even those not optimized for low-bandwidth devices. At speeds of roughly 10 Mb/s and monthly data usage around 10 GB, the home Internet connection can offer short-form video (e.g., YouTube) and replace FM radio. Between 10 and 100 Mb/s, with data budgets of at least 100 GB, streaming video-on-demand becomes plausible, while, longer term, a full TV replacement at 4K quality is likely to push the monthly data volume per household to 1 TB and above.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What kind of Internet do we want?

Beyond speed and monthly data volume, there are at least three other dimensions along which one might characterize Internet access: **latency, symmetry and uniformity**. Latency, typically expressed as round trip time, may vary between 20 ms to the edge of the access provider for fiber and LTE to more than one second for satellite links. Dog-leg routing of traffic through far-away interexchange points may further increase the effective latency. Latency reduces the usability of interactive applications such as phone calls, telemedicine, distance learning and some games, increases the load time of web pages referencing network-based APIs, and may reduce the achievable throughput of bulk data applications. Traditionally, most residential access links, such as ADSL and HFC, have been highly asymmetric, with download speeds ten times higher or more than upload speeds. Creating content requires higher upload speeds, and thus more symmetric networks. Finally, some networks for challenging environments may offer *non-uniform access to content*[3], where some content, cached locally, is available immediately and at high bandwidth, while other content may only be available after significant delay measured in minutes or hours, e.g., after fetching it during low-usage overnight hours. Similar ideas are also implemented by modern entertainment systems on commercial aircraft, which host high-bandwidth content locally, supplementing a lower-bandwidth Internet access channel. Some of the "Internet in the box" projects discussed in the workshop report occupy spots on this continuum, with the ideas exploring aspects of related to delay-tolerant and disruption-tolerant networks, or more classical web proxy caching. (For example, the ICOW work[4] places caches on public transit vehicles. Earlier, we had explored local applications, such as bulletin-board systems[5].)

## Centralized vs. Distributed Infrastructures

All societies above a certain level of development depend on four key infrastructures: potable water and waste water, energy such as electricity and natural gas, transportation and communication. In each case, albeit to differing degrees, these infrastructure services can be provided with various degrees of centralization or local and individual autonomy. Recently, the delivery of electrical energy has probably been most visible in exploring these trade-offs, whether through solar powered lanterns and cell towers on one end of the spectrum, or huge wind farms at the other. For communication, a purely local infrastructure seems to have inherently lower value than connecting to the global Internet, even if such purely local infrastructure can clearly be "better than nothing". Even for communication, there are trade-offs of having infrastructure such as satellite that requires very little coordination among participants and very little on-the-ground investment by local governments vs. a fiber infrastructure that requires the consent and participation of thousands of property owners and local governments, for example.

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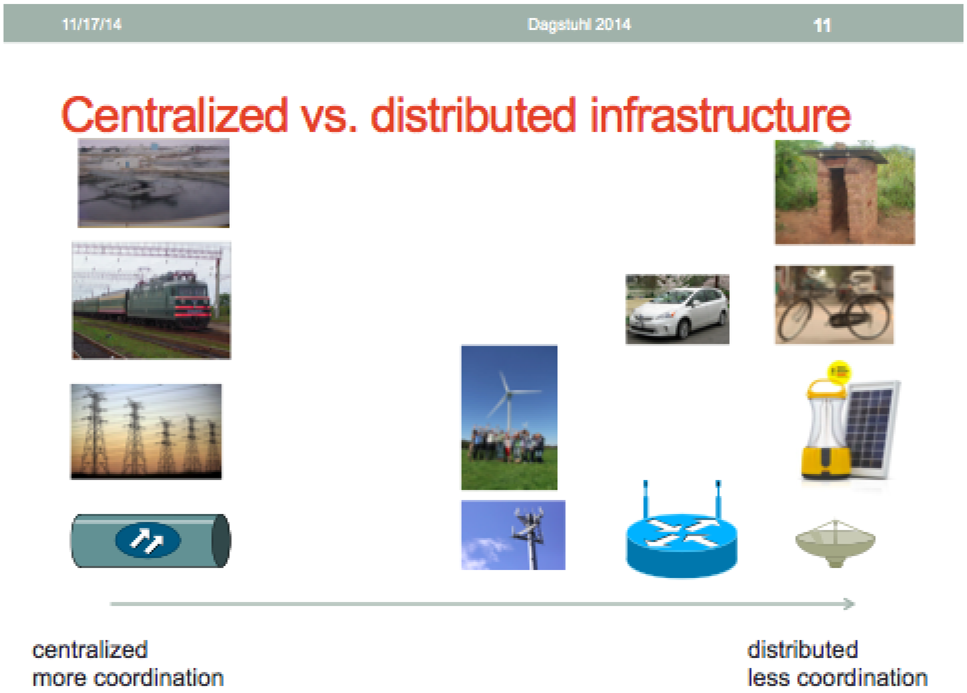
[3] The allusion to NUMA concepts in computer architecture is intentional.

[4] Se Gi Hong, SungHoon Seo, Henning Schulzrinne, and Prabhakar Chitrapu, "ICOW: Internet Access in Public Transit Systems," Under review at IEEE Communications Magazine.

[5] Arezu Moghadam, Suman Srinivasan, Henning Schulzrinne, "7DS - A Modular Platform to Develop Mobile Disruption-tolerant Applications", IEEE NGMAST 2008, Wales, UK, September 2008.



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Centralized vs. distributed infrastructure

centralized
more coordination

distributed
less coordination

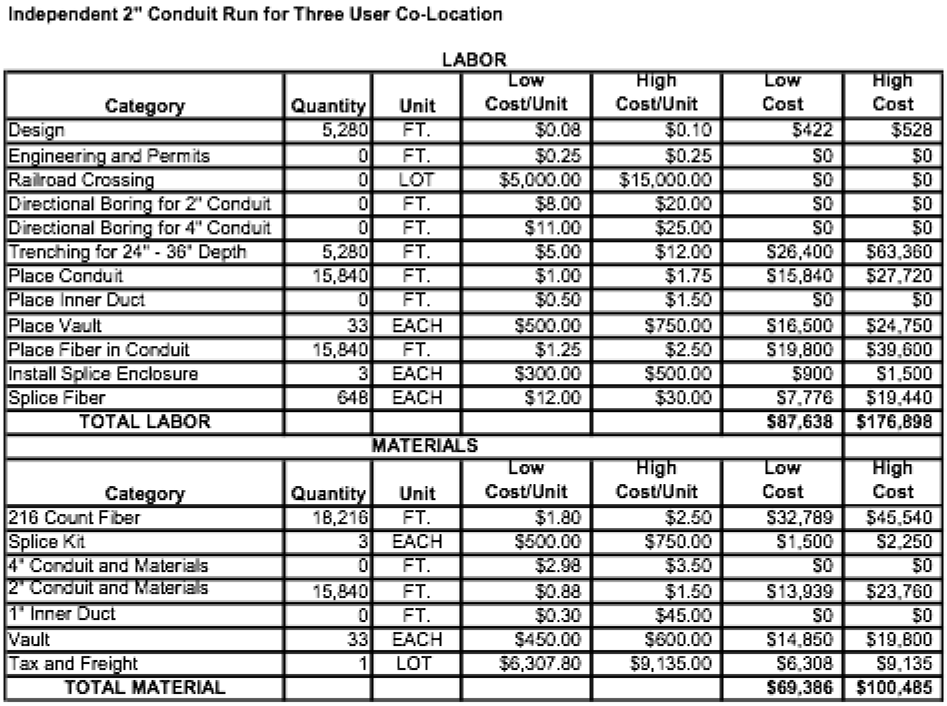
## What’s Expensive About Networks?

The network engineering and research community has spent most of its efforts on making networking equipment more efficient and cost-effective. However, for most network build-outs, the electronics, optical components and fiber contribute only a small fraction, often less than 30%, of the total cost. For example, a fiber cable with 48 strands might cost $5,000 per mile, while the finished cost of a middle-mile deployment may range between $50,000 and $70,000 per mile. Cables with more fiber strand are proportionally cheaper; for example, a 144-strand cable costs roughly $10,000 per mile.

The cost of deploying fiber is driven first by the number of homes passed, regardless of how many of those homes subscribe, and then the actual number of subscribers. Depending on how networks are built out, the second cost component is only incurred when the carrier or community has a paying customer. For typical densities in urban and sub-urban environments, the cost seems to be around $1,000 per home passed for recent deployments. The per-home optical network termination units (ONUs) used to be relatively expensive, at $300-$400 per home, but have been dropping to around $100 to $200. The costs are generally higher if ducts have to be placed underground, compared to stringing fiber on utility poles, but duct or other underground burial tends to yield a more reliable network. Actual historic FTTH costs range between $1,000 and $1,300 per home, for outside plant only.

To first approximation, it appears that the cost per home is closely proportional to the distance between homes within one network deployment. Thus, for the same population density, serving homes spaced one-by-one along rural highways may be much more expensive than serving small villages where homes are clustered.

The figure below shows an example calculation of a fiber build-out[6]. Other cost examples include a build-out with 96% aerial and 4% buried construction, in the Northeastern United states, with a cost of $30,000 per mile. Aerial overlash can be cheaper at $15,000 per mile, while buried fiber can cost $89,000 per mile.



**Independent 2" Conduit Run for Three User Co-Location**

LABOR

| Category | Quantity | Unit | Low Cost/Unit | High Cost/Unit | Low Cost | High Cost |
|---|---|---|---|---|---|---|
| Design | 5,280 | FT. | $0.08 | $0.10 | $422 | $528 |
| Engineering and Permits | 0 | FT. | $0.25 | $0.25 | $0 | $0 |
| Railroad Crossing | 0 | LOT | $5,000.00 | $15,000.00 | $0 | $0 |
| Directional Boring for 2" Conduit | 0 | FT. | $8.00 | $20.00 | $0 | $0 |
| Directional Boring for 4" Conduit | 0 | FT. | $11.00 | $25.00 | $0 | $0 |
| Trenching for 24" - 36" Depth | 5,280 | FT. | $5.00 | $12.00 | $26,400 | $63,360 |
| Place Conduit | 15,840 | FT. | $1.00 | $1.75 | $15,840 | $27,720 |
| Place Inner Duct | 0 | FT. | $0.50 | $1.50 | $0 | $0 |
| Place Vault | 33 | EACH | $500.00 | $750.00 | $16,500 | $24,750 |
| Place Fiber in Conduit | 15,840 | FT. | $1.25 | $2.50 | $19,800 | $39,600 |
| Install Splice Enclosure | 3 | EACH | $300.00 | $500.00 | $900 | $1,500 |
| Splice Fiber | 648 | EACH | $12.00 | $30.00 | $7,776 | $19,440 |
| **TOTAL LABOR** | | | | | **$87,638** | **$176,898** |

MATERIALS

| Category | Quantity | Unit | Low Cost/Unit | High Cost/Unit | Low Cost | High Cost |
|---|---|---|---|---|---|---|
| 216 Count Fiber | 18,216 | FT. | $1.80 | $2.50 | $32,789 | $45,540 |
| Splice Kit | 3 | EACH | $500.00 | $750.00 | $1,500 | $2,250 |
| 4" Conduit and Materials | 0 | FT. | $2.98 | $3.50 | $0 | $0 |
| 2" Conduit and Materials | 15,840 | FT. | $0.88 | $1.50 | $13,939 | $23,760 |
| 1" Inner Duct | 0 | FT. | $0.30 | $45.00 | $0 | $0 |
| Vault | 33 | EACH | $450.00 | $600.00 | $14,850 | $19,800 |
| Tax and Freight | 1 | LOT | $6,307.80 | $9,135.00 | $6,308 | $9,135 |
| **TOTAL MATERIAL** | | | | | **$69,386** | **$100,485** |

It is currently unknown whether combinations of fiber to the neighborhood (FTTN) and VDSL, such as G.Fast, or wireless, whether 5.8 or possibly 60 GHz, can offer a long-term attractive alternative. They may trade-off an initially lower investment with higher operational costs or lower reliability, as well as practical difficulties such as where to place DSLAM and radio components. A more systematic exploration of this trade-off, with real-world cost figures, would be enlightening.

Current field engineering wisdom seems to have converged on a number of recommendations for reducing the cost of building new “greenfield” or overbuilt networks:

- To reduce the cost and difficulty of deployment, active network elements are placed in as few locations as possible. This avoids negotiating for “fiber huts” with local communities or finding in-building space that is accessible for maintenance. Recently,

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[6] CTC, 2009 (“Brief Engineering Assessment: Efficiencies available through simultaneous construction and co-location of communications conduit and fiber”).

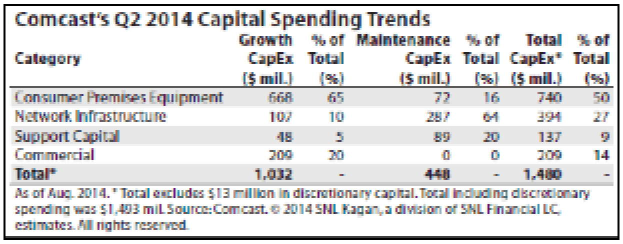
even passive optical networks place the splitter in the head-end and create fiber home runs.
- To reduce the cost of dispatching technicians, all per-home fiber drops and other installation is performed at once, e.g., in one Google “fiberhood”.
- To reduce the cost of in-home installation, each home is connected through an all-in-one optical network unit that includes, for example, a high-speed 802.11ac wireless interface that can directly provide network connectivity to the whole home. (Early Verizon FiOS deployments had the ONU in the basement, which is then connected via coaxial cable and MoCa data transmission to the set top box. The set top box is placed near the family TV and also contains a Wi-Fi interface. This requires in-home cabling.)
- Any active in-network components are reverse-powered through the home, to avoid having to connect to utility power.
- To the extent possible, home owners are asked to self-install, as had happened earlier with DSL and cable modems. If ONUs become standardized, it may also be possible for the carrier to ask the consumer to purchase the device, possibly using the Equipment Installation Plan (EIP) model now popular in the United States for smartphones, further reducing capital outlays for the carrier.
- Communities and other government entities responsible for roads, railways and pipelines should, by default, install at least fiber ducts or dark fiber whenever a road, railroad or pipeline is built or major improvements are made.

Given the large cost differential between the cost of fiber and the total construction cost, there seems to be room for significant improvement on the civil engineering side. One can imagine autonomous underground boring vehicles, possibly leveraging advances in horizontal drilling pioneered by oil shale fracking, that place fiber or ducts with minimal human intervention.

While the capital investment for fiber or other network access technologies is substantial, it is a small fraction of the total cost of operating networks. Below, we show three examples that illustrate that, across three continents, the capital costs are roughly 15% to 16% of the revenue.

| Company | Revenue | Capital expenditures | % |
|---|---|---|---|
| Comcast (US), 3Q14 | $11.04B | $1.644B | 14.9 |
| Telekom (DE), 3Q14 | €15.6B | €2.58B | 16.5 |
| Safarikom (KE), H1FY15 | Ksh 79.34B | KSh 12.37 | 15.5 |

These capital expenditures include costs other than for building networks. For example, the table below shows the Q2 2014 capital spending for Comcast, the largest US cable communications company. About half the spending is for customer premises equipment, primarily video set top boxes.



Comcast's Q2 2014 Capital Spending Trends

| Category | Growth CapEx ($ mil.) | % of Total (%) | Maintenance CapEx ($ mil.) | % of Total (%) | Total CapEx* ($ mil.) | % of Total (%) |
|---|---|---|---|---|---|---|
| Consumer Premises Equipment | 668 | 65 | 72 | 16 | 740 | 50 |
| Network Infrastructure | 107 | 10 | 287 | 64 | 394 | 27 |
| Support Capital | 48 | 5 | 89 | 20 | 137 | 9 |
| Commercial | 209 | 20 | 0 | 0 | 209 | 14 |
| **Total*** | **1,032** | - | **448** | - | **1,480** | - |

As of Aug. 2014. * Total excludes $13 million in discretionary capital. Total including discretionary spending was $1,493 mil. Source: Comcast. © 2014 SNL Kagan, a division of SNL Financial LC, estimates. All rights reserved.

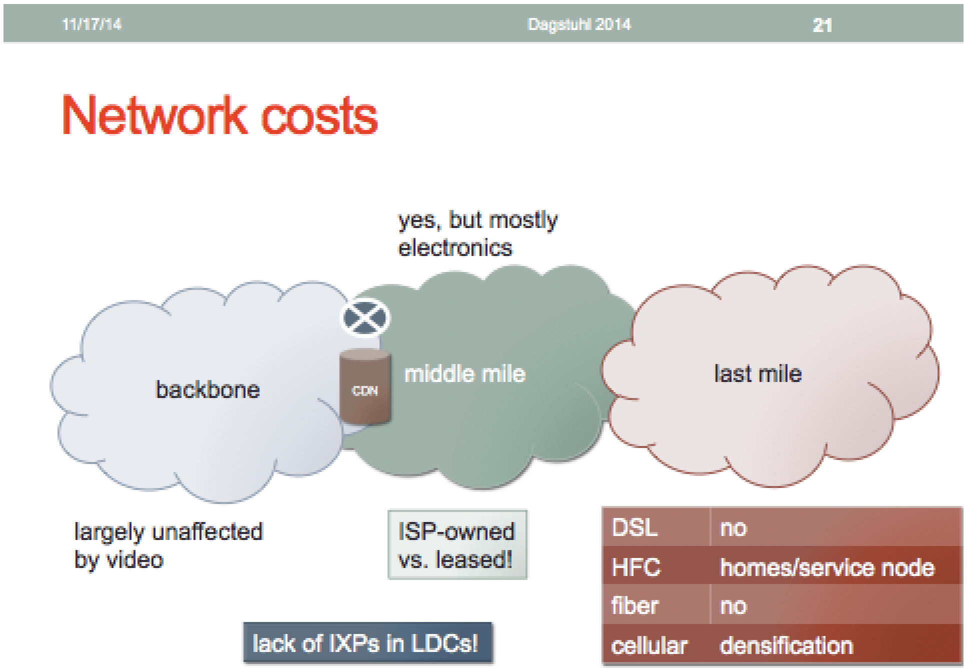
This observation indicates that attempts to reduce the cost of network operations may be more productive than reducing capital expenditures. For example, self-configuring and self-diagnosing networks could reduce the number of field service calls and customer support incidents. Simpler billing models may reduce the need for extensive billing-related expenses. In general, fiber networks have significantly lower maintenance costs than copper or coax networks. One of the gaping holes for engineering solutions that address these problems is the apparent lack of any public data on the cost of operations in real, particularly large-scale, networks. Community networks and networks run by public organizations may offer opportunities to gain insight into real-world operational costs. Without precise cost models, it is impossible to say, for example, whether and where replacing FTTP networks with FTTC plus wireless models is cost effective.

## The Cost of Carrying Bits

In the figure below, we try to capture, grossly simplified, the three principal components of network costs, namely the Internet backbone, middle mile and last mile, i.e., access. The relative impact of each cost factor depends on the size and geographic scope of the network operator. For example, a small rural network operator may have very limited competitive choices among middle mile providers that can carry its traffic to the nearest interexchange point (IXP). This motivated the United States BTOP program to fund middle mile access, e.g., in Vermont. On the other hand, larger operators with a significant footprint can probably justify either leasing dark fiber or building their own, so that the cost of the middle mile infrastructure is more modest as it can be amortized over large traffic volumes.

As the figure tries to illustrate, the volume-dependent cost also differs significantly among the three components. For example, the middle mile may only require additional electronic components to increase bandwidth, while HFC networks may need nodes to be split. If the last mile is based on fiber, there is essentially no incremental cost of carrying additional bits on that last mile. (This does not necessarily argue for flat pricing; it has been argued that charging based on data consumption reflects the value users place on network connectivity.)

As video has come to dominate Internet traffic, much more of the content can be cached close to the edge, either at the IXP or even at the fiber head end. Thus, additional video volume may only impact the volume-insensitive components of the network.



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## Network costs

yes, but mostly electronics

backbone

CDN

middle mile

last mile

largely unaffected by video

ISP-owned vs. leased!

lack of IXPs in LDCs!

| | |
|---|---|
| DSL | no |
| HFC | homes/service node |
| fiber | no |
| cellular | densification |

In many parts of North America and Europe, the cost of Internet transit has decreased steadily, as shown in the figure below. The cost is shown in dollars per month and Mb/s. (Transit capacity is typically sold at the 95th percentile of 5-minute traffic intervals.) In addition, many large "eye ball" networks, i.e., networks serving consumers, peer settlement-free, i.e., without charge, with other networks, or, in some cases, even charge content distribution networks (CDNs).

Overall, the cost of delivering bits across networks has now, in the United States at least, dropped below the physical cost of delivering bits on disk or DVD. As an example, the postage cost of shipping a Netflix DVD round-trip is approximately $0.70, translating into $100 per TB of data. For user-created data, the DVD-R cost itself is about $0.25, or roughly $30 per TB. Typical CDN pricing is $7 to $20 per TB.[7]

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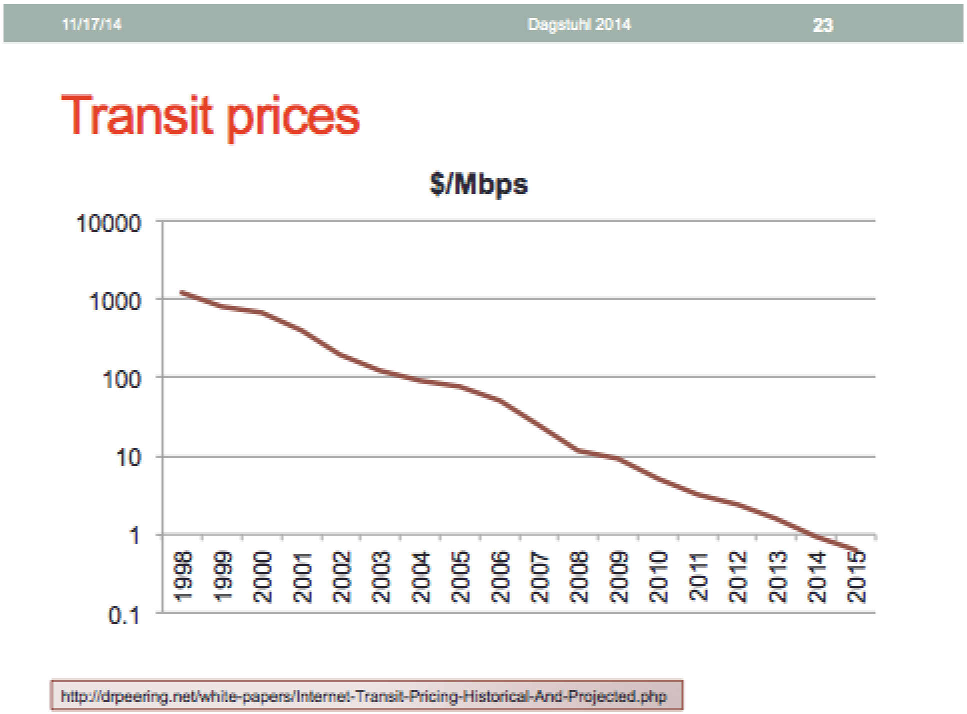
[7] See cdnpricing.com for examples and history.



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Transit prices

http://drpeering.net/white-papers/Internet-Transit-Pricing-Historical-And-Projected.php

## How to Finance Networks?

As noted earlier, building new network infrastructure requires an initial substantial outlay of capital. Since the take rate is often not known ahead of time, an investor, whether for-profit or community, incurs substantial uncertainty how much revenue they can expect. The uncertainty grows if there is a lower-performance competitor in the same area that might be able to undercut the new entrant on price or upgrade their own facilities. There are a number of approaches that can be tried to provide “patient” capital or reduce the need for up-front investment:

- **Wireless mesh networks** essentially allow a network to grow with each new user. The only, albeit substantial, investment is middle-mile backhaul. However, such networks may require significant expertise to set up and are probably best suited for DSL-like per-user bandwidths.
- **Demand aggregation** can take many forms, with Internet cafes, community centers, libraries and schools offering well-known examples. Cooperatives can aggregate both last-mile and middle-mile demand.
- In some countries, governmental and non-governmental organizations provide **loans** at low interest rates to eligible entities to fund the construction of networks. Similarly, **rural electric cooperatives** may have longer investment horizons than public companies.

- **Vendor financing** may be another option, where vendors of equipment and construction services retain a portion of the revenue. This is attractive if the vendor can obtain better financial terms than the local network operator.[8]
- **Franchise models** have been successful in areas ranging from take-out food to dog kennels, but appear to be uncommon for providing Internet access. Franchising provides two key benefits: It allows to centralize functions that require significant technical expertise and that enjoy economies of scale, such as, in our case, network management, billing and other OSS functions, as well as bulk purchasing. Franchisees contribute their own capital, labor and knowledge of the local market. However, the investment needed for each local area may well exceed the typical small-business franchise investment of up to, say, $500,000 in the United States. (At $1,000 per home passed, this would suffice only for small rural communities. Indeed, the emergence of wireless Internet service providers, without the benefit of franchising, seems to support this scale estimate.)
- Broadband Internet access is unique among residential infrastructure, as it is often added long after a home is built. For gas, water, and electricity, home owners typically finance the last few meters as part of the cost of construction, through a long-term low-interest mortgage. For FTTH, the per-home connection costs are as large as half the total. With standardization of interfaces, it is conceivable that at least new homes and developments make fiber part of the initial construction. Indeed, this idea has been proposed several years ago[9] under the moniker "**homes with tails**", but seems to have achieved limited traction in practice.
- In theory, it might be possible to have content providers, whether commercial or not-for-profit, pre-fund the construction of networks, allowing them to reach new consumers or users. However, aggregating diverse content creators and avoiding the free-rider problem appear to be challenging for an infrastructure that is inherently shared. (This is a very old idea - after all, radio and TV stations fund their own transmission systems.)

# How to Pay for Networks?

American households have significantly increased their spending on telecommunication services, as shown below[10]. Given that overall disposable household income, and in particular income not committed to health care, housing and food, has not been increasing for most households in Europe and the United States, there may be limited opportunity for additional growth. In many countries, expenses for cellular and Internet services have displaced paying for landline phone service.

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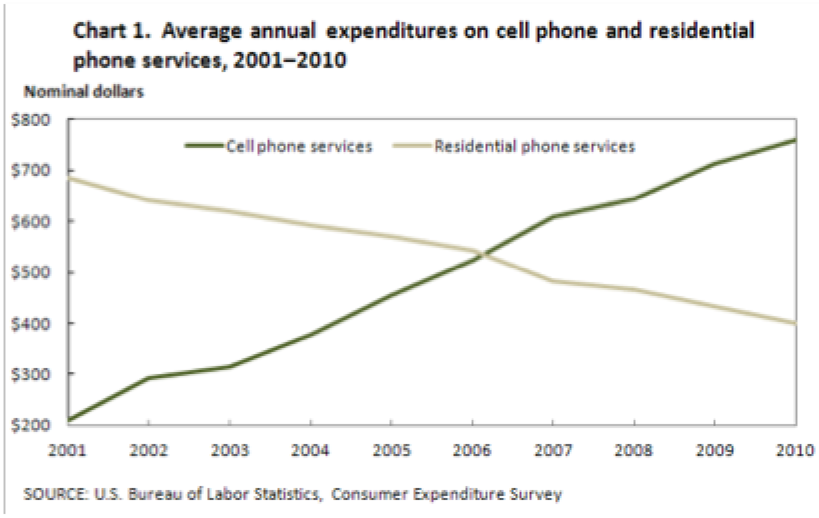
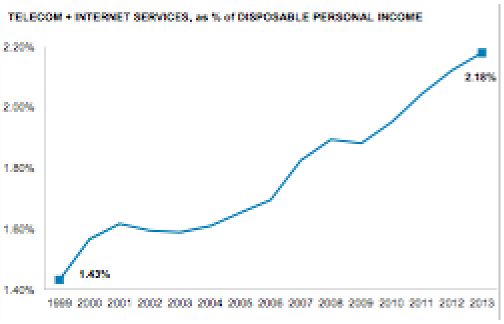
[8] However, this model can endanger the vendor, as large telecom equipment vendors found out after the 2000 telecom bubble burst in the United States and many competitive local exchange carriers (CLECs) were unable to meet their debt obligations.

[9] http://www.newamerica.net/publications/policy/homes_tails (2008)

[10] See Morgan Stanley, *Macro Meets Micro: A Five-Year View of the Telecom Services Industry*, July 2014 and Consumer Expenditure Survey, U.S. Bureau of Labor Statistics December 2011, Volume 2, Number 12 (http://www.bls.gov/opub/btn/archive/consumer-spending-in-2010-pdf.pdf).





It is well-known that the value of bits to the user differs dramatically, with the lowest-bandwidth applications having the largest value per bit. For example, at 10c per minute, a GSM voice call at 13 kb/s costs roughly $1,020 per GB, while 4G data is sold at approximately one hundredth of that price, at rough $10 per GB. Consumers have been willing to pay 10c for each SMS, which translates to $625,000 per GB, even if the short message fills the 160 byte capacity.

While a detailed analysis is beyond the scope of this review, experience seems to indicate that consumers place significant value on predictable charging models[11]. Even simple usage-based charges generates complaints about discrepancies between volume measured by the end system and by the provider or surprises when better connectivity increases the cost of viewing videos. Application-based charging encourages traffic masking, i.e., converting expensive bits into cheaper ones, which then requires deep packet inspection or other countermeasures.[12] For bandwidth-constrained networks, time-of-day charging appears to have the advantage of

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[11] Andrew Odlyzko, "Will smart pricing finally take off?", http://www.dtc.umn.edu/~odlyzko/doc/smart.pricing.pdf, Oct. 2013.

[12] For example, Skype masqueraded as web traffic at some point, both to bypass restrictive firewalls and to avoid VoIP limitations.

being easy to understand, and probably approximating more sophisticated congestion-based charging.

Given the roughly factor-ten difference in bandwidth costs between 4G and landline networks (and arguably the largely zero incremental cost for the user), mobile operating systems have already adapted by automatically delaying high-bandwidth activities such as software updates to times when Wi-Fi is available. (Unfortunately, side-loading of video does not appear to be automated yet. Operating systems, including those for tablets and laptops, could provide significantly better policy support to applications.)

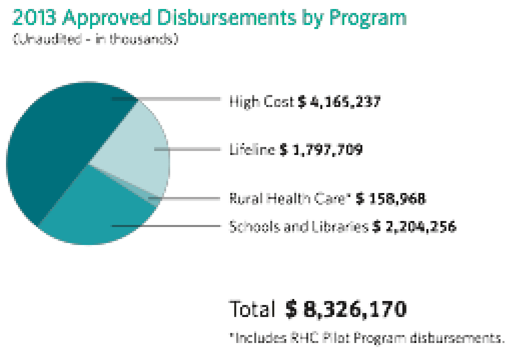
## Zero-rating Content - An Alternative?

The idea of having content providers or advertisers pay for network access, thus reducing the cost burden particularly on low-income consumers, has received a fair amount of discussion. The economics appear to be challenging, however. For example, at a CPM (cost per thousand) for a video pre-roll advertisement of roughly $10, this translates into 1 cent per video. Since the content creator, e.g., the creator of a YouTube video, receives some compensation and the video distribution service also incurs costs, significantly less than that amount will be available to zero-rate other content. A 720p H.264 video consumes approximately 20 MB per minute, i.e., the typical 30 second video ad itself generates 10 MB. At the incremental rate of $10/GB, the cost is $0.01 per MB. Thus, at current rates, the advertising revenue could not even cover the cost of the ad itself, let alone other content that the user might want to watch.

## Universal Service

The concept of universal service, i.e., providing telecommunications services to all residents regardless of geography or income, has a long tradition, dating back in the United States to at least the 1934 Telecommunication Act. There have been three traditional mechanisms to provide service to low income households and high-cost areas, by cross subsidy, by explicit subsidies by rate payers in general and finally through general tax revenue. Both Europe and the United States have had implicit subsidies within the dominant telecommunication provider, i.e., AT&T and the Bell Operating Companies, as well as explicit subsidies, with the United States choosing universal service fees imposed interstate telecommunication charges. Implicit subsidies include obligations to serve all reasonable requests within a defined geographic areas, such as “carrier of last resort” obligations in many US states. They also include higher-than-cost long-distance rates, intercarrier compensation for terminating calls in rural areas, higher business line rates and above-cost rates for services such as caller ID.

The United States has a universal service program that consists of four parts, with the most relevant for purposes of this discussion being the Connect America Fund to support high-cost (largely rural) areas and Lifeline, for low-income households. In 2013, the program disbursed more than $8.3 billion, i.e., roughly $75 per household and year. High-cost and LifeLine support is paid to carriers, while the rural health care and school and library (e-rate) fund is paid to organizations that then purchase telecommunication services.



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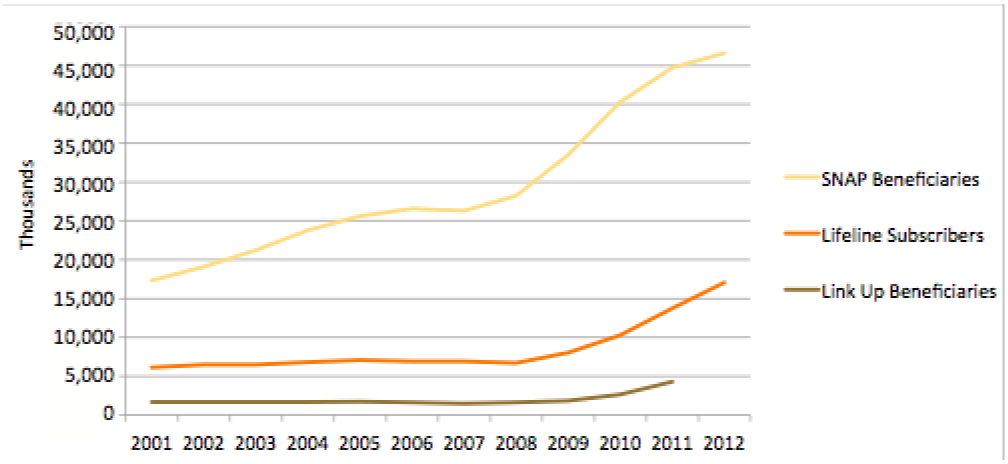
A detailed treatise of universal service is well beyond the scope of this summary. The programs have needed significant reforms to address inefficient and fraudulent expenditures. Also, the current contribution mechanism relies on a decreasing portion of consumer and business telecom expenditures, and there is no clear path on whether and how to include Internet access, for example, in the contribution base. Currently, broadband with speeds of 4 Mb/s down and 1 Mb/s up is eligible for support. An increase to 10/1 Mb/s has been proposed.

Currently, the FCC is conducting a small-scale ($100 million) experiment on allocating high-cost support for higher-speed broadband based on a reverse auction, i.e., the entities with the lowest relative cost per subscriber served receive support, thus encouraging an efficient use of funds.



Ellig[13]

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[13] J. Ellig, "Reforming the FCC's Low-Income Phone Subsidies", 2013, http://mercatus.org/sites/default/files/Ellig_FCC-phone-subsidy_MOP_101813.pdf

The Lifeline[14] fund largely supports a $9.25 subsidy for mobile phone service, which is offered competitively by a number of MVNOs. A typical plan includes 250 minutes of voice calling per month, along with text messaging. There has been discussion, but no action, on extending Lifeline funding to data services. Subscribers have to be on a social service plan such as SNAP ("food stamps") or be within 135 or 150% of the poverty limit. Each household is eligible for only one phone. Currently, the number of LifeLine beneficiaries is significantly smaller than the number of eligible households as measured by the number of SNAP recipients, as shown in the figure above.

The private EveryoneOn[15] effort offers discounted Internet access, either through some HFC companies (5/1 Mb/s) or via 4G/3G wireless to low-income families with children eligible for free school lunches. For example, 1.2 GB of 4G wireless data is available for a monthly fee of $10 for families with children that are participating in the free school lunch program. The Comcast Internet Essentials program serves approximately 350,000 households in 2014[16]. The latter program was instituted as part of a merger condition.

These programs illustrate that there are at least two ways to offer affordable Internet access within the existing industry structure, often in combination. From a provider perspective, the carrier wants to avoid losing price-sensitive customers that currently pay significantly more to low-cost plans. Providers can limit the performance of such plans, or make them otherwise inconvenient, so that they are only attractive to households that cannot afford regular plans. Thus, such plans typically only offer limited speed or data budgets. However, reducing the performance too much will likely limit the take rate or may cause users to abandon a service that is unreliable or not capable of supporting common Internet experiences such as watching video content. Secondly, and probably more effectively, such programs can restrict eligibility by income. Providers may thus primarily reach customers that would otherwise not subscribe at all. Since many families move in and out of poverty, they may also help to attract new customers that stay even after they are no longer eligible for the discounted rate.

In summary, addressing availability, affordability and relevance requires both engineering and economic approaches. To make programs sustainable, they need to offer services that meet modern Internet expectations, if logistically possible. Predictable limitations are likely to be more successful than highly-variable quality, but there appears to be little quantitative research on many aspects of universal service, including the cost of building and operating networks.

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[14] http://www.fcc.gov/guides/lifeline-and-link-affordable-telephone-service-income-eligible-consumers

[15] https://everyoneon.org/

[16] http://corporate.comcast.com/images/MB-10-56-Comcast-Internet-Essentials-Annual-Report-2014-07-31.pdf