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LET THEM EAT CELLPHONES: WHY MOBILE WIRELESS IS NO SOLUTION FOR BROADBAND

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The policy of serving rural America through wireless broadband offers false hope for the future and promotes inefficient use of resources in the present, argues Professor Noam. Rural mobile broadband will never, he says, be a satisfactory substitute for wired (fiber or coaxial) systems for meeting foreseeable needs for increased throughput, creating a new "digital gap." It is at best a temporary Band-Aid for addressing the increasingly uneven distribution of broadband quality. Eventually its inherently second-rate characteristics will drive the national network to an all-wired infrastructure. It would be better to recognize and address this now.

There are many dimensions to digital diversity. One of them is the diversity of speed. Soon, just about everyone will be connected to some form of broadband and the discussion of a digital divide will shift from penetration to quality.

One essential dimension of quality is speed. This article will argue that the reliance on mobile wireless – common to national broadband plans in America and most developed countries – to overcome uneven distribution of broadband connectivity is only a temporary Band-Aid. It will not prevent a significant new digital gap: that of transmission speed. To reach this conclusion, the article analyzes the trend of data speeds one can expect for the entertainment uses of households. It compares these requirements with the trends and potentialities of mobile wireless as a transmission pipe, and observes a major and inherent shortfall. The under-projections of demand and over-projections of supply have led many countries, including the United States, to emphasize mobile wireless as a solution to the uneven distribution of broadband. But the analysis concludes that the wireless strategy will work only in the very short term, and that it is necessary to move quickly beyond connectivity to a speed-oriented strategy.

Let us begin with two clarifications. First, although everybody calls it "speed," this is really a misnomer since electronic signals travel pretty much at light speed. What everyone calls "speed" is really the data transfer rate – the bit rate per second. Other people call it "bandwidth," which is equally imprecise. This characterization uses an analog concept for a digital reality. However, since everybody is using the term "speed," we will utilize it as shorthand for data throughput. A second clarification is to distinguish between wireless in general and mobile wireless. The former includes

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fixed and focused transmissions on a variety of bands. The latter is a subset – a smart technology that keeps people connected as they move around, offered by a small number of network providers, and operating on well-defined frequencies.

In March 2010, the Federal Communications Commission in Washington, DC, with some fanfare, presented its National Broadband Plan (NBP).[1] The plan, while excellent in its comprehensive overview of a digital ecosystem, was significantly hobbled by a major restriction – a dismal budget reality that prevented the Obama Administration from providing funds to a project that it declared to be a prime national initiative.[2] Within such constraints the NBP managed to maneuver creatively.

The NBP report covered hundreds of information-dense pages. A central regulatory action recommended to the FCC was the provision of broadband to unserved and under-served populations,[3] primarily in rural areas by way of wireless, and that is also the focus of this article.

What has happened since the NBP was unveiled in early 2010? The good news is that during 2010, homes with fiber passing (or reaching closely nearby) increased by about 9.5 million, and cable TV's superfast DOCSIS 3.0 became available to 25 million additional households. But little of this was due to the plan or to stimulus moneys. Actually, in the preceding year (2009) those upgrades had been still higher, 9.8 million for telecommunications service and 30 million for cable service, with no plan or stimulus provided. A study at the Columbia Institute of Tele-Information of projected investment shows that these patterns were expected to decline in 2011 and beyond as the upgrade and deployment programs approach completion.[4] Basically then, the plan's goals on bottom-line connectivity seem to be met by regular market forces. This trend, however, seems to be petering out as penetration has risen. The task ahead is more about unserved or underserved areas, as the NBP recognized.

The National Broadband Plan's target, proclaimed by the Administration – 100 million households with an Internet connectivity of 100 megabits per second by 2020 – was an uncomfortable bumper sticker for the plan's authors, whose goals were more complex. But some bottom line is inevitably needed to measure progress, and using such a yardstick like the "100 square" target was hardly ambitious. South Korea, which in 2010 already had nearly universal service at the level of 100 Mbps, announced a target of 1 gigabit per second to every household. Japan aims to reach a 100% fiber penetration in 2011, up from 50% in 2009. Australia is providing fiber to the neighborhood for 93% of the population at 100 Mbps, with last-mile upgrades for gigabit connectivity to follow with demand.

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[1] Federal Communications Commission, *Connecting America: The National Broadband Plan* (2010) (*hereinafter National Broadband Plan*).

[2] Eli Noam, "Paying for the American National Broadband Internet Plan," *Financial Times*, Apr. 5, 2010, accessed Jan. 10, 2012, http://www.ft.com/cms/s/0/89f0b142-40e3-11df-94c2-00144feabdc0.html#axzz1j6K3u7WG.

[3] *National Broadband Plan*, 73-119.

[4] Robert C. Atkinson and Ivy Schultz, *Broadband in America: Where It Is and Where It Is Going (According to Broadband Service Providers)*, Report to the Federal Communications Commission, Nov. 11, 2009, 2nd ed., May 2011, accessed Jan. 12, 2012, http://www4.gsb.columbia.edu/null/download?&exclusive=filemgr.download&file_id=738763.

One can downplay the importance of bit throughput rates ("speed") and stress instead progress in applications and penetrations.[5] But this works only for a while. Applications and network performance are intertwined. Just a short time ago hardly anyone watched video over the Internet. Most Internet video ventures collapsed because their speed requirements were ahead of the user base. Today, that problem has declined considerably and there is room for YouTube, Hulu, and Netflix. Millions of people access their video entertainment online.[6] Netflix has overtaken Comcast as the number one video subscriber service in the country.[7] Yesterday's vision becomes today's commonplace, tomorrow's entitlement, and the-day-after tomorrow a human right.[8] Applications are of course important, but historically governments have been more successful in infrastructure with huge externalities such as roads, airports, or transmission lines, than in applications like trucking, airline service, or refrigeration.

The moderate speed goal of the NBP – in terms of pushing the leading edge of infrastructure – has been further lowered by a shift of emphasis. In several speeches in 2011 President Obama selected the wireless portions of the NBP for special emphasis.[9] The broadband priorities of the U.S. government have been focused publicly on the emerging new generation of wireless mobile and fixed phones and devices, also known as 4G or its main variant, LTE. The idea is to liberate 500 megahertz of spectrum, to auction it off to providers of 4G – presumably to mobile telecom companies who would more than double their spectrum – and to use the proceeds to create broadband connectivity for unserved areas and people.[10]

On first glance this looks ingenious and promising: strengthening rural broadband, and at no cost to the taxpayers. And to many people it also makes technical sense.[11] They believe that just as cell phones became the substitute and competitors for regular voice phones, so will wireless become the substitute and competitor for "legacy" wireline broadband. They believe that wireless will solve the problem of broadband competition. It will solve the rural connectivity problem. And it will solve the budget deficit problem that today plagues just about every country.

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[5] Blair Levin, "The Idea Behind the National Broadband Plan," presentation to the Federal Communications Bar Association, accessed Dec. 16, 2011, http://www.knightcomm.org/wp-content/uploads/2011/03/FCBA-030611.pdf; Blair Levin, "The National Broadband Plan at 1: As the Plan Grows," prepared speech, accessed Dec. 16, 2011, http://www.knightcomm.org/wp-content/uploads/2011/03/speech-draft-031711.pdf. See also other presentations available at Blair Levin, "National Broadband Plan: A Quartet for an Anniversary," accessed Dec. 16, 2011, http://www.knightcomm.org/national-broadband-plan-a-quartet-for-an-anniversary/.

[6] Stephanie Flosi, "comScore Releases September 2011 U.S. Video Online Rankings," *comScore*, Oct. 21, 2011, accessed Dec. 14, 2011, http://www.comscore.com/Press_Events/Press_Releases/2011/10/comScore_Releases_September_2011_U.S._Online_Video_Rankings.

[7] Peter Svensson, "Netflix's Internet Traffic Overtakes Web Surfing," *ABC News*, May 17, 2011, accessed Dec. 14, 2011, http://abcnews.go.com/Entertainment/wireStory?id=13619217.

[8] For example, Estonia has legislated broadband connectivity as a human right.

[9] Cecilia Kang, "President Obama Pitches $18 Billion Wireless Broadband Plan," *Washington Post*, Feb. 10, 2011.

[10] *National Broadband Plan*, 84-85.

[11] James N. Barnes, "Strengthening Rural America's Position in the Global Broadband Adoption Race," *Choices: The Magazine of Food, Farm, and Resource Issues* 25, no. 4 (2010), accessed Jan. 10, 2012, http://www.choicesmagazine.org/magazine/article.php?article=158.

Therefore, when it comes to the future role of wireless, everyone wants the answer to be "yes." Governments – because this makes it possible to claim success in bringing broadband to rural areas, and in creating competition. Telecom providers – because it will reduce the regulatory burden on them, and also hopefully give them more spectrum. Startups and technologists – because it provides opportunities for new applications. There are not many skeptical voices. This article is one.

Let us look at the elements of the mobile wireless strategy. First, will it happen? Second, will it do the job of spreading next-generation broadband? Third, is it future-proof?

First, will it happen? Let's look at the spectrum issue. Where would the new spectrum come from? Partly from several existing allocations and governmental users, though whether this will actually materialize must remain in doubt because each of these uses has its fierce advocates. In the National Broadband Plan there is no attempt to go after big slices of government spectrum, even where it is largely technologically superseded, such as domestic radar outside of perimeter defenses.[12] A second part of the new spectrum for mobile communications would come from other mobile uses, especially from satellite mobile service, which has not lived up to expectations.[13]

Most of the remaining spectrum (120 MHz) would hopefully come from existing TV broadcasters, who would voluntarily give up all or some of their over-the-air spectrum, attracted by the carrot of an unspecified slice of the auction revenues and goaded by the stick of unspecified spectrum user fees. The imposition of user fees, for the first time, would make broadcasters pay directly for their use of spectrum frequencies. (The idea is also floated about to earmark these revenues to public broadcasting. But that is politically far-fetched. Earlier in 2011 the House of Representatives voted to defund NPR's meager $40 million annual budget.[14] Conservative Republicans are unlikely to change course and offer billions of off-budget dollars to liberal public broadcasters.)

But will this voluntary transfer happen? Unless financially imperiled, most telecommunications broadcasters have no intention to voluntarily surrender what they have come to consider their spectrum patrimony, or be pushed to yet another band or channel. They would demand the assignment of a new channel of comparable quality. The National Association of Broadcasters has come out in opposition, arguing that the FCC plan (shutting down channels 31-51) would "threaten and devastate the industry."[15] The plan would close down, it is claimed, 672 full-power stations, plus over 4000 low-power stations. Some could be relocated to vacant slots but hundreds could not.[16] Some broadcasters may give up a slice of their spectrum, since with digital broadcasting they need

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[12] Eli Noam, "Curb In-Air Delays for Free," *Financial Times*, Dec. 17, 2007, accessed Jan. 10, 2012, http://www.ft.com/intl/cms/s/0/1f124c7e-acd8-11dc-b51b-0000779fd2ac.html#axzz1j6K3u7WG.

[13] Jaejoo Lim, Richard Klein, and Jason Thatcher, "Good Technology, Bad Management: A Case Study of the Satellite Phone Industry," *Journal of Information Technology Management* 16, no. 2 (2005): 48-55.

[14] Jennifer Steinhauer, "House Votes to End Money for NPR, and Senate Passes Spending Bill," *New York Times*, Mar. 17, 2011, accessed Dec. 15, 2011, http://www.nytimes.com/2011/03/18/us/politics/18congress.html.

[15] National Association of Broadcasters, "Promoting Spectrum Policies that Serve the Public," accessed Jan. 11, 2012, http://www.nab.org/advocacy/issue.asp?id=2025.

[16] National Association of Broadcasters, *The Potential Impact of the FCC's National Broadband Plan on Broadcasters and Viewers*, working paper, July 2011, accessed Jan. 11, 2012, http://www.nab.org/documents/newsRoom/pdfs/072511_spectrum_presentation.pdf.

less spectrum to stay in the single-channel business. Perversely, the kind of broadcasters most likely to sell or lease their spectrum frequencies are those who operate rural TV stations with small audiences. But in those areas spectrum is not scarce. In contrast, in the metropolitan areas where 4G use would require significant spectrum, broadcasters are less willing to sell.

Broadcasters still directly service about 15% of American households (and many more over cable), and are the primary means by which candidates for Congress reach their constituents. Thus Congress will not easily approve an involuntary displacement of free (i.e. advertiser supported) broadcasters or a high spectrum usage fee unless their rural constituents benefit substantially. It is therefore being argued that the reallocation of spectrum would make a positive contribution to a budgetary deficit reduction. The figure $28 billion is frequently mentioned.[17] However, any calculation of net proceeds needs to subtract the pay-offs to broadcasters for their "voluntary" relinquishment of their spectrum, the cost of potential clearing of other channels and bands where no unoccupied channels exist, the tax deductibility and amortization of the spectrum licenses by their new holders, as well as the potential need to support poor TV viewers when they are forced to receive over-the-air channels on vastly different bands.

And of any truly incremental revenues, only a portion would actually go to broadband infrastructure[18] – a one-time $5 billion allocation for expanding rural 4G wireless. Virtually nothing would go towards fiber or cable infrastructure upgrades, or to an upgraded traditional copper-based DSL. $9.6 billion would go to cut the federal deficit (not counting the above-mentioned offsets).[19] An additional $10.7 billion would go towards a public safety network, of which about one third would pay public safety users to vacate their spectrum for 4G use. Only that third can be counted as a contribution towards broadband. In other words, a major struggle with TV broadcasters in the name of broadband Internet will result, under the best of circumstances, in generating only $8.2 billion towards infrastructure, all of it for 4G wireless. This does not make it a wrong policy – it is just not one that makes a big financial difference.

The second question to address is whether the mobile wireless approach will do the job of creating broadband availability for rural America. And here, too, one must be skeptical of whether this is

[17] Olivier Sylvain, "The New Spectrum Scarcity," *Concurring Opinions*, Sept. 16, 2011, accessed Dec. 15, 2011, http://www.concurringopinions.com/archives/2011/09/the-new-spectrum-scarcity.html. See also Marc Martin and Marty Stern, "White House Jobs Bill Includes Spectrum Auction Plan," *TMT Law Watch*, Sept. 13, 2011, accessed Dec. 15, 2011, http://www.tmtlawwatch.com/2011/09/articles/white-house-jobs-bill-includes-spectrum-auction-plan.
[18] The White House, "President Obama Details Plan to Win the Future through Expanded Wireless Access," Feb. 10, 2011, accessed Jan. 11, 2012, http://www.whitehouse.gov/the-press-office/2011/02/10/president-obama-details-plan-win-future-through-expanded-wireless-access.
[19] This raises another question, though not one of communications policy: should the nation sell off long-term assets in order to fund current consumption? Is this not like eating one's seed corn? See Eli Noam, "Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access," *Journal of Law and Economics* 41, no. S2 (1998): 765-790.

enough.[20] The performance of 4G as a broadband platform is modest and will be soon insufficient, as will be shown below.

Moving more spectrum to mobile and fixed wireless users is a laudable goal and deserving of support. But it is hardly a national broadband push. It is mostly a mobile enhancement. Its main contribution would be to improve coverage for every smartphone user in the country with higher data speeds, to make some base-line connectivity broadband ubiquitous geographically, and to create competitive alternatives to the existing cable-telco broadband duopoly. These are important accomplishments. But they do not solve the rural broadband problem.

Promoters of the 4G wireless claim that it would reach speeds of up to 300 Mbps.[21] More sober projections speak of 13 Mbps.[22] Even this number is unrealistic, as will be discussed below. And if it were to perform at 10 Mbps, it would still reach only a fraction of the speed of wireline alternatives. In comparison, fiber supports today 150 Mbps and can easily be upgraded to gigabit speeds as demand emerges.[23] Cable's DOCSIS 3.0 modem service runs at over 50 Mbps and can readily reach 200.[24] Even DSL, using slightly improved telephone networks, can reach in newer versions over 20 Mbps.[25] In other words, fiber and cable are 20 to 100 times as fast as optimistically projected 4G rates, and DSL is about twice as fast – and they have decent headroom to further raise their speed, as will be shown. If millions of people were to stream movies over wireless, the networks would come to a crawl, unless one would add huge amounts of spectrum (unavailable) or a very large number of cell sites (expensive and environmentally unsound).

Let us do a simple back-of-the-envelope calculation. Suppose we succeed in liberating new spectrum totaling 300 Megahertz to 4G. Each cell site could use one-sixth of these frequencies without interfering with its neighboring cell site. (The allocation of non-interfering frequency groups to adjoining cell sites is one of the main principles of cellular technology). Furthermore, duplex (2-way)

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20 This conclusion is not based on lack of enthusiasm about the wireless medium. The author has been a long-time wireless enthusiast as a licensed Radio Amateur, Advanced Class, and has operated mobile radio transmitters and receivers since before mobile wireless became a consumer product. Among his regular *Financial Times* publications are half a dozen favorable columns on the topic – celebrating the progress of wireless in the US (Eli Noam, "The Re-Assertion of America in ICT," *Financial Times*, June 18, 2010); advocating more government spectrum for civilian use (Eli Noam, "Curb In-Air Delays for Free"); opening up underutilized spectrum (Eli Noam, "The Third Way for Spectrum," *Financial Times*, Mar. 13, 2003 and "The Fourth Way for Spectrum," *Financial Times*, May 29, 2003); accelerating the move away from analog broadcasting (Eli Noam, "The Other Transition: Analog Switch-Off," *Financial Times*, Jan. 16, 2009); and identifying the superiority of mobile-based TV (Eli. Noam, "Coming Soon: Mobile, Immersive, Interactive Entertainment," *Financial Times*, July 17, 2009).

21 Michelle Donegan, "LTE Hits 300 Mbit/s," *LightReading*, Feb. 6, 2008, accessed Dec. 19, 2011, http://www.lightreading.com/document.asp?doc_id=145112.

22 Brian Nadel, "4G Shootout: Verizon LTE vs. Sprint WiMax," *Computerworld,* Feb. 3, 2011, accessed Dec. 19, 2011, http://www.computerworld.com/s/article/9207642/4G_shootout_Verizon_LTE_vs._Sprint_WiMax?taxonomyId=79&pageNumber=3.

23 Sean Buckley, "Verizon Debuts 150/35 Mbps FiOS Speed Tier," *Fiercetelecom*, Nov. 22, 2010, accessed Dec. 19, 2011, http://www.fiercetelecom.com/story/verizon-debuts-15035-mbps-fios-speed-tier/2010-11-22?utm_medium=rss&utm_source=rss.

24 Cable Television Laboratories (CableLabs), "D3: World Class Speed," working paper, unknown date, accessed Dec. 19, 2011, http://www.cablelabs.com/cablemodem/downloads/docsis_30.pdf.

25 Jeff Tyson, "How VDSL Works," *Howstuffworks*, accessed Dec. 19, 2011, http://computer.howstuffworks.com/vdsl2.htm.

communications would require a channel in each direction.[26] We assume that a Hertz translates into two bits per second of bandwidth. This would mean that the 300 MHz of spectrum would enable a 2-way pipe of 50 Megabits per second. This pipe would be divided up by the several companies providing service in the area of the cell site. It would also be shared by users in the same cell site. Therefore, any time more than five people try to use the cell site area intensely at the same time – through all of the four network providers combined – the average speeds (combining uploads and downloads) would drop below the claimed "realistic" 10 Mbps (50 Mbps divided by five users). And of course many more than five people would use the cell site area if it provides their only or primary connectivity to the Internet. By way of comparison: in 2011, there were 256,920 cell sites in the United States,[27] which translates to 1197 mobile users per cell site. (Cell sites are adjusted in their geographic size depending on population and user density.) If we assume a utilization rate of 10% of users at peak usage, this would translate into 120 users per cell site. Such users would therefore divide up the new spectrum to about 420 kilobits per second per user, less than one half of a megabit per second. The only way to counteract this would be to construct a large number of additional cell sites, so that the number of "pops" (people) per site would drop. But even if there were a cell site dedicated for each single user (less than one pop per site), the speed, by the above calculation, would be only 50 Mbps. This is not a matter of better engineering, it is physics. Engineering might improve spectrum efficiency (perhaps doubling the number of bits per Hertz) and other elements, but the headroom is neither large nor cheap.

Thus, wireless is not going to catch up with wireline. Figure 1 below shows the technology trends for wireline cable (i.e. fiber) and for wireless. As much progress as wireless technology is making (the solid line), it is not gaining on wireline technology (the scatter of x-points). Wireline seems to stay roughly two orders of magnitude ahead, i.e. about 100 times as fast, while actually accelerating over wireless in recent years.

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[26] Kang.
[27] CTIA, "Wireless Quick Facts," accessed Dec. 19, 2011, http://www.ctia.org/advocacy/research/index.cfm/aid/10323.

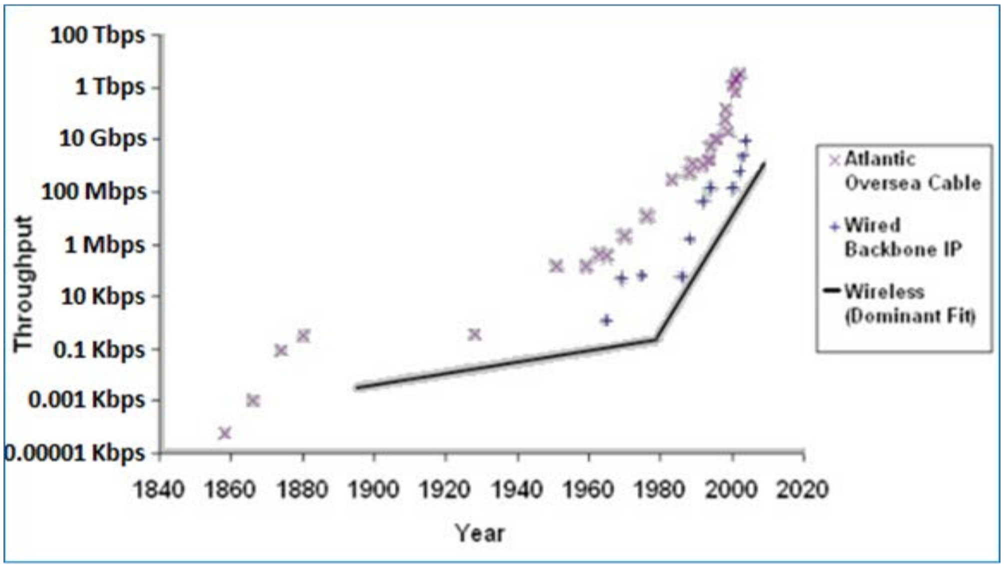

Figure 1: Wired and Wireless Data Throughput Evolution Comparison[28]

Secondly, and at least as importantly, these are engineering numbers, not economic ones. The problem with wireless is that it has negative economies for speed, i.e. to add speed becomes progressively more expensive, while wireline has positive economies for speed. If one doubles network speed for wireless one needs more spectrum. Such additional spectrum is more expensive than that previously acquired because it becomes harder to clear, it is more fought over by companies, it occupies less desirable frequency bands, and it requires bigger political and regulatory battles. One also needs more cell sites to stretch spectrum. Cell sites become more expensive as the easier locations are used and landowners become savvier. Neighbors fight cell towers for reasons of aesthetics, property values, and public health concerns. These cell sites also serve fewer people, so average costs rise. In contrast, adding to the bit rate of fiber wireline requires mostly upgrading the electronics at the endpoints, and this can be done without high transaction costs.

We thus conclude that for both wireline and wireless, average costs per bit transmission at first decline with speed – but then the trends diverge. For wireless the first units of load are expensive, then it becomes cheaper to add additional bit speeds, but eventually the higher costs of upgrades and operations kick in and average cost rises. This describes a U-shaped average cost curve. Not so for wireline, for which cost per bit keeps dropping with speed and will continue to do so for a long time.[29]

For a while we moved down that U-curve of wireless to lower costs. But this will not continue. A voice call over wireless requires about 8 Kbps. As we shall discuss below, an uncompressed HDTV

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[28] From Mario A. Amaya and Christopher L. Magee, "The Progress in Wireless Data Transport and its Role in the Evolving Internet," Working Paper ESD-WP-2008-20, Massachusetts Institute of Technology, Nov. 2008.
[29] Dave Burstein, "Wireline Costs and Caps: A Few Facts," *Fast Net News*, Mar. 16, 2011, accessed Jan. 11, 2012, http://dslprime.com/dslprime/42-d/4148-costs-and-caps.

signal uses about 3 Gbps, or about 300,000 as much, and on top of that the length of a session is higher and usage peaks are more pronounced. This changes the underlying economics. Wireless is inherently a limited resource – not as limited as people think, but still limited. It is also a shared resource in which users collide – though one could make the resource more efficient.[30]

This difference – economies of speed for wireline, and diseconomies for wireless – is crucial. It means that as we move to higher speeds it makes no economic sense for wireless to be the substitute for high-speed wireline when it comes to fixed locations such as homes and offices. It would be a waste of scarce spectrum. Wireless has its unique uses in mobile and nomadic applications, or in inaccessible areas. There, people would accept a lower speed for lack of an alternative. It might also be a tail for a wireline network, using directional microwave or over-the-air lasers. This would not require much spectrum because interference and sharing of lines would be low, while transmission rates could be high. But mobile wireless would not be a truly effective alternative platform to wireline.

There are many people who do not conceive of the need for more speed than 4G offers. This is short-sighted. First, there is the simple matter of convenience. If it takes one minute to download a movie over cable or fiber, it would take mobile wireless, at a speed that is slower by a factor of 100, one hour and 40 minutes. And even this download speed is achievable only when there is no congestion due to many other users downloading at the same time.

Second, applications will continue to rapidly grow in their needs for speed. Let us do another back-of-the-envelope calculation. An HD-quality TV picture has 1080 horizontal lines and 1920 vertical lines, i.e. 2 million pixels; 3 primary colors are required for each pixel at 8 bits/color; and 60 frames per second is the TV standard. This means that such an HDTV signal requires 3 Gbps of speed, plus some for audio. A household will realistically require a second and third channel for other broadband applications, including simultaneous uses such as TV watching, games, and channel surfing by other members of the household, or for multi-tasking. This would mean a transmission speed requirement of about 10 Gbps. Compression reduces this, of course, maybe by an optimistic factor of 100 (see discussion below), and one could reduce the frame rate to 30. This would bring down the required bit rate to 50 Mbps, though at the expense of quality and latency. (Latency, or the effect of time delays, is important for multiplayer games.)

And this is not the end for speed requirements. With TV screens becoming flatter, bigger, and cheaper, the pixel density will have to grow just to maintain sharpness. The next generation of TV resolution – "4K" – has 4096 times 3072 lines, or about 12.7 million pixels. (In Japan, the national public service TV operator NHK is developing an Ultra HDTV standard with even more pixels, up

[30] The author has proposed an economic arrangement to get rid of this inefficiency, not a property rights arrangement or a regulatory arrangement. Spectrum use would be unlicensed but users would pay a usage fee, with prices based on congestion. No exclusive license would exist. See Eli Noam, "Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access."

to 32 million).[31] There are 3 pixels per color (4 for NHK), and they will require an increase to 16-bit colors to deal with the greater sharpness. The frame rate will be at least 60 frames per second, and more likely 72 plus. This adds up to 44 gigabits per second (176 Gbps for NHK's standard). To create 3D capability requires a doubling of these figures. Two-way interactivity doubles this again. Superior audio such as 5.1 or 7.1 sound, superior digital sampling, and multiple language tracks will also require some more bandwidth. Adding all this up results in a transmission requirement of about 200 gigabits per second. Three such channels per household would bring the transmission requirement to 0.6 of a terabit (for NHK's standard, it would be 2.5 Tbps), far above today's low-megabit networks.

(This does not even include a future "immersion" TV, which would wrap around the viewer. Such a TV would permit a user to participate in the content, like a game player or a user of virtual worlds, and to be inside the imagery with its visual and auditory action.[32] Such a kind of TV is a logical extension of video games, and its emergence is entirely predictable and inevitable. In terms of bit speed requirements, it would need about another 16-fold expansion just to increase the horizontal and vertical angles. This would bring it, uncompressed, to about 8 terabits per second. This is about 3 million times as much as the speed of 4G under National Broadband Plan speed projections, and about 18 million times if 4G is more realistically utilized and thus slowed down.)

Obviously, all of these numbers will be squeezed by compression and other techniques. But this is the reference point, the gold standard from which engineering must artfully whittle bits away to fit the narrower channel. Today, MPEG-2 compression ratios are about 15-30. MPEG-4 compression ratios are about 50.[33] But compression does not work as well for live events, interactive competitive games in which speed is important, or for transmissions in which there is a lot of fast action, such as sports. Its lossiness reduces picture quality, and it costs money to compress and decompress in terms of more advanced hardware. But even if we compress and reduce bandwidth by a presently futuristic factor of 1000, one would still require 600 Mbps per household for the 4K generation of TV.

From today's perspective there might not be much of an imminent consumer demand for such television service. But that is also what people said when color TV began to supplant black and white, when 1080 lines of HDTV doubled the 525 lines of the NTSC standard, when DVDs replaced VCRs, or when cable TV introduced twelve channels instead of the four or five over-the-air signals. Viewers get used to higher quality and quantity almost immediately and they never go back. This is part of a historic trend on increasing "bit-consumption" per second, which is depicted in the graph below.

31 Your Dictionary, "Ultra-HD - Technical Definition," accessed Dec 16, 2011, http://computer.yourdictionary.com/ultra-hd.
32 Eli Noam, "If Fiber is the Medium, What is the Message? Next-Generation Content for Next-Generation Networks," *Communications & Strategies*, special issue (Nov. 2008): 1-15.
33 Kane Computing, "Compression Ratio Rules of Thumb," working paper, unknown date, accessed Jan. 11, 2012, www.kanecomputing.co.uk/pdfs/compression_ratio_rules_of_thumb.pdf.

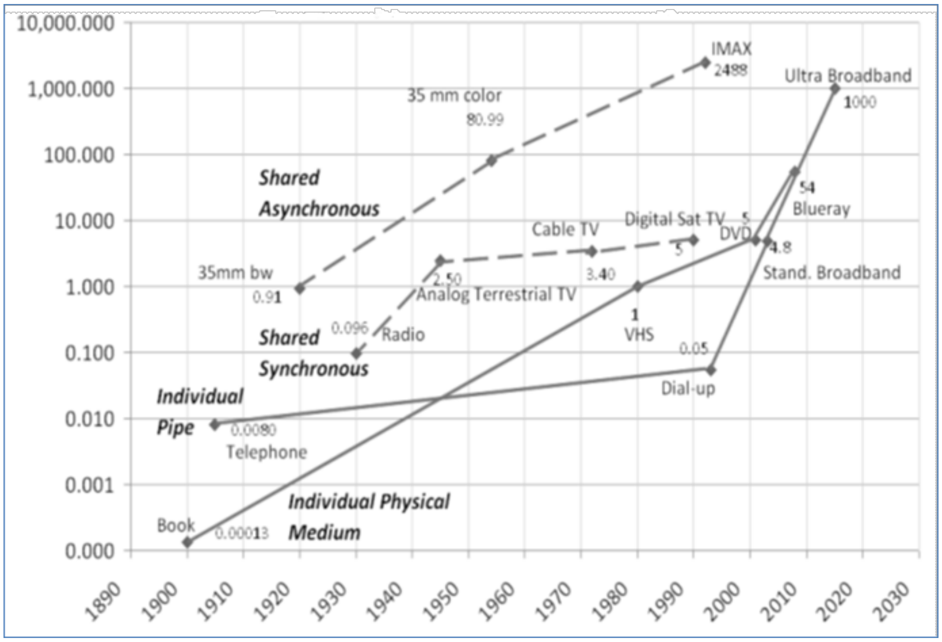

Figure 2: Bit Richness of Different Media per Second[34]

Thus, we should not underestimate the continued push towards superior video quality. The National Broadband Plan, too, mentions that transmission speeds of broadband have been rising at the rate of 20% per year.[35] This is a good reminder that we should not fashion national policy on assumptions of a static TV.

There are other dimensions, too. First, the cost to users. Because of the relative scarcity of spectrum, mobile 4G broadband service would be more expensive than wireline services, when used as a way to match high demand with limited supply. Satellite-based broadband internet, even in its forthcoming next generation, is even more expensive.[36] And there will be no savings in hardware because people will not do their taxes or type their resumes on a smartphone, so they would still require a computer or an advanced tablet device.

Second, there is a cost to taxpayers. From the taxpayer's perspective, 4G wireless coverage would also be more expensive than DSL for large parts of the country. This may be surprising, but it is shown by the FCC itself in a map provided as part of the background to the National Broadband

[34] From Eli Noam, "If Fiber is the Medium, What is the Message?: Next-Generation Content for Next Generation Networks."
[35] *National Broadband Plan*, 20.
[36] SatelliteInternet.com, "High Speed Internet," accessed Dec. 19, 2011, http://www.satelliteinternet.com/high-speed-internet.

Plan.[37] The map shows that for the western and northeastern parts of the country, closing the broadband gap by means of DSL would be cheaper than doing so with 4G.[38]

Third, there are restrictions on users. The inherent limitations of wireless communications mean that their use would be more "managed" by the network operator to keep data flowing. In other words, the openness of the Internet, protected through rules of net neutrality[39] (which are also a priority for the Obama Administration), would be harder to sustain in the more limited wireless 4G environment because the network operator will inevitably have to prioritize some types of communications over others. The FCC rules on network neutrality, for example, differentiate between wireline and wireless network providers, giving the latter more flexibility in network management.[40]

Thus, we should not expect rural areas to sit quietly and use their little 4G mobile screens or tablets while their metropolitan brethren enjoy 2-way, 3D, 4K, 5.1 sound, and 6-foot screen televisions. Would rural areas accept for long the 4G mobile communications as their broadband platform – at a lower speed, higher price, and with less openness? At first, it would of course be an improvement for those who currently have no broadband access at all, and would provide competitive alternatives to others. This would be welcomed with open arms. But soon, the reality of a second-rate quality of connectivity will sink in. And when market-based supply is not forthcoming, due to cost and population density, it leads to political solutions for upgrading the service level to match that of metropolitan areas. Thus, 4G wireless is only a temporary substitute.

Already, most rural households are not dependent on wireless for broadband. A majority of such residents are passed by cable TV which enables much faster speeds, and still more rural households have a phone connection.[41] Given the past trend of rural telecom and cable, these wireline connections will be upgraded and will reach most rural households that are already wired. This does not require green-field construction. This leaves out only those relatively few homes that are not connected to any communications network, yet have electric power. Their problem can be dealt with by fixed wireless, provided by entrepreneurial WISPs (wireless Internet service providers) and their high-speed directional microwave service, without such a tiny tail wagging the rest of the country.[42]

Why then not move the national effort to fiber (with possible tails of coax, fixed wireless, or over-the-air lasers), which is future-proof, in contrast to wireless? The problem is that the federal budget

[37] A current version of this map is found at the NBP website. Broadband.gov, "Broadband Maps," accessed Sept. 2, 2011, http://www.broadband.gov/maps/availability.htm.
[38] The FCC map probably ignores the potential of fixed 4G in rural areas, which could provide higher speeds at a lower cost than DSL, and is often operated by independent wireless Internet service providers, the so-called WISPs. They often use license-free bands in low density areas where spectrum is more plentiful, thus not requiring costly relocations of existing users.
[39] "Times Topics: Net Neutrality," *New York Times*, Dec. 22, 2011, accessed Jan. 11, 2012, http://topics.nytimes.com/topics/reference/timestopics/subjects/n/net_neutrality/index.html.
[40] Matthew Lynley, "FCC Lays Down Net Neutrality Rules, Wireless Providers Exempt from Some," *Mobile Beat*, Dec. 21, 2010, accessed Dec. 16, 2011, at http://venturebeat.com/2010/12/21/fcc-net-neutrality-is-a-go/.
[41] Atkinson and Schultz.
[42] Jacob Richard, "The Advantage of Wireless Internet Service Providers or WISP," unknown date, accessed Dec 17, 2011, http://ezinearticles.com/?The-Advantage-Of-Wireless-Internet-Service-Providers-Or-WISP&id=6742049.

deficit does not permit the funding of a national fiber or rural network upgrade initiative. And the key telecom incumbents like to focus on national wireless rather than on commercially less attractive rural wireline upgrades.[43] With no public money to spend, this leaves the government to fall back on an off-budget currency – spectrum allocations – to advance its goals, and it shapes its preference to the wireless platform, despite a rhetoric of platform neutrality.

We should therefore engage in a constructive discussion on how to upgrade rural networks beyond the lower-quality 4G connectivity. And researchers need to create a stronger knowledge base for the funding magnitude required.

For fiber, the National Broadband Plan presents numbers that are so huge as to serve as deal-breakers – about $660 billion total, or about $6000 per household. The high cost cited in the NBP, whose derivation could not be found by the author in the NBP report or its technical papers,[44] seems to be based on 100% penetration by new fiber. This is unrealistic if one defines the task as upgrading 95% of existing phone and cable coax connectivities, subtracting the 20% of homes already passed by fiber, and the potential of fixed wireless or laser tails for rural areas.

Providing more spectrum for 4G is a laudable goal and should be discussed on its own merits. But such a transfer from one industry and application – broadcasters and over-the-air TV – to another industry – telecom and mobility – should not be advocated politically as a pro-rural policy, when that extra spectrum is mostly important to metropolitan areas. It is not a major broadband initiative if only $5 billion to $8 billion is allocated to that purpose and provided just once, under the best of circumstances. It should not be considered a wise deficit-reduction policy when we sell scarce assets to fund current consumption, and where the net contribution to the budget will be probably much lower than hoped. And it should not be expected to solve rural America's broadband needs.

Thus, wireless as a strategy to spread broadband is a short-term strategy. It is likely that within twenty years virtually all American households will use bandwidth well above 200 Mbps. Much of this will be provided on a commercial basis, but some will have to be generated by a variety of public support policies. In twenty years there will be fiber, coax, or focused wireless/optical connectivity pretty much wherever there is copper today, using many of the same rights of way, utility poles, and ducts. And people will then wonder how today we thought that 500 kbps would be enough – just as we wonder today how our parents or grandparents got along on three or four TV channels.

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[43] Richard Bennett, "Rural Broadband: Are We There Yet?" working paper, the Information Technology & Innovation Foundation, May 2011, accessed Jan. 12, 2012, http://www.itif.org/files/2011-rural-broadband.pdf.
[44] See also Federal Communications Commission, "Calculating the Investment Gap," Technical Paper No. 1, Ch. 3, Omnibus Broadband Initiative, Apr. 2010, accessed Jan. 12, 2012, http://download.broadband.gov/plan/the-broadband-availability-gap-obi-technical-paper-no-1-chapter-3-calculating-the-investment-gap.pdf.

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