Re-Inventing Wires:

The Future of Landlines and Networks



National Institute for Science, Law & Public Policy
Washington, DC

"The Internet has become one of the defining technologies of our society. It is our central medium for commerce and communication—but more importantly—for our public discourse, engagement, and democratic governance. However, it has been hijacked by the commercial motivations that have come to re-define and constrain the availability, quality, content, and media of high-speed access in the United States."

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The Future of Landlines and Networks

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early online version

The Internet has become one of the defining technologies of the modern world. Why has America, the Internet's creator, become one of its most impoverished users among all the developed nations in terms of the proportion of its people with Internet access and the speed and quality of that access? Why has the Internet been growing in an inefficient, insufficient, and unsustainable direction? Is wireless access being oversold? Why are existing copper phone lines being abandoned when current protocols allow them to deliver data at gigabit speed? This report seeks to address these questions and propose answers and solutions. It explores the historical forces at play, the emerging technologies that will define the future of landlines and networks, and the public policy choices and opportunities that confront us today.

"The history of U.S. communication infrastructure increasingly supports the proposition that it is unrealistic to expect private monopolies, duopolies, or triopolies—regulated or unregulated—to make the long-term investments necessary to build the enduring and sustainable public broadband fiber information highway that the country needs. Corporations will invariably seek the cheapest, quickest, and most profitable path, which has led to the current emphasis on wireless."

Foreword

The paper you are about to read provides a beacon of light, a reasonable voice for our turbulent world.

It analyzes the current state of modern communications and clearly explains the benefits and accessibility of national wireline systems that can guarantee *for everyone* a superior foundation of Internet access, unequalled connectivity speed, safety, privacy, security, resiliency, energy efficiency and long-term sustainability.

This paper sets the record straight and fills our current information vacuum, offering consumers, business leaders and policy makers the critical facts they need to rethink a more intelligent and secure future with reliable, secure, wired communications more resilient to storm, flood and fire, and reducing the enormous carbon foot print from the present wireless approach. It also demonstrates why the mistaken upcoming 5G frenzy, with its millions of small cell antennas, destined to clutter all neighborhoods and public right-of-ways, is dangerous, wasteful and unnecessary.

At a time when we are fortunate, thanks to the internet, to have ready access to international medical and scientific reports demonstrating the carcinogenicity and neurotoxicity of ubiquitous microwave radiation emitted by wireless technologies, *Re-Inventing Wires: The Future of Landlines and Networks* explores a wide path of opportunity for establishing far safer and exceptionally reliable Internet connectivity that we all want and need.

Buried across North America are large networks of copper wire and state-of-the-art optical fiber that provide the bedrock for a health-safe national communication system of the future. For too long we have been misled, turned astray by corporate propaganda, by compromised politicians and by our own technical ignorance into accepting inferior, problem-ridden and expensive wireless systems. Importantly, wireless systems also have negative economies for speed, such that adding speed becomes progressively more expensive, which then requires more spectrum and cell sites.

Capitulation to imprudent wireless mania has saddled America with vulnerable and monopolistic communications services, and technological inferiority, leaving many sectors unserved, and widening the 'digital divide'. As you will read in *Re-Inventing Wires: The Future of Landlines and Networks*, the U.S. has fallen to #17 of 20 among developed countries in fixed broadband penetration as a percentage of the population.

Nationwide, locally built and financed networks that provide optical fiber-based Internet access to the premises, both metropolitan and rural, are do-able. Wired systems are comparatively far more cost-effective, and are approximately 100x faster than wireless systems. Furthermore, fiber to the home avoids the potentially disastrous outcome of populations rendered sick and disabled by acute and chronic exposure to wireless radiation pollution.

Wireline municipal broadband services, currently operating in such places as Longmont, CO and Chattanooga, TN, are demonstrating the monumental economic benefits of high-speed wired systems that pay for themselves, bringing tremendous economic growth. For example, in Chattanooga, as Dr. Schoechle points out, a $220 million investment has yielded $865 million in economic growth for the city. And in Longmont, a new municipal broadband system there provides access to fast, inexpensive $49/month 1 Gigabit service, at a fraction of the cost others pay in many other cities today, an extremely attractive offering to businesses and residents alike. *Re-Inventing Wires: The Future of Landlines and Networks* builds the case that combining fiber access systems with electric

(continued on next page)

power distribution systems, as in these two situations, can provide many synergistic advantages and opportunities for states and communities.

Re-Inventing Wires: The Future of Landlines and Networks is a blueprint for an imperative technological renaissance, and a re-envisioning of national communications infrastructure. Once communities at all levels—rural, town, city and nation—realize that they must assume local responsibility for creating safe and economical high-speed Internet access for all of their citizens, this renaissance will unfold. A sturdy, wired communication infrastructure, using wireless only as an adjunctive technology, has vast potential to become the electronic commons essential to commerce, education, jobs, the economy, social cohesion, communications and international competitiveness.

This paper presents indisputable technical, economic and sustainability reasons why wired technologies portend the best and highest future. I wish you intriguing and profitable reading.

Frank M. Clegg
Past President, Microsoft Canada
CEO, Canadians for Safe Technology

Prologue

In the fall of 2000, I had occasion to visit Sonoma County, California, to sample wine and enjoy the rugged beauty of the wild coastline. One afternoon, as I was returning to my lodging near Mendocino, I explored a remote and seldom-traveled winding backroad across wooded coastal hills that separate the inland valley vineyards from the coast.

Rounding a curve on the narrow byway, I came across a flagman with orange vest and hardhat working with a small crew digging a trench along the road. When I inquired about the purpose of the project, I was told that the crew was laying fiber-optic cable. Pressing further, I asked where such a cable could be going in such a remote and sparsely occupied area. The flagman replied that the crew was laying a portion of a new "information highway." From Silicon Valley, the fiber traversed Sonoma County, winding past the vineyards and through the coastal hills and redwood forest, to Point Arena, and then across the Pacific Ocean to Asia.

I could not but be astonished by the contrast between the serene woodland scene in front of me and the image of a major broadband electronic highway that would link terabyte data traffic to the other side of the planet. As the work crew was carefully covering the trench, leaving the scenic and secluded county road close to its original condition, I found it staggering to imagine that this tranquil, barely-paved pathway before me would soon become an essential link on a light-speed thoroughfare to China and beyond—and virtually unknown and invisible to those using it.

The following inquiry, inspired in part by the above experience, seeks to explore these unseen highways and byways—that we may better understand and shape where they shall take us.

—Tim Schoechle, PhD
Boulder, Colorado – 2018

This report asserts that first and foremost, the public needs publicly-owned and controlled wired infrastructure that is inherently more future-proof, more reliable, more sustainable, more energy efficient, safer, and more essential to many other services. Wireless networks and services, compared to wired access, are inherently more complex, more costly, more unstable (subject to frequent revision and "upgrades"), and more constrained in what they can deliver.

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"We advocate for the essential nature of landline service and for high-speed optical fiber-based Internet access to all as a basic locally-governed community service that is secure, reliable, sustainable, and affordable—comparable to water, sewer, electricity, streets and similar vital public utilities."

Executive summary

The Internet has become one of the defining technologies of the modern world. Why has America, the Internet's creator, become one of its most impoverished users among all developed nations in terms of the proportion of its people with Internet access and the speed and quality of that access? The answer arguably relates to the failure of private economic markets to provide infrastructural public goods. It is time to acknowledge that it is unrealistic to expect private capital, in this case, to build what the public needs.

How did this situation come about? …and, what can we do about it? This report, *Re-Inventing Wires: The Future of Landlines and Networks*, offers a detailed review and analysis of the complex landscape of telecommunications today. It covers the political and regulatory history that has brought us to where we are, with the present aggressive industry rush for more and more wireless devices and smartphones, hyper-commercialization, and media concentration, while leaving the public deprived of basic, fast, reliable, and affordable wired access to the Internet as an essential public utility. This wireless push is now seeking to preempt local governance so as to greatly densify antennas throughout communities, and promote a new 5G (5th generation) network, while 4G wireless has not yet been built out.

Purpose of this report

The purpose of this report is to inform the public and policy makers at all levels about the continuing value of wireline networks, the role of those networks in our national communication future *vis-à-vis* wireless networks, and to stimulate discussion about why the use of and investment in wireline is vital to America's basic infrastructure for the 21st century.

This report examines the technology of both wired and wireless communications and key issues and failures of communication law and policy including data privacy, security, net neutrality and equal access, antitrust, monopoly, energy, and public health and safety. We advocate for the essential nature of landline service and for high-speed optical fiber-based Internet access to all as a basic locally-governed community service that is secure, reliable, sustainable, and affordable—comparable to water, sewer, electricity, streets and similar vital public utilities.

With the spectacular growth and popularity of wireless devices over the past two decades, some believe that wired landlines[1] are obsolete. Nothing could be further from the truth. The notion that landlines are a thing of the past, and that the future lies with an Internet based on widespread wireless access,[2] fails to understand the business, regulatory, and public policy factors that have privileged wireless over wired, the limitations of wireless, and the dramatic advances of the wired technologies on which wireless networks and services vitally depend.

Re-envisioning the future of landlines and networks

This report challenges this wireless vision and exposes the myths, misconceptions, promotional hype, legislative failures, regulatory bias, and industry-driven politics that have overinflated public expectations of a wireless future and undermined investment in wired infrastructure. The report explains the dramatic advances that have occurred over the last few years in the technology of wires and wired networks—both optical fiber and copper—which have essentially reinvented wires.

Introduction and context

The report begins with an introductory first chapter tracing a brief history of both wired and wireless communication including some of the basic technology and terminology. The chapter situates these technologies in the social, economic, and political contexts of their times.

Wireless vs. wired

The second chapter provides a more detailed technological description and comparison among wired and wireless networking methods; identifies the basic features, advantages, and disadvantages of each; and shows how they are intertwined. The chapter also addresses the strategic regulatory and business factors at play historically and contemporaneously shaping the application and growth of these technologies, and shows the essential role of the wires.

Internet of things

The third chapter explores the *Internet of Things* (IoT), one of the newest and most promising, yet problematic themes that has emerged in popular and technical media during the past few years. In short, IoT is the idea that essentially every device or object in our environment can be connected to the Internet and thus interconnected with everything else. The promises and pitfalls associated with IoT are identified, including the notion of *smart cities*, connected cars, automatic *machine-to-machine* (M2M) communication, issues of privacy and security, socio-technical risks, social and behavioral issues, and potential risks to public health from electromagnetic fields and from the proliferation of the new media devices. The chapter explores IoT as one of the dominant popular themes today about how communications will be applied in society, and explains the risks and limitations as well as how the IoT should be conceptualized within a wired/gateway frame of reference, even though it may engage wireless devices.

The politics of the wires

The fourth chapter describes the regulatory history and political background of communications. The *Telecommunications Act of 1996*, revising and building on the *Communications Act of 1934*, set out with the ambitious and unrealistic intention to compel competition in wired and wireless markets while at the same time deregulating them. The law took the approach of *regulation by market* (e.g., cellphone, cable, landline, etc.) rather than by *service* (e.g., voice, video, data, etc.), based on the flawed assumption that lack of competition in one market could be compensated for by competition from other markets offering similar services. The chapter examines the ironic consequences of this approach, showing how deregulation led to the reconsolidation of communications monopoly providers dominated by a *triopoly* that has come to be more limiting and detrimental than the original AT&T Bell System monopoly that was broken up in the mid-1980s.[3] This historical perspective shows why the wires are inescapably a public utility.

Reinventing the wires

The fifth chapter describes new physical and signaling technologies of the wired communication methods or media mentioned in earlier chapters, including copper phone pair, DSL, cable, Ethernet, and optical fiber, and examines how these now offer advanced performance and features beyond what was once imagined—creating a renaissance in copper and fiber. As a result, the distinction between *technology* and *services* has become more ambiguous as they both become folded into various parts of the "protocol stack" and new features/characteristics are

added and new services/applications are enabled. A development of particular importance has been the introduction of low voltage DC power delivery over Ethernet cabling (POE) and the merging of Ethernet and USB in ways that can revolutionize home and building wiring as well as improve the devices that plug in to it.

Energy use and efficiency of communications

Chapter six addresses issues of energy use and efficiency of communication, rapidly-growing problems for wired and wireless networks and products as the centrality of the Internet in our lives and our economy continues to increase. Energy consumption in communication networks is growing at an unsustainable rate—possibly doubling every two years—with the biggest culprits being data centers and (most significantly) wireless access networks. New approaches to this problem are examined.

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Policy failures, issues, and business strategies

Chapter seven addresses major policy failures, issues, and business strategies surrounding the institutionalization of communication infrastructure. The chapter looks at national policy and the roots of various problems and failures, and explores the reasons wired access networks, such as community fiber are, and are always likely to be, superior in performance to wireless access networks—and should be considered public utilities. The chapter also examines the politics and corporate business issues surrounding deliberate systematic blocking of municipal and community fiber, and the industry's political and regulatory push for wireless access networks—particularly 5G—and it explains why these are bad public policy. Finally, the chapter reviews the battle for *net neutrality* and argues in favor of this concept, which is critically important to society and enjoys overwhelming public support.

Conclusion and recommendations

The report concludes with an eighth chapter that summarizes key observations and conclusions, examines possible futures and trends, and offers specific recommendations. The report offers a three-part strategy. First, it recommends breaking up the monopolistic and anticompetitive triopoly that dominates our Internet provision, particularly by enabling a national build-out of publicly owned and controlled community broadband fiber networks that will bring fiber as close to users as possible as basic public wired infrastructure. Secondly, it recommends preserving, renewing, or expanding the use of existing (or new) copper wiring (and rights-of-way) wherever appropriate as a *tail* in the access network and within homes and buildings. Thirdly, it recommends a policy of resorting to wireless access only at endpoints, primarily for things that move, or in situations where wiring is not possible or practical—but not relying on wireless for basic access.

These recommendations stand in sharp contrast to present policy rhetoric promoting dependence on wireless access networks, such as 5G—and to reliance on privatized or semi-privatized (e.g.,

"These recommendations stand in sharp contrast to present policy rhetoric promoting dependence on wireless access networks, such as 5G—and to reliance on privatized or semi-privatized (e.g., public-private partnerships) for Internet access, whether wired or wireless."

public-private partnerships) providers for Internet access, whether wired or wireless. Rather it is recommended here to shift the policy discussion back toward Internet as a basic public utility and toward a re-commitment to its founding principles of net neutrality and equal access.

Summary of conclusions

This report asserts that first and foremost, the public needs publicly-owned and controlled wired infrastructure that is inherently more future-proof, more reliable, more sustainable, more energy efficient, safer, and more essential to many other services. Wireless networks and services, compared to wired access, are inherently more complex, more costly, more unstable (subject to frequent revision and "upgrades"), and more constrained in what they can deliver.

- High-speed optical fiber-based Internet access networks should be available to every community and every member with a direct hard-wired connection to every household and workplace.
- The Internet has become a basic public good vital to our society, and it should be available to all in a safe, reliable, fair, affordable, and energy efficient manner.
- Wireless access service is not an adequate substitute for wires, and should be considered adjunct to wired access service.
- Thus, in principle, community networks should be financed, constructed, and managed in a manner analogous to such public infrastructure as municipal water systems, sewers, streets, or libraries.

A final comment

The Internet has become one of the defining technologies of our society. It is our central medium for commerce and communication—and, more importantly—, for our public discourse, engagement, and democratic governance. However, it has been hijacked by the commercial motivations that have come to re-define and constrain the availability, quality, content, and media of high-speed access in the United States.

Today, we are at a turning point. The basic organizing principles of our society are at stake. The Internet is our public commons, and it must not be enclosed or walled off by private interests. As in the early days of the telephone or electricity, access must be made available to all—and in a form that is fast, affordable, neutral, sustainable, enduring, safe, fair, and just. To accomplish this, action must be taken at all levels of governance—but the roots of all political action are—and must be—local.

[1] The terms *landline*, *wireline*, and *wired* are used in their most general sense, and more or less synonymously throughout this report, although there are contextual differences. For example, *wireline* is a term from the telephone industry, with some drawing a distinction between *landlines* mounted on poles vs. those in underground conduits. These three terms stand in contrast to *wireless* that simply means radiating across free space.

[2] The wireless expectation includes primarily WiFi, smartphones and tablets, 4G LTE cellular networks, and on the promise of a superfast 5G (fifth generation) along with the coming Internet of Things (IoT) wherein all electronics (and everything else in our midst) are wirelessly interconnected.

[3] The irony here is that competition and deregulation are usually at the same end of the regulatory policy "spectrum." The *Telecommunications Act of 1996* argued to remove regulation and let the "market" rule. It ignored that competition may not develop in all markets or services. It also assumed that competition in one market would compensate for lack of competition in other markets offering similar services. Most importantly, it allowed (and unintentionally encouraged) consolidation in each market through mergers and acquisitions with lack of anti-trust enforcement or restrictions.

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1 Introduction and context

According to a recent article in *The New York Times*, about three quarters of U. S. teenagers have access to a mobile phone, most go online daily, and about one quarter use the Internet "almost constantly" (Dougherty, 2016, p. BU 5, para. 3). As recounted in the article, during a market research focus group interview of teenagers on behalf of *Wishbone*, a social media app owned by Science Inc., "…a questioner asked the group when they were least likely to be online. 'When I'm in the shower,' a girl responded. Nobody laughed, because it was barely an exaggeration." Vast numbers of young people, bonded to their mobile devices,

> …have created a growing advertising market and fortunes for apps like *Snapchat* and *Instagram*, which is owned by *Facebook*. This year companies are projected to spend $30 billion on in-app advertising in the United States, roughly double what they spent in 2014, according to eMarketer, a research company. …*Wishbone,* which is about a year old and already has about three million monthly users. Since July it has ranked among the top 30 most-downloaded social media apps in Apple's App Store, according to App Annie, a data and analytics company (Dougherty, 2016, p. BU 5. Para. 4–5).

The situation described above is not unique to young people, nor to the United States, although the apps and the way they are used vary with demographic groups. Users of mobile devices share in common a perception that their devices are connecting directly to each other and to *the cloud* somewhere over their heads in the sky. Users have little consciousness of the vast and complex wired infrastructure that carries their messages, mostly by optical fiber. Only the last few miles, or perhaps few yards, is actually wireless, and that hop is the biggest bottleneck, being the slowest and least reliable link in the chain. The wires have become as completely invisible as the wireless radio waves.

How did this pervasive wireless dependency come about? What is it costing us, monetarily and otherwise? Where is it leading us? What might we be losing and what do we need for our future? This paper explores these questions.

1.1 A brief history and context

The electric telegraph, a system for transmitting messages across distance along a wire was patented by Samuel F.B. Morse in 1837 and crossed the continent by 1861. Copper wires soon became essential to operation of the railroads and became the basic medium for all manner of commerce, news, information, and social interaction, including the telephone wiring infrastructure legacy that has until recently linked all communities in the nation, urban and rural.

Only three decades following wired telegraphy came wireless telegraphy. Soon known as "radio," it was patented in 1886 by Guglielmo Marconi, who developed it into a commercial communication system, and later into the radio broadcasting industry.[4] Both wired (telephone) and wireless (radio) technologies came to be recognized as enormously important to society. As radio and telecom technologies evolved, the technology and institutionalization of the new media were shaped in large part by public policy. In the late 1800s the International Telecommunications Union (ITU) was formed to set standards for the interconnection of national telephone and telegraph systems and to allocate the radio spectrum. In the United States, Congress passed the *Communications Act of 1934* instituting a regulatory framework for communications and establishing the Federal Communications Commission (FCC) to regulate interstate communications by wire and by radio, and later by television, satellite, and cable throughout the country.

Although telephone and radio technologies advanced rapidly, the law underlying the activities of the FCC and the roles played by the Commission were not substantially revised until the *Telecommunications Act of 1996*. The most significant revision pertained to how the Commission would deal with the merging of telephony with wireless technology—the new cellular phone industry. The 1996 *Act,* adopted in the wake of the breakup of the AT&T monopoly per a U.S. Justice Department antitrust suit, essentially placed wireless phones and what we now call broadband (Internet) services outside the regulated realm of local wired telephone access networks that were categorized and regulated as *common carriers*. This distinction has, over the past two decades, been associated with massive unintended consequences, which are a major focus of this paper.

1.2 The key issues of telecom today

Public attention today regarding communications is focused on many important and interrelated topics. These topics can be narrowed down to six, listed below. Each of these will be dealt with in this paper, particularly with respect to its relevance to the future of wired broadband. A complete list would, of course, be much longer, but this list allows an organized approach to the most pressing and defining issues. All of these issues overlap to some extent.

- Landline legacy and its value
  The existing wired infrastructure, including copper, is basic infrastructure—a public good, and a public right-of-way that needs to be preserved and maintained. Private, for-profit business interests should not be allowed to abandon or destroy this national and community asset.
- Municipal fiber and broadband access (wired technology)
  The institutionalization of municipal fiber and broadband access is an emerging national issue focusing on the public need for broadband access and the right of communities to install their own networks. Private, for-profit telecommunications monopoly corporations have obstructed community and municipal broadband network initiatives, and at the same time, have failed to develop such networks in their own systems, resulting in monopoly, scarcity, excessively high costs, and inferior service.
- Wireless technology—mobile phones and tablets, 4G LTE, WiFi, and 5G
  Wireless technology has produced popular user devices and services (e.g., mobile phones, tablets) and new signaling methods and protocols (*e.g.,* long-term evolution [LTE] longer-range cell-phone protocols and short-range premises signaling methods and protocols [*e.g.,* WiFi]). These may have value, but are not substitutes for wired access networks.
- Net neutrality and equal access
  Net neutrality is a currently active national regulatory initiative to limit the ability of carriers (internet, phone, and cable network operators) to offer preferential service to some customers over others, imposing their corporate priorities, practices, and business models on information access for our whole society.
- Privacy and surveillance
  Issues surrounding privacy and surveillance are subjects of national and international debate about the extent to which governments and corporations can, will, or do monitor and gain access to all kinds of message traffic (including metadata and content).[5] Commoditization and monetization of customers' data and behavior by an out-of-control advertising industry has become a primary economic driver of the information technology industry.
- Internet of Things (IoT)
  Internet of Things is a global emerging technology that proposes to enable virtually everything in our environment to be interconnected electronically using ever-cheaper electronics and an expanded Internet addressing scheme, IPv6. The risks and rewards associated with this technological development remain unclear.

1.3 Basic telecom infrastructure

It is clear that wireless devices and services offer value and are likely to continue to expand. At the same time, short-term business and policy decisions are being made that could be destructive of the basic wired infrastructure, which represents an ongoing value to our society and its future. Despite the spectacular growth and popularity of wireless devices over the past two decades, none of them could exist but for the wired infrastructure and technology that underlies the wireless network. At the end of the day, wireless communication can never approach the speed and reliability of wired networks.

Wireless is not a substitute for wires and can be best understood as a convenient adjunct at the end of the wire. Wireless is most needed for things that move, such as people and their cellphones, vehicles, laptop and tablet computers, etc., and is also useful to reduce the tangle of wires associated with dense accumulations of electronic instruments and appliances often found in households. Because of the convenience factor associated with the latter category of use, wireless is increasingly over-applied to a wide and increasing range of applications.

While it is correct to suggest that demand for wireless has been to a large extent driven by convenience, it has also been driven by regulatory and policy directions that have disadvantaged wired networks in the marketplace, creating a wireless juggernaut that in many respects diminishes public access and convenience while wireless providers and their allies in business and government mislead the public about the adequacy and potential of their systems.

1.4 Wires are essential

This paper is about why the nation's wired communication infrastructure at all levels—rural, town, city and nation—constitutes an electronic commons that is essential to commerce, education, jobs, the economy, social cohesion, communications, and national competitiveness. It is also about how and why this infrastructure is at risk, and about how popular beliefs, social forces, policy choices, and private business decisions threaten to damage this precious civic asset. The propagation of myths and commercial hype concerning technology can lead to mistaken perceptions in the public mind—and among politicians and policymakers—concerning what choices exist.

1.5 Wireless

Wireless cellphones, and more recently, "smart" phones, tablet computers, and other wireless devices have proved useful and popular. However, problems associated with excessive wireless use and dependency are emerging and include risks to public safety, security, and privacy; energy waste; and uncertain effects on public health. The World Health Organization has listed cellphone and other wireless radiation as a "possible carcinogen," a concern that has been validated by a recent U.S. Government National Toxicology Program study. Do we risk another lurking tobacco-, lead-, or asbestos-like health situation? Do we risk foreclosing possibilities for appropriate and beneficial low-power wireless (e.g., "energy-harvesting") devices by drowning them with excessive radio noise, constituting a form of electro-smog, or crowding out spectrum needed for valuable environmental sensor networks? Is it time to re-examine and perhaps re-adjust our headlong rush to make everything in the world wireless and connected, whether it is needed or not (e.g., wireless charging)?

"While it is correct to suggest that demand for wireless has been driven to a large extent by convenience, it has also been driven by regulatory and policy directions that have disadvantaged wired networks in the marketplace, creating a wireless juggernaut that in many respects diminishes public access and convenience while wireless providers and their allies in business and government mislead the public about the adequacy and potential of their systems."

Tutorial on Radio Waves

When a steady direct electric current (DC) passes along a wire, it creates a steady magnetic force field around the wire. If the current increases or decreases, the field changes accordingly. If the current reverses, the field reverses. The faster the current change, reversal, or alternation of the current (AC), the greater the field expands through the space beyond the wire. The higher the frequency of the AC, the more the field energy wants to jump out of the wire and pass through space. This is how radio waves work. Lower frequency radio waves are longer and can pass around corners or obstacles. Higher frequency radio waves pack in more energy but are confined to more line-of-sight paths. If the wire is wrapped in foil or shielded, the energy can be confined to the wire and not radiate into space. This is how coaxial cable retains its energy. Visible light is essentially a very-high frequency radio signal. X-rays are of an even-higher frequency. Microwaves are lower in frequency, ranging as low as 100 MHz (3 meters). A frequency of 10 GHz is a wavelength of about 3 centimeters. This is the range of most cellphone and WiFi communications. The proposed next generation cellphone network, 5G, tends to go to ever higher frequencies (e.g., 60 GHz and higher) with wavelengths measured in millimeters

1.6 The medium and the message

The lesson to be learned here presents a variant on Marshall McLuhan's influential comment that "the medium is the message" (McLuhan, 1964; McLuhan and Fiore, 1967). McLuhan focused on the thesis that a society's dominant media of communication, more than the content of messages transmitted, have compelling implications for how messages are received and processed by individuals, and in turn have profound effects on the character and capabilities of cultures and society more broadly. What we learn from careful study of wired versus wireless networks is that a society's or community's choice of infrastructural medium of communication exerts major influence on the choices of products and services made available to end users, and indeed, on the messages purveyed (particularly with reference to commercial influences). Infrastructure, in turn, has major implications in the long run for who we are as a society and a public. Numerous studies of the *social construction of technology* demonstrate that inventions are seldom institutionalized as the inventors and their contemporaries envisioned.[6] What will be the effects of the ubiquity of wireless media on the learning and thought processes of children and young people? What kind of social and political environments are we creating? The answers are unclear.

A great clamor is taking place to extend Internet access to all, including across the world to poor and developing nations, but what is actually offered all too often betrays the potential of the global network and falls far short of what is needed by global institutions and diverse communities. Despite the hype and the lofty stated intentions, what is actually offered and provided tends to be more of the same highly constrained, corporatized, commoditized, and hypercommercialized services, revealing the self-interested monopolistic motivations of the technology industry. Meanwhile, choices that should be made by public policy are left by default to the largesse of corporations and billionaires.

1.7 The role of telecom

It is important that issues surrounding implementation and institutionalization of networked communication infrastructure be better understood at this time of increasing dependence on the Internet and on information technology, automation, and robotics (*i.e.,* on what the National Institute of Standards and Technology [NIST] call "cyber-physical systems," NIST, 2015); of widening social and economic inequality; of disparities of income and wealth; and of a worsening digital access gap in America between the rich and the poor and between urban and rural communities—a gap characterized as the *digital divide*. Ironically, these gaps have become worse in the United States compared with most other industrialized countries and also with many developing countries. The United States has fallen in rank to number 17 of the top 20 among developed countries in fixed broadband penetration as a percentage of population (29.71 subscriptions per 100 inhabitants) (TIA, 2014, pp. 6-8). The U.S. ranking is just as bad when it comes to speed of access, according to the ITU and the OECD (Crawford, 2013, p. 271).

This report seeks to identify primary causes and possible remedies for the problems that have been identified in this chapter. It is important to build a strong understanding of the complex matrix of forces surrounding network development in order to guide public and private investment in communication infrastructure that serves to assure reliability, economic well-being, sustainability, resilience, social cohesion, and public health. The field should not continue

to be ceded primarily to the self-interest of private corporations, but include other influences including societal leaders with more diverse expertise and interests.

1.8 Scope of this report

The paper first considers major established and emerging issues in the discourse regarding wired vs. wireless network technology, including issues pertaining to market, business, regulatory, and political factors. These include investigation of the reasons for the proliferation of wireless networks and services; driving legislative, regulatory, and political factors and issues; marketing hype and consumer demand; emerging mythology and mirage of the Internet of Things; Orwellian societal implications of machine-to-machine (M2M) communication and cyber-physical systems; and the daunting cyber-security and privacy consequences of these technologies.

The paper then focuses on key technological factors that have entered the equation on both the wired and wireless side, as well as on issues affecting related industries and social concerns, such as those associated with energy. These factors include dramatic advances and important trends in wireless and mobile device technology and ever-more dramatic advances in the speed and performance of wired networks and signaling. Also considered are important, related, and emerging scientific issues including those surrounding the biological effects of electromagnetic fields.

Finally the paper considers public policy implications of technical choices in the context of crucial economic, social, and political considerations. It identifies key actors and their interests. Some of these issues include net neutrality, climate change, social equity, jobs, economic dislocation, economic development, public health, and national competitiveness. The paper draws conclusions on key points in the conflict, and offers recommendations.

"The United States has fallen in rank to number 17 of the top 20 among developed countries in fixed broadband penetration as a percentage of population (29.71 subscriptions per 100 inhabitants) (TIA, 2014, pp. 6-8). The U.S. ranking is just as bad when it comes to speed of access, according to the ITU and the OECD (Crawford, 2013, p. 271)."

2 Wireless vs. Wired

Voice telephone networks date back to the 1800s.[7] They were adapted during the 1970s, as mainframe computers came into use, to carry data using analog modem technology. In the 1980s AT&T and other international phone companies (national monopolies at the time) began to introduce digital voice and data network packet-switching technology[8] to update the infrastructure historically associated with voice telephony. The court-ordered divestiture of the AT&T Bell System in 1984 opened the door to competitive markets in data and in customer equipment. The first generation wireless mobile phone was introduced by Bell Labs in 1983.

When comparing wired and wireless communication technologies, one of the most important metrics is data rate (or *speed*). The graph in Figure 2.1 shows the relative speeds of the principle broadband access technologies in use today measured across a horizontal axis. Wired technologies are shown above the axis and wireless technologies are shown below the axis. Media represented in red are those currently in a mature state of development, blue are not yet fully deployed and standardized, and green are in a developmental stage.

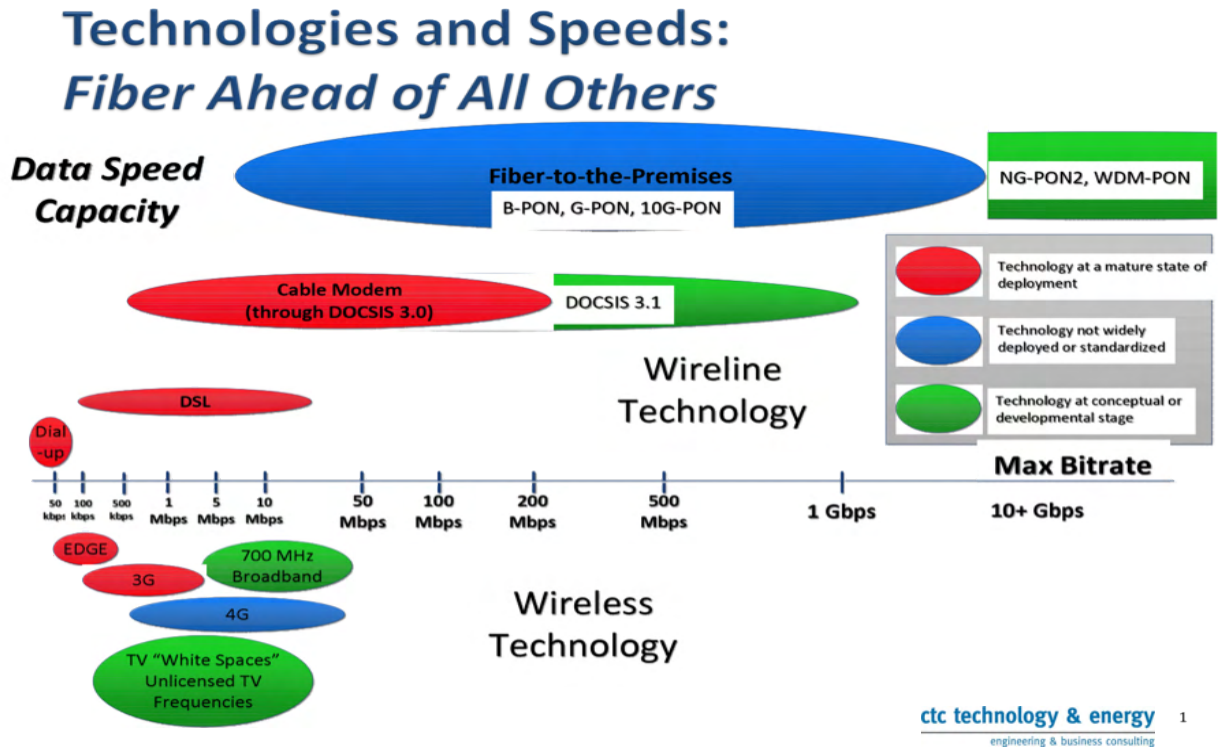


Figure 2.1—Relative data speed capacity of wired and wireless technologies

The diagram illustrates that even conventional cable TV service and telephone digital subscriber line (DSL) wireline services are generally faster than the fastest wireless, and optical fiber is orders of magnitude faster than all others (CTC, 2015). Wired and wireless technologies will continue to advance, but it is reasonable to say that wired will always be far faster.

2.1 Why speed matters

Most users experience the bandwidth capacity of transmission media in terms of speed—the amount of time required to operate various applications. What speed means in terms of services is shown in Figure 2.2 as a comparison of typical download and upload times for files of a specified size (CTC, 2015).

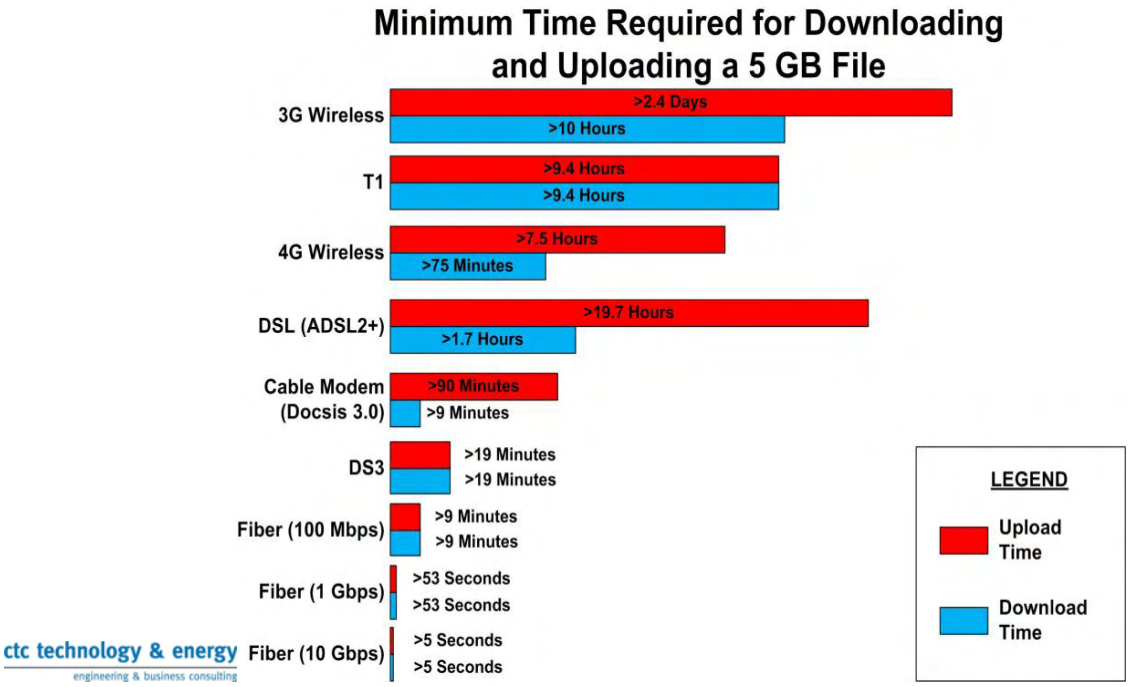


Figure 2.2—Comparison of download and upload times

Speed has implications for the user experience by way of the amount of data that can be sent to and from a user's device for a particular application in a reasonable amount of time. The importance of speed, or requirement for bandwidth, varies widely among applications (e.g., graphics, movies, sound, data), user devices (e.g., laptop, notebook, iPad, mobile phone, monitor, smartphone, etc.), and other factors (e.g., need for user interaction, response time, etc.).

Accessing data and applications on small-screen devices with small or no keyboards inherently limits the user experience. For portable devices with wireless connectivity, graphics must be lower resolution and displayed in a more compact form than would be optimal for a larger higher-resolution screen. Keypads must be tiny or crammed onto the same display space. Normal typing is not practical, and applications must make use of touch-screen, pointer, voice-prompting, interactive voice technologies, or other forms of interaction. Access tends to be highly asymmetric, with upload speed requirement being relatively modest. Also, these devices must be adapted for use in high noise or high light-level environments. Bandwidth tends to be more limited and more expensive than for non-mobile wired devices. These limitations are the price of portability and convenience. Notebook and tablet devices represent a compromise, providing larger screens than phones while still allowing some measure of mobility.

As a result, the applications used on small portable devices provide somewhat downgraded service that is fundamentally different than those used on larger screen and/or fixed devices. Mobile app designers operate under different sets of standards and practices, making mobile an essentially different medium. For example, users dealing with large or complex text or spreadsheet documents (*e.g.,* business, online learning, video, medical, *etc*.) would likely find the experience much more workable and/or effective on a larger screen/keyboard device that enjoyed wired, or at least WiFi, access.[9]

Because of the pervasiveness of wireless connectivity, product markets more broadly tend to be circumscribed by these more limited devices, effectively crowding out markets for superior goods that would otherwise be available for important community applications, such as communication devices for use by medical units, police, and fire departments. In short, the speed limitations of wireless networks and proliferation of mobile devices impose constraints on the entire network and, in turn, on the availability of a wide range of other products and services.

2.2 Proliferation of wireless "things"

The present-day proliferation of wireless sprang initially from two key factors: the development of economical (initially analog) wireless phones and the deregulation of wireless services with the *Telecommunications Act of 1996*. To this was added a third key factor, the introduction of digital data packet-switching communication technology associated with the Internet,[10] and a fourth, the World Wide Web, an application service that made the Internet useful and easy to use. Another added factor has been making radio spectrum bands available for wireless services, some by spectrum auction (*e.g.,* mobile telephony) and some by opening unregulated frequency bands for low-power short-range devices (*e.g., WiFi*). The sections that follow will deal with two different approaches that have been taken: LTE phone networks and WiFi devices. A third and newer approach, just beginning to emerge and not yet entirely defined, is the Internet of Things (IoT), a topic that will be addressed separately.

2.2.1 Wireless phones

The wireless phone industry went from analog (voice) to digital (data) technology in its second generation and is now in its fourth generation, known as 4G or long-term evolution (LTE). Introduced by the European Telecommunications Standards Institute (ETSI), LTE is the dominant framework of the cellular system today.[11]

> 2G and 3G are still around, but 4G was initially implemented in the 2011-2012 timeframe. LTE became a competitive race by the carriers to see who could expand 4G the fastest. Today, LTE is mostly implemented by the major carriers in the U.S., Asia, and Europe. Its rollout is not yet complete—varying considerably by carrier—but nearing that point. LTE has been wildly successful, with most smart phone owners relying upon it for fast downloads and video streaming. Still, all is not perfect.
>
> 5G will probably be more revolutionary than evolutionary. It will involve creating a new network architecture that will overlay the 4G network. This new network will use distributed small cells, with fiber or millimeter wave backhaul, be cost- and power-consumption conscious, and be easily scalable… 5G radios will be more complex than ever… Can we even call them phones anymore?
>
> So we will eventually get to 5G, but in the meantime, we'll have to make do with LTE. And really, do you honestly feel that you need 5G? (Frenzel, 2016, p. 28).

Table 2.1 provides a brief summary of the generational history of wireless phones, showing the medium's timeframe, standards and/or standards-setting bodies, and key technologies. The technology of 5G is unsettled and under development and technical standards are incomplete.

Genera-tion	Timeframe	Standards/bodies	Technology
1G	1980s (1983)	AMPS Advanced Mobile Phone System	Analog Frequency division multiplex
2G	1990s (1991)	GSM/3GPP Consortium Global System Mobile 3nd Generation Partnership Project	Digital CDMA - Code Division Multiple Access GSM
3G	2000s (2001)	GSM UMTS Universal Mobile Telephone Service CDMA2000	Digital CDMA
4G	2010s (2010)	LTE Long-term evolution	Digital GSM/EDGE enhanced data rates for GSM evolution UMTS/HSPA high-speed packet access
5G	2020s	5G, 3GPP	Digital, small cells, 3.5–5 GHz bands, millimeter wave or fiber backhaul (14–79 GHz), software-defined networks, IPv6 internet protocol version 6

Table 2.1—Summary of mobile phone generations

The modern cell phone or *smartphone* is not a telephone in the traditional sense, partly because the voice quality is so poor and also because its function has shifted to provide platforms for data services other than voice. Prior to the development of digital mobile phones, the purpose of telecommunication was real-time two-way voice communication, wired and wireless. When deregulation of wireless telephones removed service quality requirements, digital compression and coding techniques were applied to cram as many channels as possible into the available spectrum. Accordingly, voice quality was allowed to diminish to the lowest level that customers would tolerate.

> So why do we mobile subscribers—all 4.5 billion of us—put up with such crummy voice service? In the early days of cellphones, their fickleness wasn't such a big deal. Back then, mobility was a luxury, a handy supplement to a dependable wired line. But now, more and more people are cutting the cord—or never installing one. Today in the United States, for instance, 40 percent of homes rely exclusively on mobile phones for making and receiving calls. In Africa, cellular subscriptions outnumber landlines 52 to 1, according to the International Telecommunication Union (Hecht, 2014).

Another cause for the degeneration of voice quality as telecommunications went mobile was that the network changed from a single homogeneous network designed for *isochronous* (timing dependent) voice transmission to a more heterogeneous packet-switched network designed for data that is not time-sensitive (i.e., the Internet). Perhaps surprisingly, transmitting high-quality two-way voice through a complex network is a more difficult engineering challenge than streaming video, audio, or data, that flow mostly in one direction. Improved voice quality can be achieved using new 4G LTE protocols known as VoLTE (voice over LTE), but these are not yet fully implemented or widely deployed.

2.2.2 WiFi-enabled devices

As laptop computers began to proliferate, the computer industry's Ethernet local area network (LAN) standards[12] were extended by the development of successive generations of wireless (WILAN) versions of the protocol—known as *WiFi*. [13] WiFi now provides a convenient portable "last-hundred-feet" connection to the Internet via inexpensive Ethernet-to-WiFi routers (or wireless access points) that have found their way into homes, businesses, coffee houses, airports, libraries, and other private and public spaces. WiFi is not a true access network but rather simply an extension of a wired access network that may be installed to a particular premises, such as cable, DSL, or fiber broadband. Enabled by WiFi access to the Internet, new generations of portable electronic devices, including light notebook computers, notepads, tablet computers, *iPods*, and, of course, smartphones, have become ubiquitous. In addition, Internet protocols such as voice over Internet protocol (VoIP) have made possible cheap, or free, voice (and video) calling service that functions as an alternative to the conventional wired and wireless telephone network. In essence, WiFi combined with high-speed premises landline broadband access (e.g., cable, DSL, optical fiber, etc.) has provided an alternative path to the wired and wireless network for voice and data.

2.2.3 Wireless *vs.* wireless

LTE wireless (i.e., 4G cellular) phone products and networks can provide an alternative access network. They have developed in parallel with wireless WiFi-enabled computer devices and phones, resulting in a race of sorts as firms from the cellular phone industry and the Internet computing device industry compete for first-mover advantage, each wanting to carry customers' data over their respective networks. New generations of personal devices, including smartphones, are appearing on the market with both LTE telephony and WiFi Internet data capability, competing to provide primary access to the Internet.

As a result of increasing mobile device use, cellular network providers are creating smaller and smaller cellular sites, or *femto cells*–even located within buildings–which provide short-range, highly localized LTE network access as a last-hundred-feet link to the network. Some smartphone device manufacturers are developing dynamic *hand-off* protocols so that calls can be seamlessly shifted between WiFi and cellular service without call interruption. But whereas WiFi/Internet is generally free, cellular/LTE costs the customer money. Cellular operators would like to keep the traffic on their networks where they can charge subscribers fees based on data volume and other services.

Cellular/LTE and WiFi/Internet access points depend on high-speed wiring within buildings. New *Ethernet* 802.3 cabling standards are being developed to support extremely high data rates up to 40 gigabits/per second over copper wire and to also deliver low-voltage DC power over the same wire to power femto-cells and/or WiFi routers. The wireless links do well to run at 10 megabits/per second. Few users realize that those wires are there.

2.3 Wires and wired "things"— Broadband access

Most of the preceding discussion has been about the *access network*—the final (or close to final) link to users' devices. However, it should be recognized that behind the access network is a much more complex and diverse backbone network, or *core network*, often referred to as *the*

cloud. The diagram in Figure 2.1 shows the relationship between these networks, referred to collectively as a "multi-service network" by Huawei researcher Dr. H. Anthony Chan (2016, p. 6). All the networks beyond the access network operate on optical fiber.[14] According to optical network researchers at Battelle Memorial Institute, about 29 exabytes[15] of data—the equivalent of 16 million *Blu-Ray*™ video discs—are transmitted through this core network every day (Walenta & Osterling, 2016, p. 40).

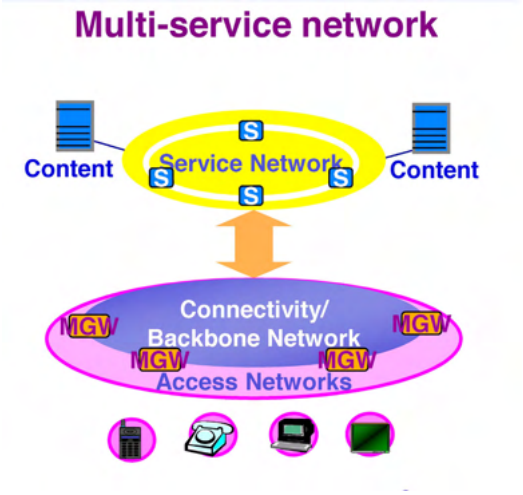


Figure 2.3—Core Network Architecture

Although a detailed understanding of network technology is not necessary to understand the arguments put forth in this paper, it is useful to look at the basics because the technical legacy, characteristics, and limitations of the different access networks have had a major influence on the roles they played in the past and on their trajectory for the future.

2.3.1 Access networks

Figure 2.3 shows the overall architecture of our present day global public communications network (including both voice and data services)—generally referred to as the *Multi-service network*. This architecture has two components, the *access network* (shown at the bottom) and the *core network* (everything else above the *access network*). The access network provides the final link to the customer or customer premise. The basic access network options include:

- Wired coaxial cable service (from local cable TV "head-end") to customer premises.
- Wired DSL landline telephone (from local phone company central office switch) to premises.
- Wired optical fiber (from local Internet service provider) to premises.
- Wireless (from cellular provider's local cell site (e.g., 4 G LTE)) directly to the users' devices (discussed above).

For the first three cases listed above—coaxial cable, DSL, and fiber—the access network terminates at a premises gateway device (i.e., a modulator/demodulator or *modem* device) where signals change protocols and signaling methods, usually to Ethernet cable or WiFi,[16] to finally connect directly to the user's computer, tablet, or other device.

The last option, wireless access (e.g., via 4G LTE), was discussed in the previous section. Recently, phones, tablets, and other devices, which are increasingly Wi-Fi-enabled, are, accordingly, moving toward a hybrid (or dual) configuration. This is because they can alternatively connect either through their cellular provider or through a premises gateway and use the wired access network. Using the latter method may avoid some of the content, data, and access limitations and fees imposed by the wireless cellular network operators. VoIP is one example. Following is a brief description of wired access network signaling technologies.

2.3.2 Coaxial cable

Coaxial cable is a high bandwidth, or *broadband*, copper wire technology, which can carry a broad spectrum of analog radio signals (including television channels) simultaneously, much as transmitted over the air, but with higher quality and less interference. Cable TV was introduced by localized entrepreneurial operators in the United States and Canada to deliver TV signals to communities outside of major urban centers. These communities received poor quality over-the-air TV or none at all due to distance, geography, or other factors. For this reason, early cable television was dubbed *Community Access Television* or *Community Antenna Television* (CATV). Cable TV networks were built out widely during the 1970s through the 1990s in a largely unregulated environment through local municipal monopoly franchise arrangements. Cable initially avoided the regulation by the FCC that governed radio and TV because the signals were confined to the wire and available only to subscribers.

The cable industry adapted to the introduction of the Internet in the late 1990s by developing a technical transmission standard, known as *data over cable service interface specification* (DOCSIS), for carrying digital data traffic within the cable wire on a portion of the spectrum not being used by analog TV. DOCSIS also allowed for upstream data traffic from the subscriber to the cable "head-end," thus making cable a two-way medium, enabling digital telephone service as well as Internet access for subscribers. A new version of DOCSIS is now being deployed that will replace analog RF transmission entirely and make cable into a fully digital broadband *pipe* operating at moderately fast data rates of about 40 Mb/ps. Coaxial cable enters the premises and is terminated at a subscriber's *cable box* gateway device. This box is equipped with a cable modem and three output plugs: an *RJ-45* Ethernet plug, *RJ-11* phone plug, and coaxial TV connector, each of which delivers services to the subscriber's devices.

2.3.3 DSL

DSL was adopted by the regulated telephone industry during the late 1990s to compete with cable for delivery of high-speed digital data over ordinary existing copper *twisted-pair* phone wires. This was a difficult technical challenge but DSL eventually succeeded in achieving data rates of 7 to 10 Mb/ps and sometimes as high as 50 Mb/ps (i.e., VDSL), depending on the local configuration of the phone wires. DSL allowed the delivery of Internet service and even, in some locations, up to three digital TV channels. However, the public switched telephone network (PSTN) operators suffered the disadvantage of having to compete as regulated common carrier monopolies with the cable providers, that were essentially unregulated monopolies in their markets.

2.3.4 Fiber

Optical fiber technology, as noted earlier, is capable of delivering data rates that are orders of magnitude greater than conventional cable, DSL, or wireless. Fiber is essentially a wire that carries data encoded on light beams at much higher frequency than the radio frequency used by cable, DSL, and wireless, and so can pack in much more data. The main disadvantage of this technology is that the fibers are relatively difficult and expensive to terminate or *tap into*,—not a simple electrical connection. Fiber terminations require special connectors, repeater amplifiers, and other equipment, so they are avoided or minimized. If the fibers break or are cut, it is not a trivial matter to repair them, so they are usually carried in conduits and buried, rather than stringing them on poles like conventional phone pairs or coaxial cable.

The telephone industry's traditional ideal and goal has been fiber to the curb (FTTC) or fiber to the home (FTTH), whereby fiber optic cables terminate on a gateway modem box at the curb or premises where digital data is converted to Ethernet over copper wire. This gateway would then separate out and deliver TV, voice telephone, and Internet service within the home. Fiber to the curb or home is an expensive undertaking and difficult to do for a regulated phone operator facing competition with an unregulated cable operator. Barriers presented by regulatory and competition issues have limited the deployment of FTTH (generally referred to as FTTx). One interesting exception is the Verizon Fiber Optic Service (FiOS™) network.[17] FiOS offers the public an excellent FTTH full service (Internet, telephone, and TV) option in some cities (e.g., Boston), but it has been sidetracked by Verizon in favor of more profitable wireless services.

In the above cases, it can be seen that access technology issues are inextricably interwoven with regulatory, public policy, and institutional/business structural issues. This is why in some countries, such as South Korea, virtually everyone has at least 50 Mb/ps broadband access provided by government. Ironically, the United States is far down the list in both speed and access in spite of the fact that it originated most of the technology involved, including the Internet. The next section will examine why this is the case.

2.4 Regulation of wires—shaping the market

The provision of wired landline services in the United States has suffered chronic failure since the mid-1900s when the national regulatory framework was reformed by the *Telecommunications Act of 1996.* This failure has been one of policy and regulation, as well as of markets, resulting in disproportionate build-out of wireless, languishing wired broadband services, and retarded national economic development.

2.4.1 Legislation—the *Telecommunications Act of 1996*—misreading the future

The *Telecommunications Act of 1996* was the first overhaul of the *Communications Act of 1934* that established the FCC. During the 1990s and preceding decades, new technologies, including cable, wireless, and Internet, emerged that did not fit within the long-standing regulatory regime. Unfortunately, reform fell largely to the armies of lobbyists for the dominant incumbent service providers of the time, including AT&T, the regional Bell operating companies (RBOCs), such as Verizon, and the cable giants, Comcast and Time-Warner.

The goal

Although the stated primary goal of the 1996 legislation was deregulation of the converging broadcasting and telecommunications markets to enhance competition, the consequences were, for the most part, anti-competitive.[18] Service providers in direct competition with each another found themselves subject to different regulatory rules because they employed different technologies.[19] Perhaps the *Act*'s most mistaken reading of the future was the distinction drawn between regulated and deregulated *Title I telecommunications* services (i.e., conventional wireline telephony), regulated *Title II broadcast* services (i.e., television), and unregulated *information* services (i.e., Internet). Increasingly, all of these services have come to be delivered via Internet technology, yet they are regulated entirely differently.

The reality

The result of the 1996 *Act* and associated deregulation of the sector has been the "stranding" of common carrier landline facilities and the unleashing of extreme concentration of the market power of cable and wireless carriers. AT&T and its divested fragments, the RBOCs, have re-combined into even larger than earlier entities, abandoning much of their local landline operations and spinning off to ride the deregulated surge of wireless. At the same time the cable firms, having largely escaped regulation entirely, have concentrated even more, dominating wired access, eliminating competition in Internet access, and facing only anemic competition from DSL by regulated landline carriers.

Harvard telecommunications law scholar, Susan Crawford, described the situation in detail in her 2013 landmark book, *Captive Audience* (Crawford, 2013). She summarizes as follows.

> …the phone companies are riding a wave of explosive growth in wireless data, and the two largest have carved off this separate marketplace for themselves. If anything, the wireless situation with regard to Internet access is even worse. Wireless carriers have no obligation to refrain from discriminating in favor of their own business plans.
>
> …The American copper wire telephone system is becoming obsolete, as consumers move to cellphones for voice service and the physical switches used in that network reach the end of their useful lives. The telephone companies who built that regulated network are hoping to get rid of the obligation to maintain it now that cable has decisively won the battle for high-speed wired communication in America. Some municipalities are trying to install fiber-optic networks for themselves, but their efforts are routinely squelched by lobbying campaigns and other tactics launched by incumbent network providers at the state level. Because America has deregulated the entire high-speed Internet access sector, the result is expensive, second-rate, carefully curated wired services for the rich, provided by Comcast and Time Warner; expensive, second-rate, carefully curated wireless services (or no service at all) for those who cannot afford a wire; close cooperation among incumbent providers; and no public commitment to the advanced communication networks the rest of the developed world is adopting (p. 259).

Crawford then observes,

> At the same time, the longtime consensus in the United States that basic, nondiscriminatory, affordable utility communications services should be made available to all Americans is being dismantled, state by state—just as America's peer countries are coming to the view that it is a national priority to replace copper with fiber for all their citizens as soon as possible (p. 260).[20]

"The result of the 1996 Act and associated deregulation of the sector has been the "stranding" of common carrier landline facilities and the unleashing of extreme concentration of the market power of cable and wireless carriers...

...What have been the consequences of dysfunctional legislation? The cable and telecom monopolies failed to develop the high-speed wired Internet access market and some have sought to disable, abandon, or mis-apply what does exist in this realm. AT&T and Verizon have pushed to decommission their landlines, claiming that they are uneconomical and unnecessary because they have been replaced by wireless services—a self-fulfilling rationale."

The consequences of the Telecommunications Act of 1996

What have been the consequences of dysfunctional legislation? The cable and telecom monopolies failed to develop the high-speed wired Internet access market and some have sought to disable, abandon, or mis-apply what does exist in this realm. AT&T and Verizon have pushed to decommission their landlines, claiming that they are uneconomical and unnecessary because they have been replaced by wireless services—a self-fulfilling rationale. In California, Assembly Bill AB2395 promoted by AT&T lobbyists seeks to decommission landlines in parts of the state (Young, 2016; Knutson, 2014). The Communications Workers of America (CWA), Verizon's largest union, accused the carrier of abandoning its copper landlines in portions of the northeastern United States (Kushnick, 2015). In certain areas where wireless coverage is poor, such as rural Maine, residents may end up with no phone service at all (Bell, 2016). Even when landline operators are granted rate increases to build new fiber facilities to replace copper lines—such as, for example, Verizon's FiOS—these builds may not be what they appear, diverting the funds, as New York Attorney General Eric Schneiderman suggests:

> Verizon New York's claim of making over a "billion dollars" in 2011 capital investments to its landline network is misleading. In fact, roughly three-quarters of the money was invested in providing transport facilities to serve wireless cell sites and its FiOS offering. Wireless carriers, including Verizon's affiliate Verizon Wireless, directly compete with landline telephone service and the company's FiOS is primarily a video and Internet broadband offering (Kushnick, 2015, para. 16).

In conclusion, telecommunication legislation and the ways it has been (mis)interpreted have privileged wireless over wired networks. Wireless is useful and popular for good reasons, but the policy regime has disproportionately favored it against the public interest. Although wireless can offer the convenience of mobility or portability, it is not an adequate substitute for wired access. Also, telecom operators offering both regulated wired and unregulated wireless services have chronically diverted ratepayer funds intended to support wired services into subsidizing their wireless services (Kushnick, 2015). The politics of wires and wireless will be examined in some depth later in this report.

2.4.2 Regulation—the FCC—the captured regulator

Crawford has described how the communication media audience became "captured." Similarly, Harvard ethics scholar, Norm Alster, describes the FCC as "captured" in his report, *Captured Agency: How the Federal Communications Commission is Dominated by the Industries It Presumably Regulates* (Alster, 2015).[21] Alster finds the modes of capture to be many, including lobbying, *revolving door* appointments, and political pressure—all traceable to the huge amounts of money to be made by the industry.[22] Alster notes:

> …a former executive with the Cellular Telecommunications Industry Association (CTIA), the industry's main lobbying group, has boasted that the CTIA meets with FCC officials "500 times a year"…. Money—and lots of it—has played a part. The National Cable and Telecommunications Association (NCTA) and CTIA have annually been among Washington's top lobbying spenders. CTIA alone lobbied on at least 35 different Congressional bills through the first half of 2014. Wireless market leaders AT&T and Verizon work through CTIA. But they also do their own lobbying, spending nearly $15 million through June of 2014, according to data from the Center for Responsive Politics (CRP). In all, CTIA, Verizon, AT&T, T-Mobile USA, and Sprint spent roughly $45 million lobbying in 2013. Overall, the Communications/Electronics sector is one

of Washington's super heavyweight lobbyists, spending nearly $800 million in 2013-2014, according to CRP data (Alster, 2015, p. 1).

Money buys influence. For example, Thomas Wheeler, appointed as FCC Chairman by President Obama and formerly head of both the CTIA and the National Cable Television Association (NCTA), raised over $700,000 for President Obama's campaigns. This is a familiar pattern in the FCC revolving door, as can be seen in Figure 2.4 (Alster, 2015, p.3). With the Trump administration, a new Chair has been appointed, Ajit Pai, who hails from Verizon where he was formerly chief counsel, continuing the same pattern.

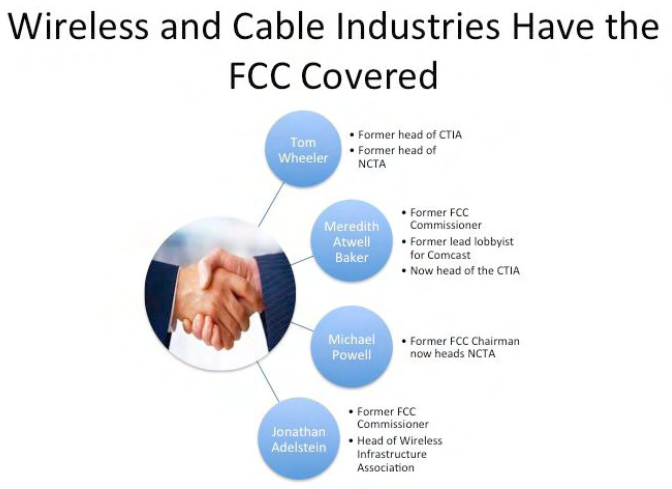


Figure 2.4—Recent "revolving door" FCC Commissioners (Alster, 2015, p. 3)

Politics and money can cut two ways. In a later section, we will see how the net neutrality debate has recently taken an unexpected but predictable turn in the struggle for power and influence in communications policy, which may work to undermine the dominance of the AT&T/Verizon/Comcast triopoly. By mid-December 2017, the new FCC Chair Ajit Pai orchestrated a radical reversal of the Net Neutrality policy, a reversal that is an extremely unpopular move that has set up yet another major battle in the ongoing struggle.

2.5 Mobile must-haves—the roaming toll booth

The mobile wireless industry, effectively unleashed from regulation, has followed a phenomenal trajectory, tying its customers (and essentially everything they do) to their cellular smartphone and the associated recurring subscription model, institutionalizing the overlap among cellular, the Internet, and the advertising industry. As the mobile device becomes an indispensable element of everyday life, we walk (and drive) around with our eyes and ears glued to little screens, processing information and advice from robotic assistants. The *network effect* generates an endless fountain of venture-funded entrepreneurial *apps* that tie our everyday lives to the newest new thing, fostering increasing dependency on the cloud and bringing about planned obsolescence of gratuitous hardware and software "upgrades" and services. The underlying business model for the biggest players (Google, Facebook, Amazon, etc.) is inevitably and ultimately the generation of advertising revenue. Estimates ranging from about 30% of Internet traffic to more than half is believed to be generated by botnets clicking away in cyberspace to

generate fake ad revenue (Cookson, 2016; LaFrance, 2017), and concerns have emerged that the six largest ad agency client billings are inflated or fraudulent (Cookson, 2016a).

2.5.1 The driving forces of the wireless industry

The discouraging aspects of the wireless account presented so far should not be taken to imply that the diffusion of wireless technology has not been useful, creative, and valuable—much of it certainly is. Wireless has had enormous, and often beneficial, impacts on society, economy, and politics. However, it is important to understand what is behind the screen—what drives the industry, what the effects and limitations of the technology are, and where its trajectory is taking us. The *self-driving car* we hear so much about is a telling example. In the absence of measurable consumer demand, industry is surging forward, soliciting investment and lobbying government to subsidize development, justified by a case put forward by precisely those who will profit mightily from the sale of related hardware, software, services, and a wealth of personal data. Although ostensible public benefits related to safety and convenience are publicized by interested parties, little public debate exists to identify and evaluate unintended consequences, which may include obliteration of large sectors of jobs. A new study by the University of Michigan shows that "the majority of consumers in the United States still have concerns about riding in autonomous cars," and the study "…highlights the unshrinking rift between the average driver and an industry's vision for the future" (Morra, 2016). 5G wireless may be a similar example, as political pressure is applied by industry on state legislatures to preempt local regulation of the antenna placement in neighborhoods on utility poles, lamp posts and other public infrastructure.[23]

2.5.2 The motives of the wireless industry

The dominant business model that has emerged for communication technology is based on commercial advertising and monetization of the personal, behavioral, and demographic data that are the raw materials of advertising. The heart and soul of the Internet has become hyper-commercialized, with the relentless pursuit of money driving most activity and innovation, rather than any public purpose. Statistical data presented at the 2015 Telecommunication Industries Association (TIA) *Network of the Future* conference in Dallas showed that the largest bandwidth user on the Internet was Netflix and the largest single content category on *You Tube* was cat videos.[24] When content simply becomes anything it takes to carry advertising, this may have yet-to-be-understood consequences for culture and society as well as impacts on future innovation and technological change. The history of technology teaches that technologies are "socially constructed," and rarely, if ever, end up being what the originators intended (Pinch and Bijker, 1984).

In addition to advertising, another motive for the wireless industry is selling more electronic chips, phones, and software. A keynote session speaker at the conference, a research scientist from Sprint, asked the question, "why are we talking about 5G?—we're not done with 4G yet!"[25] A possible answer was offered at a recent technical meeting of the IEEE Communications Society held at the University of Colorado, Boulder, when a distinguished expert and IEEE fellow, Professor Dr. H. Anthony Chan of Huawei Technologies, Plano, Texas, presented an in-depth technical lecture on *5G and Future Wireless Internet: Challenges and Emerging Technologies* (Chan, 2016). Chan noted that a new generation of wireless has been introduced each decade, and that 5G is intended to supplement or supersede 4G LTE by around 2020. He

described the existing and planned architecture for wireless access and supporting wired core networks and stated that the intention was to support "ever higher speed" wireless access to the Internet. Chan also noted that wireline is always faster whereas wireless is about mobility as well as convenience.

In spite of the highly technical nature of Chan's presentation, when asked about the basic motivation driving 5G, he had a surprisingly concise and non-technical answer: "…if technology does not change, the company will die…it is about more jobs…engineering and manufacturing." Chan added, "people must buy a new phone."

"The dominant business model that has emerged for communication technology is based on commercial advertising and monetization of the personal, behavioral, and demographic data that are the raw materials of advertising. The heart and soul of the Internet has become hyper-commercialized, with the relentless pursuit of money driving most activity and innovation, rather than any public purpose."

3 The "Internet of Things"

The Internet of Things (IoT) emerged as one of the dominant popular themes today about how communications will be applied in society, and it has become one of the primary assumptions and justifications for expansion of wireless networks. This chapter examines both the promise and limitations of the IoT concept, and explains why IoT should be conceptualized within a wired/gateway frame of reference, even though it may engage wireless devices.

The IoT is a pervasive theme that has emerged in the popular and technical press during recent years. IoT is the idea that every device or object in our environment can be assigned an IP address and be directly connected to the Internet. The implied geometric expansion of the network is based in part on the adoption and diffusion of a new Internet Protocol standard, version 6 (IPv6), which is replacing IPv4, and increases the Internet packet address field from 4.3 billion unique addresses today to 340 trillion trillion trillion unique addresses in the future.

3.1 Motivation for IoT

The ostensible benefit associated with IPv6 and IoT is that inexpensive sensor and actuator devices of all kinds can be simply and directly connected with pretty much everything, making data and capabilities available to a growing plethora of applications existing on smartphones and other devices in the Internet "cloud". For example, my smartphone screen could display the temperature in my home in real time and allow me to adjust my thermostat from anywhere in the world. This notion of IoT has spawned a frenzy of investment in all manner of devices by startup ventures and established companies—from smart toothbrushes to light bulbs, umbrellas, and toasters. It seems clear that much of this is being driven by the potential to make money by selling new devices and apps, not by the desire to add value to meet a real market need.

This vision implies problems that are both technical and behavioral. Technical questions surrounding the assumed need for expanded address space and the practicality of using it are implied by the performance limitations of low-cost devices and their vulnerability to security, privacy, safety, and dependency risks. Additionally, behavioral and social questions arise concerning to what extent there is need for such devices and applications and what are the potential psychological and social risks and dependencies associated with them. These include risks to public health created by exposure to pervasive microwave radiation, especially risks for young children who may be subject to a range of mental, emotional, and learning impairments. Other effects and risks of electronic media device's emissions, including a potential relationship to cancer, may have implications for both children and adults alike. A broader question may be, to what extent is the IoT push mainly about selling more silicon chips, software apps, and personal data rather than about addressing genuine societal and personal needs. Before building out a massive wireless infrastructure to support the IoT, including new and untested 5G millimeter wave antennas, it may be worth considering to what extent a trajectory of technological development driven by the imperative to increase sales of silicon chips, software, and data will likely result in a reasonable provision of consumer satisfaction and the broader social good. This paper takes a skeptical and less than optimistic position.

"Before building out a massive wireless infrastructure to support the IoT, including new and untested 5G millimeter wave antennas, it may be worth considering to what extent a trajectory of technological development driven by the imperative to increase sales of silicon chips, software, and data will likely result in a reasonable provision of consumer satisfaction and the broader social good. This paper takes a skeptical and less than optimistic position."

3.2 Technical issues around IoT

3.2.1 Flawed rationale for IoT

IPv4 has been in use since the mid-1990s, providing a large (32 bit) address space of 2^{32} bits or 4,294,967,296 unique addresses. Parts of that space were allocated to early Internet users in a manner that has now become inefficient.[26] At key junctures it could have been re-allocated and plausibly still could be (although ownership and institutionalization would make this difficult). The much larger address space of IPv6 (as noted above, 2^{128}, equivalent to approximately 3.4×10^{38}, or three hundred forty trillion trillion trillion, unique addresses) may be excessive when certain factors are considered.[27] These factors include the architecture of the access network, the way addresses are used, and the additional message packet length and processing power needed by simple end devices to use IPv6's longer address field and expanded protocol. In any case, IPv4 and IPv6 are likely to co-exist for a long time.

3.2.2 Evolved architecture—gateways and sub-networks

In actual practice, electronic devices tend to be clustered in homes, buildings, or industrial facilities and operate in a locally connected manner as local area networks or sub-networks. Such local networks then may connect to the Internet via a "gateway".

Sensor devices that are simple, low-cost, and often battery-powered, have been around for a long time—since long before the term IoT came into vogue—as have home and industrial automation Internet-connected systems. These work by keeping wired and wireless transmissions extremely short and sending messages through local hubs or gateways[28], which process the data and send it onward to end devices and servers. Accordingly, message traffic gets processed, translated, and re-addressed at the premises gateway level, such that the lowest-level device does not need or want an IPv6 address.[29] Simple and cheap devices cannot afford the overhead of unnecessary IP addressing and protocol stack processing. Additionally, it is common practice to use IP addresses in a mode called *dynamic address assignment*, whereby IP addresses are only temporary and re-assigned periodically using an Internet function known as *dynamic host configuration protocol* (DHCP). These practices tend to make IPv6 excessive, cumbersome, and superfluous because any device messages will be passing through a gateway that will ultimately discard the local IP addresses.

3.2.3 Security and vulnerability

IoT devices are a potential weak point for security. Inexpensive IoT sensor and actuator devices are vulnerable because they do not generally have the processing power to manage increasingly complex security protocols and encryption schemes, and it would be a challenge to update them, even if and when processing power is adequate.[30] Hacking and theft of data is an increasing problem and security is probably the biggest pitfall in the IoT vision. It is probably not desirable to have end devices talking directly to the Internet because of security issues in addition to issues related to network reliability, transmission delay, and network transmission latency. User devices are usually situated in a local environment and need to default to a local stand-alone operating mode to deliver reliable service. In any case, IoT devices need to connect to the Internet via a secure gateway if users are to have any hope of security.

3.2.4 Privacy, safety and dependency

The maintenance of privacy is a monumental problem in information technology networks in general, which has been greatly aggravated with the emergence of the IoT. Data privacy is closely related to, and interwoven with, security, but with IoT the privacy problem takes on a new dimension because the primary basis of business models around Internet applications and ventures is the collection and sale of personal data in some form or other—data that then feeds a commercial advertising business model. This model exists in direct tension with consumers' basic rights to privacy of their personal information. As a result, industry has little incentive to fix privacy problems.

3.2.5 Privacy loss

The IoT opens a new path to, and enables the collection of, huge treasure troves of data about the most intimate details of our lives. Vulnerability to data capture is aggravated by the fact that devices can be captured by "botnets"—automated networks of computing devices that have been captured or compromised.

> In late December, a researcher at enterprise security company Proofpoint noticed something strange: a security gateway was logging hundreds of thousands of malicious e-mails that were clearly being sent out by over 100,000 Linux-running devices, but they weren't PCs. Rather, they were Internet-connected consumer gadgets including routers, TVs, multimedia centers, and even a fridge.
>
> …He expects to see a lot more of what he refers to as "thingbots" as connected devices spread throughout the home, especially since the security in place on so many of these gadgets is just a simple Web interface that asks you to set up a username and password (Metz, 2014).

IoT gadget developers have no motivation to deal with security problems but seem to prefer to focus their resources instead on getting out the newest app revision. The IoT privacy problem is not only about how to deal with inadvertent access to data, but also (and more importantly) about deliberate and authorized access. The use of a local premises "gateway" can mitigate or limit the problem by providing firewalls, filters, and policy servers within sub-networks of devices that can define and enforce privacy policies. International technical standards for such gateways are under development now and could help stabilize the IoT market. Otherwise, the industry faces the risk of data thefts, attacks, or catastrophic scandals that could result in consumer, government (regulatory), or industry backlash.

3.2.6 Lock-in and stranding

IoT industry technical and market strategies may be designed in part to force or lure customers into a dependency relationship in order to lock in their continued use and secure them as sources of marketable data. Additionally, dependency on cloud-based services may leave users stranded and/or at the mercy of shifting corporate fortunes and priorities, as occurred, for example, in the case of the *NEST/Revolv* home automation system. As reported in the *Financial Times*, "NEST Labs, bought in 2014 by Google for a stonking $3.2 billion…is under siege for…its abrupt decision to discontinue the Revolv hub, which NEST inherited via an acquisition, …[leaving] owners understandably angry that their $300 smart home controller is soon to be a useless box of circuits" (Bradshaw, 2016). The case is instructive. A detailed account of this episode is provided

by *Business Insider* (Price, 2016).

> …Nest acquired Revolv, a smart-home device maker, nine months after it was itself acquired by Gooogle. …Revolv's team was to work on "Works with Nest," Nest's API program, but customers' existing Revolv products continued to be supported—until recently.
>
> [Then in March] Revolv updated it's website to announce that it is closing down completely, pulling the plug on its existing products in May. "We're pouring all our energy into Works with Nest and are incredibly excited about what we're making," wrote Revolv founders Tim Enwall and Mike Soucie. "Unfortunately, that means we can't allocate resources to Revolv anymore and we have to shut down the service." (p. 1)

According to the *Business Insider* account, a critic of NEST's "intentional bricking" the Revolv product asks:

> "When software and hardware are intertwined, does a warranty mean you stop supporting the hardware or does it mean that the manufacturer can intentionally disable it without consequences?" he writes. "[Nest CEO] Tony Fadell seems to believe the latter. Tony believes he has the right to reach into your home and pull the plug on your Nest products.."…
>
> But the case raises broader questions about the extent of ownership in the digital age and whether this could set a precedent for other devices going forwards.
>
> "Which hardware will Google choose to intentionally brick next?" … "If they stop supporting Android will they decide that the day after warranty expires that your phone will go dark? Is your Nexus device safe? What about your Nest fire alarm? What about your Dropcam? What about your Chromecast device? (p. 3).

3.2.7 Safety

When critical systems are linked to remote actuators and/or cloud-based software, the communication channel between the user and her/his device becomes vulnerable and may be inadequate or inappropriate. For example, being able to remotely activate cooking appliances raises questions of safety. What if something flammable was inadvertently left on, in, or near the oven or stove-top? What if a hacker in China could operate your door locks or turn up your furnace? If he turns it off, could your pipes freeze? If your smartphone works to turn something on, might you be out of the network or your battery dead later when you want to turn it off? International standards exist for safety of home systems that consider issues such as those listed above, but the standards are voluntary. Will engineers at *Google*, *NEST*, or some start-up take time to read them?[31]

3.2.8 Electrosmog and interference

The IoT vision opens the possibility of valuable applications, such as for example in the field of medicine and health. A new genre of super low-power smart sensors is in development. Known as "energy harvesting" devices, these can be applied to heart monitors and other medical reporting devices, safety devices, alarms, and temperature/water monitors. Such devices require only minimal batteries or no batteries at all because their modest electricity needs can be derived from their environments using motion, light, heat, sound, vibration, wind, etc. from energy transducers. Consequently, highly efficient communication protocols have been developed to make data transmissions very brief.[32] Many of these devices are wireless and transmit short

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packets infrequently. Perversely, overuse of radio spectrum by non-essential or trivial wireless products can produce "electrosmog" pollution that can block or drown-out useful, beneficial, and necessary uses of that radio spectrum, such as the medical devices mentioned above.

3.3 Social and behavioral issues around IoT

While the IoT introduces opportunities for any number of new applications that may be beneficial to users and society, it also introduces the possibility of new risks. It is important to inquire and raise questions about what some of the more obvious risks or categories of risk may be. For example, what are the risks of too much connection or connectedness? Could the IoT introduce systemic vulnerabilities and dependencies, and what might they be? The IoT brings attention to the specifics of how Internet access in its various forms may impact society in the future. Following is an inventory of related issues and risks regarding the envisioned Internet of Things (IoT), some of which will be addressed in further detail later in the report.

3.3.1 Socio-technical systemic risks

IoT presents a variety of potential socio-technical risks—risks associated with the adoption and integration of certain technological systems into society. For example, complex socio-technical systems are subject to what has been termed *normal accidents*—accidents that are inevitable as a consequence of system complexity (Perrow, 1985.)[33] IoT-related risks include both individual and systemic risks. These risks include exposure to known and unknown health risks (e.g., environmental and electromagnetic field (EMF) pollution), climate change risks, nuclear-related risks, privacy risks, and security risks. Possible risk categories include operational failures and unintended consequences of industrial systems, machine-to-machine (M2M) systems, transportation systems, robotics, and *smart cities*. A particular such case, described in detail later in this report, are the risks associated with excessive energy consumption as a consequence of the proliferation of, and dependency on, wireless networks. Other areas of potential socio-technical risk associated with such networks could also include educational and children's learning and developmental risks and general social behavioral risks (Carr, 2017) as well as media, political, and electoral system risks (Brooks, 2017).

3.3.2 Public health risks

Every cell in the body functions by electro-chemical signals. The body is partly regulated by a brain and wiring system composed of neurons. In this sense, it is not surprising to learn that electric and electromagnetic fields could have some effect on the body, at both cellular and systemic levels. The most obvious effect is heating, as we might know from microwave ovens. However there is growing evidence of non-thermal effects from exposure to all frequencies of the electromagnetic spectrum. A recently released preliminary report from a U.S. Government National Toxicology Program (NTP) study of the effects of low-level cellphone radiation on rats and mice showed positive evidence of cancer risk (Knutson, 2016; Patel, 2016). Previously, there had already been sufficient reason for the World Health Organization's International Agency for Research on Cancer (IARC) to list radio frequency (RF) electromagnetic radiation, as emitted by cellphones, wireless devices, and such, as a Possible Carcinogen (Dellorto, 2011).[31] Additional public health risks documented in primary research and review studies relate to oxidative stress

and free radical damage, cellular DNA damage, lowered fertility, neurological and neuropsychiatric effects, increased apoptosis, increased intracellular calcium, as well as impacts on childhood development and learning, and on addiction, mental health, and social issues.

3.3.3 Radiation biology and electromagnetic fields

As the IoT is envisioned, cellphones will be only one of many new sources of radiation. A major part of the IoT vision anticipates pervasive wireless devices using data transmission methods similar to cellular networks and WiFi. WiFi hotspots and tiny femto cell sites already bathe us with microwaves in our homes, offices, cars, trains, airplanes, airports, coffee shops, stores, and restaurants. Most of these sources never turn off and cannot be turned off. A particular concern relates to young children whose brains are in a vulnerable stage of development. Many parents now equip their children with cellphones and various other electronic gadgets, most with monitors. What are the biological effects of this radiation? There is evidence that effects are not limited to cancer and there is little reason to believe dangerous radiation is limited to any frequency. What could be its effects on childhood brain development, on immune systems, on allergies, on addictive behavior, and on learning?

Electromagnetic fields, their biological effects, and potential risks to public health is a topic that goes far beyond IoT, and it will be examined further later in this report. The purpose here is to consider the general scope of the topic relative to IoT considering the aggressive promotion of IoT and 5G wireless by the IT and semiconductor industries.

3.3.4 Learning and development

What are the effects of electronic devices and their form of mediated interaction on learning and development? There is mounting evidence that electronic media may impair learning and social development in children and that students with lower usage of phones and computers do better on tests.

> Teachers at Mountain Oak say they can walk into a classroom and immediately tell who has been using devices at home. “We see it in their behavioral problems, their ability to reason, their cognitive skills, even their ability to communicate with other people,” one teacher tells me.
>
> Jennifer McMillan, who teaches kindergarten, says she has to “have the conversation in a gentle way.” Many of these parents simply don’t understand the effects that staring at a screen can have on children’s behavior and their ability to learn (Riley, 2016, p. 2)
>
> Research backs this up: In December the Journal of the American Medical Association, JAMA, published a study showing that electronic toys hinder verbal development. An article in the journal Mind, Brain and Education found that traditional toys “sparked higher quality conversations.” (Dougherty, 2016, p. 3).

MIT researchers recently completed a study at West Point, “The Impact of Computer Usage on Academic Performance: Evidence from a Randomized Trial at the United States Military Academy”. The study concluded, “The results from our randomized experiment suggest that computer devices have a substantial negative effect on academic performance” (Carter, Greenberg & Walker, 2017). In another study from University of Texas, Austin, “Brain Drain: The Mere Presence of One’s Own Smart Phone Reduces Available Cognitive Capacity” it was shown that having a smart phone in the room reduces cognitive capacity, even if the phone is

turned *off* (Ward *et al*, 2017). It is interesting to note that France has become the first nation to ban cell phone use in schools for elementary and secondary students in classrooms as well as on breaks.

As with risks associated with electromagnetic radiation biology addressed in the preceding section, risks to learning and development associated with IoT devices go far beyond IoT. Risks associated with both RF electromagnetic fields and with the use of wireless devices in general will be examined further later in this report.

3.3.5 Cars and drivers

Evaluation of public health effects associated with increasing use of, and exposure to, electronic devices should include distraction of drivers texting or talking on cellphones. Many accidents involving motor vehicles, trains, and other forms of transportation have been attributed to talking and texting on cellphones. The ideas that multitasking involves performance risks and cannot be done effectively, and that talking on a cellphone impacts the brain significantly while driving a vehicle (comparable even to driving under the influence of alcohol), deserve careful consideration (Gorlick, 2009).

The automotive and electronics industries are eager to offer increasingly-connected cars with every imaginable form of electronics, from hands-free mobile phones[35] to entertainment systems, cameras, GPS navigation systems, and increasingly-automated control systems. All of these systems produce data that becomes the currency of electronic commerce and surveillance.

3.4 Cyber-physical Systems and M2M

While popular media focuses on the gimmicky side of the IoT, with its marginally useful home automation and trendy fitness monitors, a different side of an ever-more-connected world relates to industrial controls and machine-to-machine (M2M) communication. This less-visible side of the IoT includes networks of sensors, actuators, and processors exchanging automated messages that enable the processes that run factories, water treatment plants, electric power grids, traffic lights, and any number of other systems that modern society depends on. Such systems have long existed and technical standards to support them have been underway since well before IoT entered the popular lexicon.

3.4.1 Cyber-physical Systems

The industrial process automation aspect of the IoT has been formally organized by the National Institute for Standards and Technology (NIST) under the term “Cyber-Physical Systems” (CPS). In a 277-page draft *Framework* document released for public comment by NIST in September, 2015, CPS is defined as follows.

> Cyber-physical systems (CPS) are smart systems that include engineered interacting networks of physical and computational components. CPS and related systems (including the Internet of Things (IoT) and the Industrial Internet) are widely recognized as having great potential to enable innovative applications and impact multiple economic sectors in the worldwide economy (NIST, 2015, p. xii).

The CSP project entails standardization aspects needed to realize this vision. These include defining a vocabulary and reference architecture and designing cybersecurity and privacy

policies, data interoperability, and most notably, a global timing and synchronization scheme. The latter is particularly interesting because such a scheme deals with a functionality that was deliberately missing from the Internet, which was designed as a decentralized *asynchronous* non-deterministic network of networks.

Conventional centralized control system concepts tend to rely on deterministic centralized synchronization so that the timing of control messages is predictable and precise. This is not what the Internet was intended to be—a simple, decentralized, and asynchronous communication system that encouraged autonomy and flexibility, and with all the intelligence at the edges. To seek to re-make the Internet into a timed, synchronized system has far-reaching implications, envisioning for some an Orwellian conception of a global robotic control network. Such visions have been a recurring dystopian theme of science fiction since Mary Shelley's *Frankenstein*. Most notably, CPS suggests a vision of centralized synchronous control that was the theme of the prescient 1971 classic George Lucas film, *THX1138* (predating his *Star Wars* series) that depicted an oppressive, computer-controlled world of the future.

3.4.2 M2M—machine-to-machine

M2M communication is a broader, simpler, and more pragmatic idea than CPS, as it consists of various devices that send automatic short messages to each other, most often communicating between asynchronous processes. Industrial process control systems require tightly-coupled reliable communications, which typically are based on wired networks, but sensor networks tend to use some form of wireless.

A good example of an M2M network is provided by *Sigfox*, a French firm that has been in the sensor data collection business for years and has recently taken advantage of the hype around the IoT to raise money and expand the company's products and services. Although written up in *Forbes* magazine under the headline "This Startup Is Building A Cellular Network for Your Lightbulb and Toaster," Sigfox is neither a startup nor does the company have anything to do with home automation (Tilley, 2016). Rather, Sigfox has built a highly efficient low-power cellular radio system using unlicensed 900 megahertz spectrum to support low-data rate, low-traffic networks (i.e., typically 140 12-byte message per day or less), mainly for collecting sensor data for a wide variety of applications. Such functionality is more likely to characterize the IoT than the services to high-data-rate, big-bandwidth users characterized by industry media promotions.

3.4.3 Smart cities

The term *smart cities* refers to the application of computing and communication technologies to the systems and challenges of urban life. The term has emerged, along with IoT, to refer to an organizational and promotional category rather than to any specific technology. Municipal governments are taking the initiative to implement a wide variety of programs to meet social, economic, and environmental challenges. From the standpoint of municipal governments, these initiatives involve the integration of disparate urban information systems, control systems, and data to achieve efficient cost-effective operations. This does not imply centralized control.

Municipal initiatives through pilots and demonstration projects create opportunities for cities to become centers of innovation and collaboration as well as drivers of sustainable growth. These

activities focus mainly on key urban systems, including energy, water, mobility, buildings, and government. City strategies emphasize sustainability, community resilience, and climate action and tend to value data-driven policymaking and operational control. The related initiatives can employ a variety of public and private business models, grants, and partnerships to fund city projects.

From the standpoint of the IT and computer industries, *smart cities* will sell chips and software services and will enable companies to collect personal data, and sell it. Accordingly, smart cities may be seen as primarily an application marketing arena for M2M.

3.5 Some conclusions about IoT

As time goes by and commercial applications are found, the hype about IoT is likely to subside and expectations adjust. It is not clear how fully IPv6 will be utilized; its overhead, security and privacy issues are likely to demand the use of localized gateways, and standardization will likely be an important factor in market acceptance and growth. Implementation of municipal fiber networks may become a key factor in the growth of the IoT, particularly in the smart cities arena because wired media provide more dependable and predictable network performance.

As for CSP, the need for this version of IoT is far from clear. CSP seems to have replaced the government promotion of the *smart grid*, which was also handled by NIST, and which has subsequently languished. Smart grid was only marginally successful in gaining industry support, with the exception that large numbers of unnecessary and expensive *smart meters* were deployed. A similar situation may develop with CSP.

The hyper-commercialization of the IoT may already be on the wane as evidenced by *The Wall Street Journal* columnist Joanna Stern's characterization of the IoT as "The Internet of Every Single Thing."

> I've been testing many products that simply don't work as promised. It is time potential buyers wised up to The Internet of Every Single Thing. Until the hardware improves and the ideas get more practical, it is buyer beware (Stern, 2016).

She summarizes, questioning the basis for IoT as partly a fad.

> Technology has made our lives easier and solved some incredible problems, but a connected egg tray that reminds you to buy more? Come on. A subset of startups inventing the "world's first connected [fill in any noun here]" believe everything goes better with Bluetooth.
>
> Blame the falling price of parts, the popularity of crowdfunding sites or the flood of cash into the tech industry. But if an object has room for a chip and a battery, some entrepreneur is trying to shove them in—and replace common sense with an app alert.
>
> …There is even greater irony: Instead of solving the hassles of everyday life, they create more of them.

This chapter has explored IoT because it is one of the dominant popular themes today about how communications will be applied in society. It lays out some of the reasons that IoT should be conceptualized within a wired/gateway frame of reference, even though it may engage wireless devices. Is IoT a mirage? Is it reality? Perhaps it is both. In any case, the network performance demands of IoT in control and sensor applications are very light compared to the demands of video, advertising, and data collection applications that are claiming to justify creating 5G wireless networks. Thus IoT does not offer a convincing rationale for 5G.

"To seek to re-make the Internet into a timed, synchronized system has far-reaching implications, envisioning for some an Orwellian conception of a global robotic control network. Such visions have been a recurring dystopian theme of science fiction since Mary Shelley's Frankenstein. Most notably, CPS suggests a vision of centralized synchronous control that was the theme of the prescient 1971 classic George Lucas film, THX1138 (predating his Star Wars series) that depicted an oppressive, computer-controlled world of the future."

4 The politics of the wires

Wires have politics as does every technology. Technical choices inevitably carry social and economic consequences—advantaging some and disadvantaging others—and political power and influence invariably steps in, especially where a lot of money is involved. A deeper look at the regulatory history and political background of communications may contribute to a more complete understanding of how our present system got here and what is needed to change it.

4.1 Background—how we got here

As stated earlier, a federal court antitrust decision implemented in 1984 broke up the AT&T Bell System monopoly into seven RBOCs (also known as the "Baby Bells") and a long-distance network operator that retained the AT&T name.[36] The purpose of the breakup was to bring competition to the long-distance market and confine the natural monopoly of local wires and poles to local companies that would remain regulated monopolies.

The Bell System breakup (or divestiture)—although initially successful, at least for a while—eventually gave way to Congressional politics and money. Over time, the RBOCs amassed enough political capital to successfully lobby for legislation[37] to lift the regulatory restrictions that had been placed on them, preempt state regulation, enable a reconsolidation of the industry, and bring about a restoration of market power. The RBOCs and AT&T were able to engage in a long, convoluted series of mergers, acquisitions, and spin-offs. The final legislation in the story was the *Telecommunications Act of 1996*. As this re-grouping unfolded, many executives profited from their new roles and golden parachutes, as the RBOCs were able to spin off various unregulated media, cable, and wireless ventures, many of which were partly developed at public expense by regulated entities.[38]

The *Telecommunications Act of 1996* was intended to force competition in the telecom market while at the same time deregulating the market wherever possible. RBOCs, in the 1990s rechristened *incumbent local exchange carriers* (ILECs), wanted access to expanding cable and wireless phone technologies, long-distance phone services, and emerging media markets. The cable providers were trying to figure out how to provide voice phone service. New entrants called competitive incumbent local exchange *carriers* (CLECs—competitive LECs) wanted access to local wireline services and long distance voice phone service.

In the mid-1990s, the Internet and email remained largely the province of university campuses and the World Wide Web (i.e., the Internet browser application) was just being invented. At the same time, the legacy network of copper wires that was built over a century, connecting every home and business, persisted and continues to represent a material right-of-way that is essential to the future of our society. The upgrading of this wired infrastructure to fiber has languished as the wireless industry seeks to "hide" the wired infrastructure from public view under the pretense that the future will be all wireless, invoking the rhetoric of obsolescence and modernity while actually diverting the existing installed base of wires to feed ever-more-prolific cell sites. The wireless industry has adjusted customers' expectations downward to diminishing qualities of compressed and unreliable voice service and graphic experience—all subsidized by over-packing the spectrum and filling it with advertising.

The *Telecommunications Act of 1996* has failed so badly that it has become an urgent national priority to free up Internet access to make it available to the people. Regarding public apprehensions about AT&T's plans to disconnect some wired subscribers, the *Wall Street Journal* reported:

> Skeptics note that the U.S. telecom industry is more concentrated than at any time since the 1984 breakup of AT&T into one long distance company and seven regional carriers. Consolidation since then has left AT&T and Verizon with about two-thirds of all wireless subscribers.
>
> The all-internet protocol "transition holds many promises for consumers, but losing access to affordable voice and broadband services cannot be part of that bargain," wrote Angie Kronenberg, general counsel of Comptel, in a letter to the FCC last month on behalf of the small-carrier trade group, several companies and public-interest groups (Knutson, 2014, p. 5, para. 6–7).

To find a path forward toward universal Internet service, it is useful to begin with a viable analysis of how this situation developed and what went wrong with the *Telecommunications Act*, which was ostensibly designed to foster competition, facilitate new entry of providers and services, and democratize access to all citizens. The law's most basic assumption was that lack of competition in one medium could be remedied by competition from another medium offering a similar service. This assumption turned out to be wrong.

4.2 The failings of the Telecommunications Act of 1996

As described by Susan Crawford in *Captive Audience*, "The 1996 *Act* set up a grand bargain: it tried to force competition into all telecommunications markets while also deregulating them" Crawford continued:

> The Bells had to give smaller companies access to their circuits and the cable companies had to allow the Bells to compete with them for cable service. Local telephone companies could now offer long-distance service outside their own service areas, but in order to offer long distance inside their service areas, they had to prove that they had opened their own local phone markets to competition. Rate regulation for cable systems was ended other than for basic tier of programs; *the theory was that stiffer competition from telephone companies (now in the video business) would constrain rates* (p. 49) [emphasis added]
>
> …What the act did not do was keep the cable companies from clustering their operations ("you take Minnesota, I'll take Sacramento") or the telephone companies from consolidating. Even before it passed, two of the Baby Bells, NYNEX and Bell Atlantic, were rumored by the Wall Street Journal to be considering a merger. Within a few years, the Baby Bells were merging rapidly: SBC bought Pacific Telesis, then Bell Atlantic and NYNEX merged. There was activity in long-distance markets as well: AT&T bought Teleport, and MCI bought a metropolitan fiber network called MFS. Bell Atlantic merged with GTE and renamed itself *Verizon*. SBC bought Ameritech. By 2005 America was effectively left with two wired companies—Verizon and SBC. (Crawford, 2013, p. 49)

The saga continued with many ironic twists: AT&T effectively sold itself to SBC, with the new merged company renamed AT&T. Then Verizon acquired MCI, whose offer of microwave links between Chicago and St. Louis had precipitated the breakup of AT&T in 1984. Crawford summarized the fundamental failure of the *Telecommunications Act of 1996* and the formation of the present situation as follows:

> What happened to the competition that the 1996 law was supposed to foster? The act's fundamental assumption, that open platforms and alternative technologies would undermine the market power of the incumbent carriers over basic communications platforms—and that behavioral regulations on these actors would make structural limitations unnecessary—has proven overly optimistic. Although the phone companies were supposed to allow competing carriers to share their facilities, and the cable companies were supposed to compete with the phone companies to provide distribution of video content, data, and phone services, the opposite happened. On the phone side, without limits on mergers, consolidation and litigation foiled the act's open access mandates. At the same time, cross-technology competition between phone and cable turned out to be weak: *when it came to wired access, the incumbent cable operators had unbeatable economic advantages over the phone companies* (p. 50). [emphasis added]

Crawford concluded her criticism of the *Act* by noting that its reliance on cross-technology competition was mistaken and inadequate.

> Internet access, a service provided by both phone and cable companies, could have disrupted all these giant companies' effort to block competition, if only the open access mandates of the act had held firm. But the mergers were not what undermined the power of Internet access to eliminate the gatekeeping role that the carriers enjoyed. *It was the FCC itself* (p. 51). [emphasis added]

In the end, conflicts of interest on the part of the FCC leadership subsequent to passage of the 1996 *Act*—fed by money and politics—led to dominance of wired Internet access by Comcast and to dominance of wireless Internet access by Verizon and AT&T. As a sequel, it is with some irony that in 2016, under the leadership of FCC Chair Thomas Wheeler, a former wireless industry lobbyist, the FCC suddenly and surprisingly acted to at last move Internet access to Title II regulated common carrier status (González, 2015), a move that has been subsequently upheld by a federal appeals court (Kang, 2016). Wheeler subsequently led an accelerated push to fast-track allocation and approval of 5G wireless spectrum (Wheeler, 2016).

The advance of 5G is additionally ironic in light of accumulating evidence in bio-medical research that raises public health concerns regarding cellphone and other microwave radiation exposure—issues that the FCC has successfully fended off for many years (Alster, 2015). It may be that the FCC must re-examine its microwave exposure standards for wireless devices at the same time that the Commission deals with allocation of microwave spectrum for 5G wireless. Perhaps with some prescience, the *Telecommunications Act of 1996*, largely written by lobbyists, preempted local regulation of cell tower siting, specifically prohibiting challenges to cell site permits for health-related reasons.[39]

4.3 The consequences and emerging strategies

As the regulatory landscape changed before and following the updated *Telecommunications Act of 1996*, the carriers, jockeying for position, found that the new, rapidly-evolving, wireless mobile phone market was the place to be. First, the wireless market was essentially unregulated and so was in a strong position to colonize the regulated voice telephone business as well as the unregulated data business. Moreover, the wireless mobile market was safe from fixed-line competition from the cable industry. The unregulated wireless market also offered the opportunity to build huge barriers to entry that protected a strategy of consolidation by mergers and acquisitions. Finally, in moving from regulated telephone companies to unregulated wireless

spinoffs, startups, and subsidiaries, telecom executives could enjoy spectacular compensation opportunities in the forms of stock options, golden parachutes, bonuses, and salaries.[40]

4.3.1 Controlling the customer

Because the wireless market, historically, is largely unregulated, operators can restrict or control content, effectively making it a "walled garden." Verizon does not allow wireless subscribers to download applications or software it does not approve (Crawford, 2013, p. 160), ironically using the pre-divestiture AT&T argument that the company needed to avoid harm to its network. The control and sourcing of content is part of the reason behind AT&T's curious alliance with Apple, the purveyor of extremely popular but highly restricted and protected hardware, apps, and content.

As conventional wireline voice customers move to wireless, voice quality is vastly degraded (e.g., distorted voice, gaps, dropped calls, etc.). Smartphones are not really phones, but are designed primarily to provide screens that can display advertising. There is no money in voice because there are no ads. Smartphones are expensive and can support upselling and higher profits. Voice is highly compressed to reserve bandwidth for video and data.

Rhetoric about "enhanced services" and "moving to the 21st Century" where things are "efficient" and "modernized" and copper is "obsolete" obscures the fundamental objective of such hype, which is more and larger profits for carriers (Horton, 2014).

4.3.2 Controlling the market

By moving into the unregulated wireless business through spin-offs, mergers, and acquisitions, a few carriers have been able to gain market power and control. By large margins, most of the revenue growth for Verizon and AT&T has been on their wireless side. Crawford wrote:

> The companies know they're on solid ground with wireless. Cable distributors can't provide mobility outside of a narrow range around a subscriber's house without reselling the wireless carrier's services. Both markets—wired and wireless high-speed Internet access—are extraordinarily profitable, and by and large they do not intersect. (Crawford, 2013, p. 162)

This monopolistic situation builds in large incentives and opportunities to maintain artificial scarcity to support high prices.

Other advantages accrue to wireless because video content providers (e.g., Netflix) can be charged to access their customers, and at the same time, customers can be charged when they overrun their monthly data allotments watching video on their handheld devices, triggering overages charges. With such a business strategy, it becomes important that carriers be able to curate and prioritize the deluge of data flowing to users' handsets to meet the technical constraints of the wireless transmission medium. This could explain why these carriers have fought so hard against the extension of common carrier obligations that comprise net neutrality, which they characterize as "job-killing, cost-raising, innovation-crushing, anti-investment regulation" (Crawford, 2013, p. 162).

4.3.3 Controlling the fiber

In recent decades, Verizon and AT&T have set about acquiring wireless and wireline phone companies and moving their customers to wireless, in part by degrading, decommissioning, and neglecting the existing copper infrastructure (Munson, 2015; Bell, 2016). The dominant carriers have also neglected to promote FTTH wireline fiber, effectively leaving that market to the cable industry, and have actively sought to prevent and limit the spread of local municipal fiber networks by sponsoring the adoption of state laws preempting wireline competition from public municipalities in approximately 20 states (Vara, 2015).

Verizon, which developed FiOS, a promising alternative fiber-based multi-service FTTH network product that could have offered consumers fast, safe Internet access, throttled back on selling it and, it is claimed, diverted its fiber infrastructure, which was built with ratepayer money, to supporting wireless cell sites (Kushnick, 2015).

4.3.4 Decommissioning copper

The Communications Workers of America (CWA), the largest telecommunications workers union, claims that "Verizon isn't fixing the land lines or upgrading the networks" in a number of northeastern states, including parts of New York, Delaware, Pennsylvania, New Jersey, Maryland, Virginia, and the District of Columbia. While Verizon's media department denied these accusations, Verizon's CEO, Lowell McAdam was quoted as identifying "killing the copper" as major goal (Kushnick, 2015, p.2, para. 6). According to blog editor Ben Munson,

> The CWA announced intentions to file Freedom of Information Act (FOIA) requests to pull up data on Verizon's maintenance of legacy networks.
>
> "As a public utility in these states, Verizon has a duty to maintain services for all customers. But we've seen how the company abandons users, particularly on legacy networks, and customers across the country have noticed their service quality is plummeting," Dennis Trainor, CWA vice president for District 1, said in a statement.
>
> …This year, Verizon has made moves to divest its wireline operations to free up focus for its more lucrative wireless business. The carrier sold its wireline operations in California, Florida and Texas to Frontier Communications for $10 billion. (Munson, 2015, para. 3).

Verizon and AT&T have pushed for legislation in several states, including California and Maine, to allow them to decommission landline service and thereby force customers into wireless services. An Associated Press story carried in the *The Boston Globe* illustrates the impact of the strategy to move customers to more profitable wireless services.

> Peter Froehlich lives at the end of a mile-long dirt road in a part of Maine where pickup trucks share the right of way with wandering dairy cows. The local cable company won't run a line down the road, and his cellphone is useless because he lives in a wireless dead zone.
>
> Now Froehlich, 70, worries a new Maine law will eventually allow the telephone company to unplug him from the plain old telephone service he depends on.
>
> "If they get out of the landline business, I will have no way to connect with anybody else, unless I get in my truck and drive out," he said (Bell, 2016, para. 1).

In California, AT&T asked state lawmakers to allow the company to decommission its landlines, particularly in rural areas, and claimed that "85 percent of households in California no longer

"Contrary to industry claims, copper landlines are not obsolete, but can outperform wireless by employing new VDSL or G.fast signaling technology (Gatherer, 2017). The unstated industry motive is to force subscribers into more profitable wireless networks. The claims about obsolescence and the supposed need to "step toward to the 21st century" is a self-serving, false narrative put forward by monopolistic corporations and their political lackeys."

have a traditional landline from a traditional provider" (Young, 2016, para. 5). According to a supporter of the AT&T legislation:

> "It's a decision that the state needs to make about the future of infrastructure in California," said Mike Montgomery, executive director of CALinnovates. "Whether we're talking about roads, bridges, tunnels, schools or copper telephone networks, we really need to figure out how to take this step toward the 21st century." (para.. 4)

The California legislation AB2395 proposed that after a period of three years to educate the public about alternative services, phone companies should be allowed to discontinue landlines if alternatives (presumably wireless or cable VoIP) are available. So far, 13 states have approved such alternatives. Consumer groups and local businesses have objected on the basis of public safety and the need for legacy services not accommodated by wireless (e.g., 911, alarm monitoring, credit card transactions, etc.). Many do not realize that in the event of a power outage, conventional telephones may still work because they are independently powered over the copper phone wires.

Contrary to industry claims, copper landlines are not obsolete, and can outperform wireless by employing new *VDSL* or *G.fast* signaling technology (Gatherer, 2017). The unstated industry motive is to force subscribers into more profitable wireless networks. The claims about obsolescence and the supposed need to "step toward to the 21st century" is a self-serving, false narrative put forward by monopolistic corporations and their political lackeys.

4.3.5 Blocking municipal broadband fiber alternatives

Twenty states have passed laws that limit or prevent municipalities from building fiber access networks, largely with the help of telecommunication industry lobbyists who often write the legislation. Telecom industry positions tend to label public broadband projects as "socialistic" and frame government entities that compete with private enterprise as "un-American"—an argument that was also used successfully in the early days of electric power to justify privatization and monopoly.[41]

The city of Chattanooga has become an exemplar of a successful municipal broadband fiber network. The project was undertaken in 2010 by the local municipal electricity company, EPB, enabled by an unusual exception in Tennessee law that allows electricity providers to also provide telecommunications services such as cable and Internet (Vara, 2015).

> In 2010, Chattanooga became the first city in the United States to be wired by a municipality for 1 gigabit-per-second fiber-optic Internet service. Five years later, the city began offering 10 gigabit-per second service (for comparison, Time Warner Cable's maxes out at 300 megabits per second). That has attracted dozens of tech firms to the city that take advantage of the fast connections for things like telehealth-app development and 3D printing, and it's given downtown Chattanooga a vibrancy rare in an age when small city centers have been emptied out by deindustrialization and the suburbs. (Moskowitz, 2016, para. 2)

The Chattanooga service offers gigabit connections for $70 per month–about half the price of Comcast's 300 megabit (Mbps) connection–and offers a 100 Mbps service to low-income families for $26.99 per month. The system serves about 82,000 people, which is more than half the local Internet market. EPB spent about $220 million developing its system, which is integrated with the local electric utility. The municipality claims that it has translated this investment into $865 million in economic growth for the city (Moskowitz, 2016, para. 8).

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The Chattanooga economic revival story showed that for 2009 to 2012, the years immediately following the decision to invest in high-speed public broadband network,

> …median household income in Chattanooga grew by 13.5 percent and home values increased by 14 percent. This growth happened despite cruel austerity measures imposed by Tennessee's right-wing state government that resulted in roughly 3,000 jobs lost in the government and construction sectors. However, new businesses are rapidly locating to Chattanooga, eager to capitalize on the fastest internet in the United States (Gibson, 2015, p. 3, para. 3).

Another dimension of the municipal broadband issue relates to the *digital divide* of inequality of access for all Americans, a divide that has become a compelling matter of concern to the FCC. Issues relating to a digital divide have implications for social equity, economic distribution, and economic development more broadly—and are closely tied to the issue of net neutrality to be discussed here in a later chapter.

> "…a public Internet option may prove increasingly vital to low-income residents. Internet inequality is a growing issue in the United States: Internet connections are often required for job applications, and seven in 10 teachers assign homework that requires broadband access, according to FCC commissioner Jessica Rosenworcel; yet about one-third of low income families don't have high-speed Internet in their homes. According the Institute for Local Self-Reliance (ILSR), today there are over 450 communities in the United States offering some form of publicly owned Internet service. (Moskowitz, 2016, para. 7)

But the biggest problem facing municipal Internet services is not scale or the size of cities:

> …it's the cable companies. When Chattanooga first started planning its municipal network, Comcast sued, saying the service amounted to unfair competition for the company. It lost the suit, but Comcast and other companies have spent millions of dollars on ad campaigns and donations to local politicians in the hope that municipal providers don't expand more than they already have. The company has a history of supporting politicians opposed to public Internet service and lobbying state legislatures to pass legislation that prevents cities and towns from offering their services outside of their municipal boundaries. Eighteen states now have antiexpansion laws on the books (Moskowitz, 2016, para. 14).

4.3.6 Diverting fiber toward wireless

Verizon began to scale down its FiOS deployment plans in 2010 in spite of the prospect of $4.6 billion in federal subsidies for the FCC's "Connect America" program for affordable national broadband service under the FCC's new *National Broadband Plan* (NBP).[42] Verizon VP Thomas Tauke strongly criticized the program saying "…the FCC didn't take enough time to write the rules and moved too quickly to use those rules to regulate the Internet. …We want order, but we also don't want to hinder innovation and investment in this dynamic broadband and Internet marketplace" (Resende, 2010). The NBP had noted:

> …there would be a strong cable monopoly for video-speed broadband by 2015—a reasonable point given that only cable would be sufficiently upgraded to allow for speeds beyond 50 Mbps, that the phone companies were reluctant to make the necessary investments to lay fiber, and that there would be no competition among cable providers—and it suggested that municipalities should be able to bring high-speed Internet infrastructure to their citizens. The report also suggested a lengthy transition in which the government would switch to subsidizing high-speed Internet access rather than telephone service (so-called "universal service") (Crawford, 2013, p.60).

It is not surprising that Verizon found the NBP toxic to its business plan, and it foretold the situation that has subsequently emerged. A possible reading of Tauke's reference to "innovation" might be avoidance of regulated (i.e., wired) markets, and his reference to "investment" might mean investing in market power and monopoly. Thus, in reality, perhaps Verizon's objections had more to do with the likelihood that there was much more money and profits to be found in wireless than in fiber, and in its market coordination with Comcast. Building out FiOS would have cost $750 to $1,300 per home to wire up a neighborhood (Murphy, 2010). Verizon began to make non-compete deals with Comcast, allocating the market between wired and wireless networks. FCC allowed this and showed no interest in antitrust enforcement.[43]

Thus, fiber effectively became seen by industry as an adjunct to wireless rather than the reverse. The *Telecommunications Act of 1996* privileged cellphone towers from local regulation and ironically their fiber infrastructure took on the status of a public utility, with attendant powers of eminent domain.

4.4 Hiding the phone wires

As the primary focus of the telecommunication industry moved from regulated wireline to unregulated wireless networks and services, the wires came to be viewed by the industry as a way to support wireless. A newly self-restructured industry began to let conventional regulated public copper voice landlines languish, and more recently began to proactively decommission the landlines, possibly to broaden dependency on wireless.

But wireless comes with limitations. Cellular access towers, some 100 feet or more in height, have a range of only a few miles and limited capacity. Moreover, radio signals are notoriously subject to all sorts of impairments and transmission path idiosyncrasies. To deal with these problems, it has become advantageous to break down the system into a larger number of smaller cells. Called micro-cells, pico-cells or femtocells, these are basically miniature short-range cellphone towers positioned on utility poles, street lights, buildings, other structures, and indoors in malls, airports, and office buildings.

Sprint has introduced a femtocell strategy, which gained notoriety for proposing to "…install 70,000 antennas in the public right of way over the next few years. By comparison, it has 40,000 traditional antenna sites on towers or rooftops" (Knutson, 2016a). The strategy is depicted in Figure 4.1.

"As the primary focus of the telecommunication industry moved from regulated wireline to unregulated wireless networks and services, the wires came to be viewed by the industry as a way to support wireless. A newly self-restructured industry began to let conventional regulated public copper voice landlines languish, and more recently began to proactively decommission the landlines, possibly to broaden dependency on wireless."

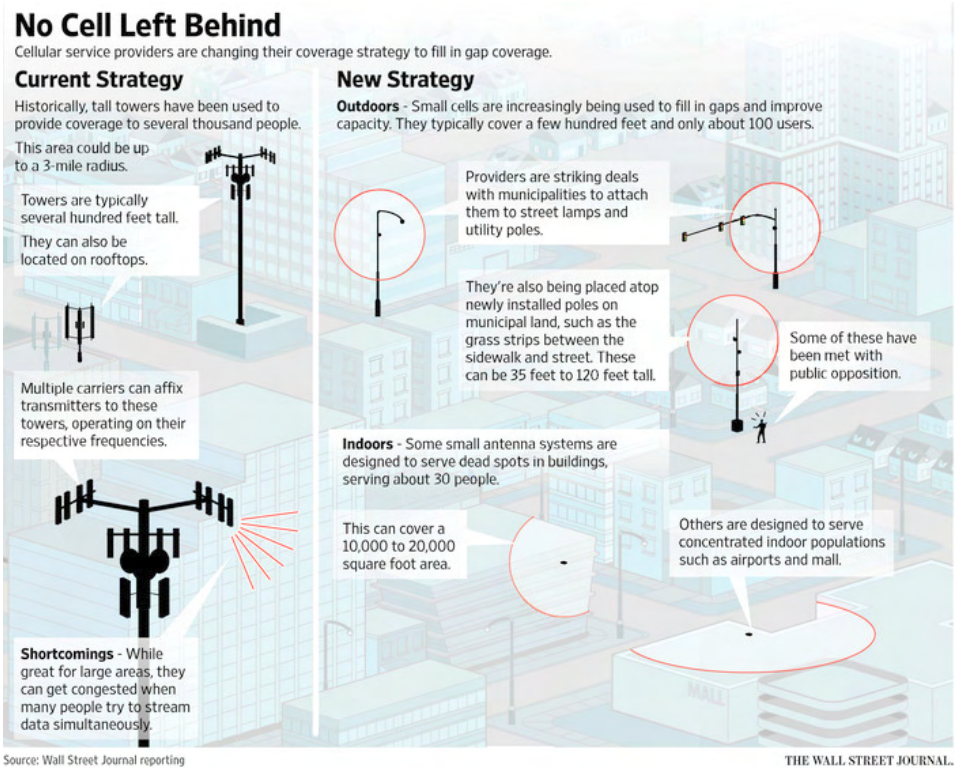


Figure 4.1—Small cell strategy (Knutson, 2016a)

This small-cell approach has been attractive to Sprint, in part because it serves to keep costs down. The small cells can cost $190,000 or less over 10 years, compared with a minimum of $732,000 for a traditional tower.

> Now that more people use smartphones to stream videos and surf the Web, carriers want to put lower-power antennas closer to the ground so that fewer people will connect to each one—resulting in less network congestion.
>
> "It's not a new concept," said John Saw, Sprint's chief technology officer. "All carriers are trying to 'densify' their networks." But Sprint's goal is to be "cheaper and faster and more innovative" than its rivals, he said (Knutson, 2016a).

This approach has met with difficulties. Sprint works primarily with Mobilitie LLC, a Newport Beach, California, company, to build cellular antenna systems from California to Massachusetts. Mobilitie, which has commenced building the system, states that its transmitting devices are typically the size of a briefcase and can be located inside boxes attached to the poles.

> [Mobilitie] has filed applications under various corporate names, including the Illinois Utility Pole Authority, NC Technology Relay Networking, and Interstate Transport and Broadband. It has used similar-sounding names in at least 30 states.
>
> Joseph Van Eaton, a lawyer who represents municipalities dealing with the applications, says the names are misleading. "You may very well end up with some of these applications being granted for exactly the reason why they like these names—it sounds official," he said.
>
> Mobilitie is willing to modify its applications to avoid being disruptive, Mr. Jabara says. "It's

> more important to be a good citizen" than to move quickly, he said. "You have to do the right thing." Mr. Jabara says the names also make it easier for local officials to understand the status of his firm. The company is a registered utility and those business names help reflect that status, he says. "In some states it's more comprehensible for a jurisdiction to work with an authority," he said. In the future, the company will most often use the name "Mobilitie" in dealings with local officials, he said (Knutson, 2016a).

Thus, ironically, while the wires (including copper and fiber) providing new femtocells with high-speed *backhaul* come to be effectively hidden from public view, their importance to the carriage of data has become more important than ever, even while cloaked by the pretense of wirelessness.

Recently, an intermediate level of backhaul has emerged that uses wireless methods to augment fiber backhaul in areas where the corporations running fiber or copper cabling find it inconvenient or unprofitable. This wireless backhaul method uses millimeter wave transmission as a cheaper substitute for some of the fiber, even though this method introduces a potentially performance-limiting bottleneck. Although wireless link can never be comparable in speed and reliability to fiber, or even copper, wireless backhaul has become part of the rationale for, and the hype around, 5G. The effect of recent FCC 5G spectrum policy has been to substitute an inferior technology for fiber and cast the transition as an advancement.

"Although wireless link can never be comparable in speed and reliability to fiber, or even copper, wireless backhaul has become part of the rationale for, and the hype around, 5G. The effect of recent FCC 5G spectrum policy has been to substitute an inferior technology for fiber and cast the transition as an advancement."

4.5 Cable wires—a case of "American exceptionalism"

Since its inception over six decades ago, the cable industry has been seen as exceptional (and treated as such by legislators and regulators) because, until quite recently, it evolved separately from other communications technologies. Following the introduction of broadcast television in the 1950s, the cable industry began as a highly localized movement called community antenna television (CATV), wherein local entrepreneurs built infrastructures to provide high-quality reception of over-the-air TV signals to viewers in remote areas for a fee.

4.5.1 Financial and regulatory exceptionalism

Entrepreneurial mom-and-pop cable operators obtained local franchises allowing them to string coaxial cable on local phone and power poles to carry TV signal from a central antenna to each subscriber. There were soon thousands of local cable operations, a distinctly low-tech business based mainly on construction financing and subscription revenue. As an essentially private

franchise system, CATV escaped FCC regulatory oversight that governed broadcasting and telecommunications services. Operators tended to be thinly capitalized, but the revenue stream was lucrative, coming from local monopoly franchises. Accordingly, the industry set about on a long path of acquisition and consolidation.

Over time, with consolidation and system expansion, cable companies grew larger and larger, formed their own content networks, and developed technical standards for voice telephony and Internet access. The most important standard was a technology known as data over cable service interface specification (DOCSIS), which enabled full-service delivery (voice, video and data).[44]

4.5.2 Technical exceptionalism

Initially, the signals transmitted over coaxial cable were essentially the same as those transmitted via the analog TV channel spectrum, but confined within a wire.[45] With the emergence of packet switching technology, and then the Internet, the cable industry developed protocols to allocate part of the cable spectrum to digital data, making cable interface boxes with standardized DOCSIS. The new DOCSIS cable boxes could provide output connectors to transmit conventional analog TV channel signals, conventional analog voice telephone, and Ethernet to carry Internet digital data for computer devices. With this merging of technologies, questions regarding how they would be regulated raised issues that the *Telecommunications Act of 1996* was supposed to resolve. The problem was basically that similar or identical services were falling under different regulations, depending on what medium was carrying them, with implications for what types of industries would be more profitable and, in turn, how the (ostensibly) public communication infrastructure would be built out.

The Act did not resolve these issues and cable largely escaped regulation. Local franchise operations were not competitive with each other geographically, so there was no antitrust enforcement with regard to TV service. The cable industry continued to consolidate into a massive monopoly with Comcast seizing the lion's share of the market, and its main rivals (by revenue), Time Warner and Charter, together accountable for less than half the revenues of Comcast. The cable industry remains essentially unregulated, except by local franchise arrangements negotiated with cities and towns, with essentially no competition for Internet access except from local regulated telephone companies with slower DSL technology.

4.5.3 Technical limitations of cable

Cable TV was initially a one-way service with TV signals flowing downstream on a coaxial cable as a "shared medium" from a cable headend to subscribers. DOCSIS enabled some data to flow upstream from each individual subscriber to the headend, but cable remained a shared medium, unlike conventional phones lines or DSL service. This meant that its speed and capacity depended on the number of users at any given moment—similar to wireless but unlike conventional wired phone service is dedicated copper wire pair to each subscriber.

Therein lies a key limitation of cable (and wireless) services—asymmetric service (where upload speed is much slower than download). Cable networks are designed primarily for the downstream flow of information, such as television content, and as such are adequately suited for downloading and streaming Internet audio, video, and other consumer products and services. However, upload speed and capacity present formidable technical challenges, subjecting the

network to congestion delay and latency problems. Two-way broadband isochronous data (e.g., voice telephony, conferencing, etc.) presents problems in such a system.

As shown in Figures 2.1 and 2.2, cable can be fast but typically provides upload speeds and capacities that are far slower than download. As Crawford points out, "…only symmetric connections would allow every American to do business from home rather than use the Internet simply for high-priced entertainment (Crawford, 2013, p. 262)." In network geek-speak, *every client should also be a server* (where each subscriber can be both a receiver and a source of information).

4.5.4 *Xfinity—Comcast's* wireless strategy

Comcast has a wireless strategy—to use local Wi-Fi at the user end of its network to draw traffic from cellular phone customers (of any network) who have Wi-Fi-enabled smartphones. Such a configuration can hand off cellular network calls to local Wi-Fi when available, allowing traffic to be diverted from the cellular network to the Internet. This is described by Jeromy Johnson, a Comcast critic, as follows.

> Xfinity is Comcast's new system for delivering content. However, rather than just delivering your internet and cable, Comcast is using your new Xfinity router as a gateway into your "smart home" and to deliver WiFi service to anyone within a few hundred feet of your home. The plan is to turn their customers' homes into public "hot spots" with the result that WiFi is nearly ubiquitous in our communities.
>
> Comcast's stated ambition is to take away some of Verizon's or AT&T's business as people will be able to use Xfinity WiFi rather than the cellular networks for their mobile data. This will also give the company much more personal data on its customers, which has become very profitable for companies (Johnson, 2015).

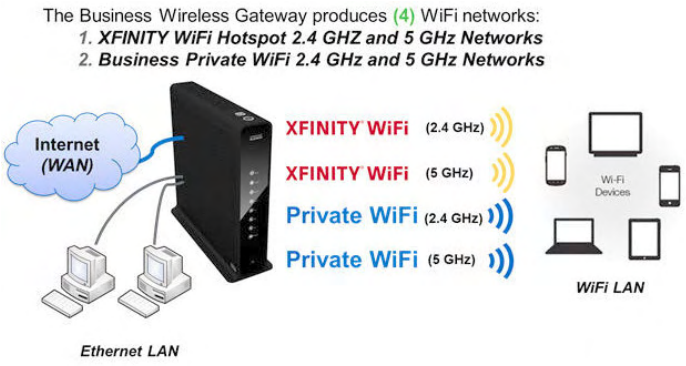


Figure 4.2—Xfinity Wi-Fi strategy (Comcast promotional image)

Figure 4.2 shows a diagram of Comcast's *Xfinity* Wi-Fi router strategy. Even though the text in the image says "Business Wireless Gateway," service is also provided to residential customers. This device essentially makes each subscriber's home into a public hot-spot, unless the subscriber knows they can opt-out or install their own router. The primary concerns articulated by Johnson are risks of exposure to excessive microwave radiation, risks to personal privacy, and diminished network performance.

4.5.5 Policy of exceptional paucity

The cable industry is a case of American exceptionalism in regulatory, economic, technical and business terms. No other society has developed communication services in such a manner. Cable service is exceptional mainly in its paucity: exceptionally high in cost, exceptionally slow in speed, and exceptionally poor in service. Comcast and Time Warner, the largest U.S. cable providers, are among the top 10 most publicly disliked businesses in America (Marte, 2012).

4.6 The triopoly—pre-empting the public and reincarnating Ma Bell

As the telecommunications market consolidated, subsequent to the *Telecommunications Act of 1996*, a comfortable and profitable triopoly formed among cable (Comcast) and wireless (AT&T and Verizon) companies. This arrangement has essentially removed competition and led to stagnation of wired and wireless broadband access in the United States, attributable to artificial scarcity and consequent high prices. Figure 4.3 shows the relative distribution of the broadband market. This clearly shows that AT&T, Verizon, and Comcast are the dominant providers by a large margin.

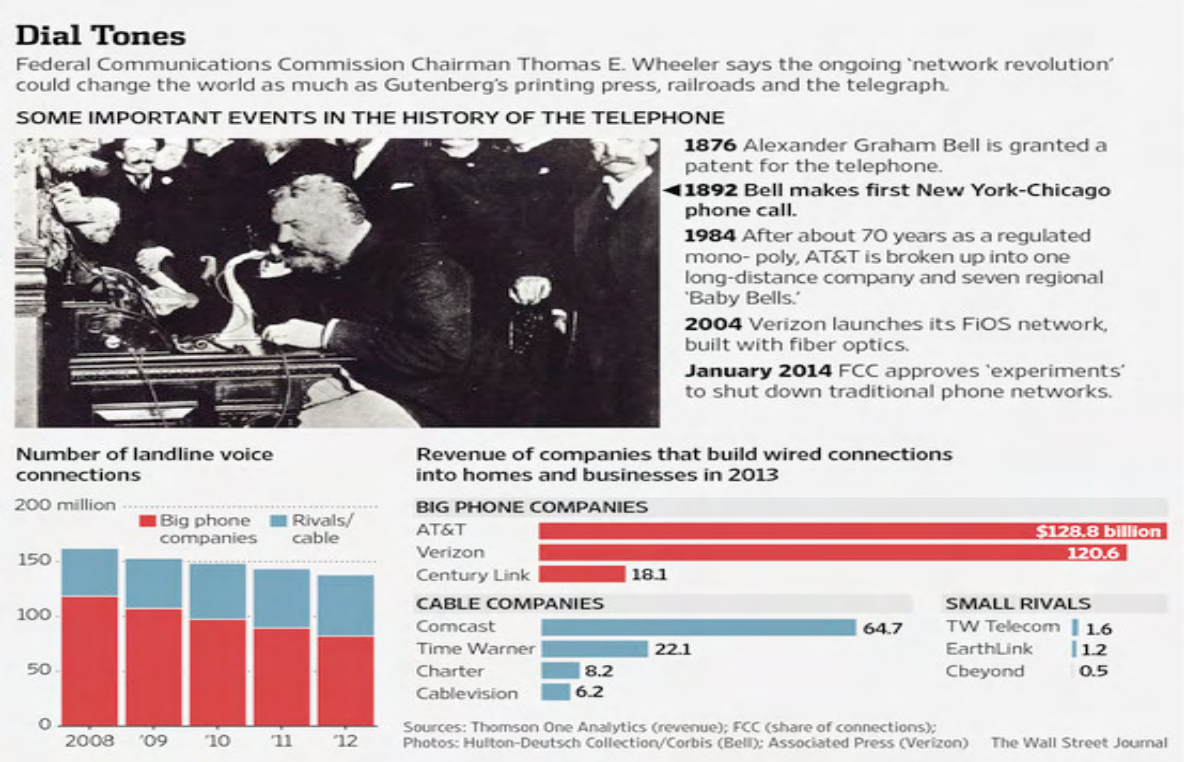


Figure 4.3—Phone and Cable companies and their market share

4.6.1 Consolidation and reincarnation

Figure 4.3 shows capacity and revenue data along with market share for the principle phone and cable companies. It is evident that the market power exerted by the triopoly of Verizon, AT&T, and Comcast collectively exceeds that of the former Bell System monopoly—this in

"Why has the richest country in the world fallen behind the rest of the world in Internet access, a technology created by American taxpayers and innovation? The answer arguably relates to the failure of private economic markets to provide infrastructural pubic goods…Expecting private interests and private capital to develop a basic public communication infrastructure invites conflicts of interest and market failure, has not been successful historically, and is not likely to be successful in the future."

spite of major antitrust litigation in 1984 (the Bell System divestiture) and a major rewrite of legislation in 1996 (the *Telecommunications Act of 1996*). The deregulation and re-regulation of telecommunication since the late 20th century has spawned a dominant triopoly of wired and wireless access carriers, making the United States one of the most-expensively networked, least-connected nations in the industrialized world.

Why has the richest country in the world fallen behind the rest of the world in Internet access, a technology created by American taxpayers and innovation? The answer arguably relates to the failure of private economic markets to provide infrastructural pubic goods, an economic maxim that is discussed in the conclusion that follows. Expecting private interests and private capital to develop a basic public communication infrastructure invites conflicts of interest and market failure, has not been successful historically, and is not likely to be successful in the future.

Dominant carriers in the United States have blocked municipal fiber by industry-sponsored legislation that prevents local governments from offering fiber broadband service "competing" with them, while at the same time declining to build out their own infrastructures. In turn, carriers are able to cherry-pick the most profitable customers and maintain artificial scarcity and high prices, while rural communities and the urban poor languish on the wrong side of the digital divide. State laws and policy arguments against municipal broadband are justified by claims that government competition and the FCC's *Net Neutrality* or *Open Internet* policy principles restrain investment because they "…depress the rate of return of broadband providers sufficiently that the stock value of those providers would be punished by financial markets" (Rose, 2010). These arguments assume that the purpose of building broadband infrastructure is to serve the needs of shareholders and the management of private corporations rather than the needs of the public.

4.6.2 Conclusion: basic public infrastructure needed

Broadband access has taken on importance comparable to other basic infrastructures, such as streets, roads, highways, bridges, sewer systems, water systems, and the like, which are taken for granted, and generally produced or ensured by public authorities. These products and services are understood to be public goods—things that tend to be underserved by the market and that only government is able to build and/or facilitate.

The wires—old and new—copper and fiber—constitute a public right-of-way and a basic public good in both senses of the term. Because the wires provide their benefits indefinitely and effectively without limit (nonrival) to everybody who wants them (nonexcludable—a gift that keeps on giving), the communication infrastructure, roads, and other public goods tend to be public goods in the vernacular sense as well—they are good for the public.

The *Telecommunications Act of 1996* set out to compel competition in wired and wireless markets while at the same time deregulating them. The irony here is that competition and deregulation are usually at the same end of the regulatory policy "spectrum"—that is, we regulate to control private companies when there is little competition and conversely we deregulate when there is adequate competition. But that is not what happened in telecommunications. The *Telecommunications Act of 1996* argued to remove regulation and let the "market" rule. It ignored that competition may not develop in all markets or services. It also assumed that competition in one market would compensate for lack of competition in other markets offering similar services. It further ignored that the boundaries between *technologies,*

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Public Goods

Public goods are products and services that tend to be under-produced by a market economy and thus usually provided by governments. Public good is a term that has related but different definitions as an economic term versus in the vernacular. In economics, a public good is a product or service that is nonrival, meaning its consumption does not reduce the quantity available for others to consume, and non-excludable, meaning that once the product or service has been produced, no one can be excluded from consuming it. As is the case for all economic goods, public goods will be priced in the marketplace at the point of intersection between marginal cost (zero for nonrival goods) and marginal revenue (zero for non-excludable goods), which is to say in an unregulated economic market, access to highways and the network infrastructure will be priced close to zero. Accordingly, in the absence of governance providing an incentive to develop these infrastructures, no economic incentive exists for private parties to produce them. Accordingly, the economic market tends to under-produce public goods, and so they tend to be produced, subsidized, and/or regulated by public authorities (thus the term "public" good).

markets, and *services* would blur, particularly with the Internet. Most importantly, as has been shown in the foregoing chapter, it allowed (and unintentionally encouraged) consolidation in each market through mergers and acquisitions with lack of anti-trust enforcement or restrictions.

With respect to telecommunication infrastructure over more than a century and a half, the privatized economic markets have repeatedly failed to provide the infrastructural goods to meet the needs of the people and there is no reason to believe continued unrestrained economic activity is the answer. As per other public goods, communication has not been well served by market mechanisms or regulated monopolies. The public must regain control over this vital public resource if the public's communication needs are to be met—and failure at the federal level shows that the solution must ultimately be local. It now falls on communities to take the initiative to build their own future, as it is not realistic to expect private capital to do it for them.

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5 Reinventing the wires

The ascendency of wireless communication devices in recent years, including the shining success of Apple's *iPhone* and Google's *Android* smartphones along with tablets, such as the *iPad*, watch computers, navigation devices, exercise tracking devices, etc., has obscured a behind-the-scenes technical renaissance—the rapid evolution of the performance of wired communication, old and new, including optical fiber and copper wires—which has literally served as the groundwork underlying the success of these consumer products and services.

Science and engineering have pushed signaling technology to new levels of performance that only a few years ago were thought to be impossible. Copper cabling has achieved performance comparable to optical fiber, particularly over shorter distances (e.g., neighborhoods, buildings, factories, and data centers), such that some standards developers have begun to refer to copper as "cabling 2.0."

Due to the inherent performance limitations of wireless signaling methods and networks, the successful application of wireless has come to depend very much on getting cell sites and wireless access points as close to the user as possible. This is accomplished through a proliferation of copper and fiber networks that are literally and figuratively invisible to the public. Representatives of the copper wire and optical fiber industries openly acknowledge that the popularity of mobile devices has created a business boom of unprecedented proportions for their products.

This chapter describes the state of wired technology and associated technical trends. It will compare wired media with wireless in terms of performance as well as other considerations, such as power delivery and energy efficiency, and will also discuss associated environmental issues. This chapter describes new physical and signaling technologies of the wired communication methods or media mentioned in earlier chapters, including copper phone pair, DSL, cable, Ethernet, and optical fiber. As a result, the distinction between *technology* and *services* has become more ambiguous as they both become folded into various parts of the "protocol stack"—new features/characteristics are added, new services/applications are enabled, and new terms and meanings are created.

5.1 Technology of wired communication

The term *wired* is defined for this paper as the use of thin drawn-out threads or rods of metal, glass, or plastic that conduct information by modulating a flow of electrical or electromagnetic energy. In practical terms, wires take two forms:

- copper conductors—
    - in plastic-insulated pairs of wires, twisted together, unshielded or shielded, with signal current flowing in each wire, in opposite directions
    - in "coax" (cable), a single plastic-insulated and shielded wire, with simultaneous 2-way transmission over the wire
- optical fiber—a single glass thread, typically combined in bundles of 12 or more, acting as a thin "pipe" for a beam of light with data transmission coded onto the light (by flickering or "modulating" the light).

These transmission media have significantly different characteristics, in both physical and data transmission terms. A data speed capability comparison is shown in Figure 2.1.

5.1.1 Copper wire

Copper phone pair

Conventional voice telephone service is provided by twisted pairs of copper wires forming loops that run directly from a local central office switch to subscribers' telephones and back.[46] In addition to coded voice signals, these wires provide a small amount of DC power from 48-Volt battery banks at telephone central offices to supply enough power to operate simple telephones. The pairs are twisted in order to provide some amount of shielding to prevent electromagnetic radiation from escaping the wires and to prevent external radiation from being picked up by the wires. Each pair of wires typically connect directly to a conventional telephone set. Multiple phone pairs are typically combined into bundles called *binders*, which are in turn combined into large cables.[47]

This system has been in place for over a century. The range of frequencies needed for voice service was modest at the time—about 3 or 4 kHz—and well within the signal carrying capabilities of a pair of phone wires. With the introduction of FAX equipment in the 1980s, images were digitized by FAX machines, encoded at 8 Kb/ps into audio tones, and sent over the 4 kHz voice band. Digital modems became popular during the 1980s and 1990s, allowing computers to send data over the 4 kHz voice band at data rates up to 56 Kb/ps.

DSL—Digital Subscriber Line

To address the need for even more data capacity, *digital subscriber line* (DSL) was developed in the late 1990s to utilize frequencies above the normal voice band frequency of 4 kHz (i.e., data over voice-grade phone pair). DSL allowed simultaneous two-way transmission of digital data using the same pairs as voice traffic, but not audible to users talking on the phone. This technique provided much more-than-heretofore efficient use of the inherent capabilities of the copper wires that had been installed for many decades. DSL is generally capable of sending data at speeds as great as 7-10 Mb/ps (and sometimes up to 50 Mb/ps in the case of *VDSL* or up to 800 Mb/ps for some *G.fast* versions) up to several miles to and from a telephone central office.[48]

The limiting factor associated with DSL is loss due to distance and the number of other pairs in the binder group that might create unintended interference or *crosstalk* with each other. Performance can be improved by locating DSL access multiplexer (DSLAM) devices in the field, closer to subscribers (typically in green cabinets beside the road or mounted on poles). DSLAM gets digital data via optical fibers from the central office and then modulates the digital data onto the appropriate local subscriber pairs, over shorter distances, and in smaller binders, resulting in less loss and interference. Newer versions of DSL, such as *VDSL* and *VDSL2* (very high speed DSL), can achieve data rates of 20–40 Mb/ps, or even higher over short distances. New standards are being established for *G.fast*, which enables throughput of better than 1 Gb/ps (or 1,000 Mb/ps) over a single twisted pair by employing new multiplexing techniques (Lavoie, 2016). For a sense of what these data speeds mean in terms of usefulness, see Figure 2.2.

DOCSIS

The main competitor to DSL, the method used by phone companies to provide Internet access today, is coaxial cable using DOCSIS for wired Internet service, as described previously. A key difference between DSL and DOCSIS is that DOCSIS is a shared service while DSL is a dedicated pair service; thus DSL is not subject to degradation from congestion in the access network. A single, dedicated DSL pair is connected from the service provider to each customer, whereas for DOCSIS service provision, coaxial cable output is shared and thus shared among multiple customers. Coaxial cable has inherently higher bandwidth than twisted pairs. This data speed difference is shown in Figures 2.1 and 2.2. DOCSIS can typically achieve data rates of 100 Mb/ps, about 10 times faster than DSL. However, DOCSIS is typically split among more than 10 user drops and so is subject to congestion depending on user traffic. Thus in practice, DOCSIS is not always faster than DSL.

Ethernet copper cable

Another form of copper wire pair that has re-entered the market for wired communication is *Ethernet*, also known as IEEE 802.3. Ethernet was one of the "winning" technologies that emerged from Xerox PARC in the years surrounding 1980.[49] The term Ethernet defines both a communication protocol and a signaling method. Initial versions of Ethernet for early local area networks (LANs) used coaxial cable and ran at 10 Mb/ps, but the protocol and signaling method were soon adapted to operate on twisted pair.

Ethernet nomenclature has the format of 10BASE-T, signifying 10 megabits per second, baseband, twisted pair. The term "baseband" means that the protocol does not use a tone or frequency band for signaling (as do FAX and modems), but rather a changing voltage level signaling/coding method such as pulse amplitude modulation (PAM). Twisted pair was much easier than coaxial cable to connect, splice, or route, so it became preferred by the market. Accordingly, during the 1980s and early 1990s *Ethernet* came to dominate the market for interconnecting computer networks and devices over many competing LAN technologies (with the exception of the industrial control market). Ethernet pairs are often packaged into cables containing multiple pairs, usually four pairs, which may be wrapped in a thin foil shield. These cables, which are based on traditional copper twisted pair phone cables, are standardized for performance specifications as *Category 1* through *Category 8* (a.k.a. *Cat1* through *Cat8*).

Contemporary Ethernet operates at gigabit speeds over Category 5 and 6 cable (available at any hardware store), and is terminated with standard RJ-45 8-contact modular connectors found on most computers, modems, routers, etc. Ethernet is highly standardized[50] and recently completed versions for twisted pair copper are specified mainly for use in residential, commercial, and industrial buildings, including data centers for 2.5GBASE-T, 5GBASE-T, and 10GBASE-T.

Coaxial cable

Coaxial cable is a form of copper wire in which one conductor is in the center separated by a tubular insulator from an outer tubular conductor shield made of a thin wire mesh. This design forms an electrical pipe that keeps radio frequency signals from leaking and keeps external signals from intruding and interfering. Coaxial cable, known as "coax," has been around a long time and is typically used for antenna feed wires for radio and television, as well as for CATV, or cable networks. Coax was also used for initial versions of Ethernet, but the performance of

shielded twisted pair has come to rival coaxial cable.

Coaxial cable comes in different performance specifications, such as RG59, RG6, and RG11 (three typical standard coax size specifications). Larger coax necessarily has lower loss, thus higher performance. Moreover, coax shield performance levels, e.g. *dual shield* and *quad shield*, contribute significantly to reduced signal loss by reducing leakage while adding to size and cost. Coaxial cable has the disadvantage of being more difficult than copper wire pair to terminate, splice, and install. Coax is usually terminated with a threaded metal fitting and nut.

5.1.2 Glass fiber

Optical fiber uses beams of modulated light carried through tiny strands of glass to serve as electromagnetic waveguides or pipes to send data, most commonly using infrared wavelengths.[51] Electronic encoded data signals are used to modulate infrared light emitted by LEDs or lasers at one end of fibers. The light carrier is guided by a dielectric waveguide, which is normally made of silica glass. Light is confined inside the fiber, within cylindrical fiber cores, by reflection and refraction, even though the fiber may bend (if the bends are not too sharp). Fiber transmissions are highly efficient and can travel considerable distances. At the receiving end of the fiber, a photoelectric sensor converts data back to an electronic signal.

Fibers require precise termination (i.e., cutting and polishing of fiber surfaces). Each length of fiber needs an electronic *repeater* or *transceiver* that receives light signals, amplifies them, and send them onward onto the next fiber link. As link reach is increased from 500 m to 50 km, so does transceiver cost increase two orders of magnitude (equivalent to 100 times). Although fiber can be terminated in the field, doing so is a laborious and expensive procedure. Accordingly, fibers are typically factory terminated in pre-cut lengths so they can plug into standardized transmitter, receiver, and transceiver devices.

5.2 Renaissance in copper wire and fiber

Wired media such as copper and fiber have continued to advance, mostly in terms of improved packaging (cabling), termination (connectors), and data signaling and encoding.[52] Today gigabit data rates have been achieved on all forms of copper (including ancient phone pairs). Alcatel-Lucent (formerly part of Bell Labs) has demonstrated glass fiber data rates of 1.4 terabits per second (Tweed, 2014)[53]. Fiber can commonly achieve commercial data rates of 25 Gb/ps using a single wavelength (color), and multiple wavelengths can be used over the same fiber. Although there have been technical improvements in wired media, particularly fiber, most performance gains have been found in signaling and encoding techniques.

5.2.1 Fiber advancements

After more than 30 years of development, optical fiber technology has improved to achieve state-of-the-art commercially available links capable of up to 50 Gb/ps rate (per wavelength/per fiber) over more than 20 km reach. The fiber industry is comprised primarily by six major, global manufacturers of optical fiber, each with proprietary design and production technologies. Minor variations result in less than optimum interoperability standards.

The implementation of optical fiber provides almost no economies of scale. Individual fibers are very thin (i.e., smaller than a human hair). Typical optical fiber cables use a minimum of 12 fiber bundles. Larger fiber cables can be bundles of 24 to 48 fibers or more. Large trunk cables can contain 24 bundles, or even more. The cost of installation far exceeds the cost of the fiber. As a result, it is common practice to overbuild capacity and leave excess fiber "dark".

Recently optical fiber has been gaining ground as a practical alternative connectivity for customer premises, i.e., fiber to the home (FTTH). The way FTTH is applied is essentially a variant of DSL technology, wherein the intermediate fiber-to-copper DSLAM is merged with the customer's optical-network-terminal (ONT), such that the copper cabling resides entirely within the customer premises. Typically a single fiber link from the service provider is split among multiple customers, similar to the structure of CATV coax networks. FTTH networks are implemented using passive optical network (PON) technology; i.e., splitters. Figure 2.1 compares the relative data speed capacity of optical fiber versus other transmission technologies. Figure 2.2 provides a comparison of download and upload times for fiber compared with other methods.

Advantages, disadvantages, and limitations of fiber

- Advantages of fiber
    - Reach: the big advantage of optical fiber lies in long-links—for a particular speed, reach can be up to 100 times farther than copper for similar cost.
    - Capacity
    - Speed
    - Reduced size and weight compared to copper for similar capacity and speed
    - Lack of radiation and electrosmog
    - Security
    - Privacy
- Disadvantages of fiber
    - Termination —requires light-to-electronic amplifier
    - Repeaters—requires light-to-electronic amplifier-and-back-to-light
    - Less standardized
    - The disadvantage of optical fiber is in short-links. Below the fiber link-length point of diminishing returns, without transceivers, copper link cost is a fraction of optical fiber link cost.
- Limitations of fiber
    - Limited-bending
    - Complex cut, repair, and splicing
    - Recently the optical fiber bending problem has been practically solved, but only for proprietary, new premium fiber types. Nevertheless, after nearly 30 years of developments, splicing, repairs, and connectors remain complicated and expensive.

Future of fiber

Plastic optical fiber (POF) continues to undergo gradual developments and improvements. The basic POF technologies have not changed in 30 years, although a gradual cost reduction has continued for related components. One might speculate that the broader application of digital

"According to Columbia University Finance and Economics Professor Eli Noam, Director of the Columbia Institute of Tele-Information, wireless has a U-shape average cost/performance curve that depends on factors such as spectrum availability, cell siting, technology upgrades, and operations. In contrast, the wireline cost-per-bit curve is straight, dropping indefinitely with speed (Noam, 2011, p. 477). Also, according to Noam, "…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" (p. 476). Accordingly, copper and fiber may be considered to be "…future proof compared with wireless" (p. 481)"

connectivity to the IoT and industrial automation applications will enable wider use of POF. For example, POF would be useful in new short-reach applications that will likely require smaller fiber size and weight, combined with the radiation immunity advantages of optical fiber.

5.2.2 Copper wire advancements

Ordinary legacy copper phone twisted pair can now deliver 1 Gb up to 70 meters (330 feet). Ethernet is specified up to 40GBASE-T (40Gbit/ps over 4-pairs) using Category 8 up to 30 meters, and down to 10BASE-T1 (10Mbit/ps over 1-pair) using Category 5 specifications, up to 1 kilometer with power (similar to current DSL technology). Alcatel-Lucent has demonstrated 1 Gb/ps rates over a standard old copper pair at 70 meters (Tweed, 2014).

Every time Ethernet seems to have reached a limit, a new version has been developed and standardized. The newest versions are 25GBBASE-T and 40GBASE-T. The practical limit for enhanced twisted pair cable links now appears to be about 25 Gb/ps reaching about 50 meters (Hess, 2016).

Active (amplified) antenna wireless inside buildings, in both WiFi and small cell LTE systems is considered to be the first "killer-app" for high bandwidth copper wire data links, and can also carry up to 100 watts of DC power. These *front-haul* copper links, originally intended to connect wireless access points (WAPs) inside buildings, are the network equivalent of the backhaul optical fiber links connecting cellular towers to wireless operators and the core network.

5.3 Technical trends, issues, and what is possible with wires

Copper wire data links with Power Delivery (PD) up to 100W DC power are a recent breakthrough. Power delivery (PD) over data wires, combined with other LAN energy-saving efficiencies (e.g. sleep mode), provides a new opportunity for a highly efficient DC power infrastructure. For Ethernet, this is called *power over Ethernet* (POE). The Ethernet wire delivers the data and also its POE power can be used to operate the amplifiers and other electronics for the cellular or WiFi access point. In this manner, a building or facility can be equipped with many access points, increasing system capacity and/or reducing network congestion. This approach, sometimes called antenna "densification," is also intended to help compensate for the limitations imposed by 5G's millimeter wave propagation characteristics (short range, lack of penetration, line of sight, moisture absorption, directionality, etc.). In summary, the industry's basic goal of PD/POE is to use copper wire to get access points closer to the wireless user.

Standard *Energy-Efficient Ethernet* (EEE) covers the energy-saving efficiencies, such as sleep mode. Power delivery opens the door to many IoT, premises-control and communications applications beyond wireless front-haul, including wired lighting-control systems, energy management, building automation, multimedia, and security applications.

5.3.1 New Ethernet connectors—with power delivery

Delivery of DC power over data wires opens opportunities for consumer products. The familiar Universal Serial Bus (USB) is being upgraded to 3.1 using the new type-C connector. A Type-C connector is designed to handle up to 100W of DC power to support a large television with 10Gb/ps data and power over the same connection. The Type-C connector includes up

to four additional high-speed pairs, adding the capacity for supporting *alternate modes* (e.g., Displayport, HDMI, SATA, and Ethernet).

New wiring and cabling standards establish an alternative to WiFi and other wireless access for use in homes and buildings. WiFi may be convenient but it typically reduces the user's effective data rate significantly. The WiFi speed penalty may be attributable to a combination of factors that include WiFi congestion, older router technology, and the reluctance of Internet providers to offer the latest WiFi routers (Ramachandran, 2012). Another benefit of the wired infrastructure described above is reduction of wireless RF background noise that might impair the operation of low-power energy-harvesting IoT devices that explicitly require wireless connectivity. Another benefit is that new wiring standards could alleviate or eliminate the need for millimeter wave backhaul and 5G wireless.

Although originally intended to enable distributed wireless, the same copper/POE technology could open opportunities for new distributed wired applications and offer higher data speeds and reliability throughout a home or building without the need for batteries or wireless transmission. It could provide the consumer an alternative to 5G backhaul or to smartphones and other devices (e.g., smoke and gas detectors, baby monitors, security devices, energy sensors, tablet computers, laptops, information displays, wired phones, etc.).

5.4 Conclusions about new wires

Following are summaries of the advantages of copper wires and the disadvantages of wireless networks for the final link to the consumer.

Advantages of copper wires for broadband access

- Reliability
- Privacy
- Security
- Energy efficiency
- Power delivery over copper phone lines
- Power delivery over copper Ethernet (POE)
- High data rates
- Lack of radiation and electrosmog
- Upgrade for existing public right-of-way to deliver broadband

Disadvantages of wireless

- Unreliability
- Latency
- Delay
- Vulnerability to security and privacy problems
- Dependency and stranding ("upgrades" and obsolescence)
- Dependency on batteries and battery charging
- Network access and traffic loading in emergencies
- Wasted energy
- Public health risks

5.4.1 Conclusion

According to Columbia University Finance and Economics Professor Eli Noam, Director of the Columbia Institute of Tele-Information, wireless has a U-shape average cost/performance (per bit) curve that depends on factors such as spectrum availability, cell siting, technology upgrades, and operations. In contrast, the wireline cost/performance curve is straight, dropping indefinitely with speed (Noam, 2011, p. 477). Also, according to Noam, "…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" (p. 476). Accordingly, copper wire and fiber may be considered to be "…future proof compared with wireless" (p. 481)

Wireless access has been artificially inflated by regulatory disparity. Present technology and a market trajectory of dependence on wireless are unsustainable as a long-term solution for many reasons, including:

- Not efficient (energy or materials)
- Not sufficient (economically or in performance)
- Not self-sufficient (energy or materials)
- Not sustainable (economically, in energy, environmentally, socially)
- Vulnerable (hacking)
- Growing health concerns

5.4.2 Recommendations

This report recommends public policies and practices that promote a nationwide buildout of FTTx (fiber to the home, curb, business, neighborhood, etc.). Such a buildout would bring benefits to our entire society and economy including:

- Providing for basic needs—Enable reliable Internet access for all that is fast, reliable, secure, enduring, affordable, safe, and supporting public goods such as local governance, education, and libraries.
- Reducing communication costs—Facilitate the efficiency of economic activity and civic engagement by reducing the costs of a wide range of economic and civic activities that increasingly depend on networked communication.
- Supporting economic growth and participation—Drive employment and economic development, following a model that dates to the New Deal WPA (Works Progress Administration) electricity grid, which greatly stimulated economy and employment in the short term while building an infrastructure that provided economic value in the long term.

The successful municipal fiber system in Chattanooga, which was built by the town's municipal electric utility, the Electric Power Board (EPB), with the aid of partial federal grant funding, stands as a stellar example of the virtues associated with a strong public wired network. Another more recent example is that of *NextLight*™, the municipal broadband system built by the City of Longmont, Colorado municipal electric company providing FTTH symmetrical gigabit service throughout the city and its adjacent electricity service area initially for $49 per month per subscription. The synergy between broadband "streets and highways" and the provision of information access and electricity as public goods represents a rich opportunity for our communities and society.

Recommendations to maximize the use of wired communications technology:

- Build-out local FTTx Internet access nationwide.
- Re-think the entire digital network architecture for a sustainable future by addressing all of the issues identified in this report (e.g., access, security, privacy, dependency on advertising, dominant interests, monopoly/antitrust, net neutrality, IoT, public health and safety, etc.).
- Use wireless only where appropriate (e.g., for things that move)
- Commit fully to the principle of network neutrality and equal access for all.
- Challenge the traditional obsession with privatization concealing what are actually "taxes" behind arcane utility rate structures or "public-private partnership" ventures.
- Critically reconsider the notion that public goods can effectively be built by private for-profit business interests who have conflicting financial incentives.
- Develop policies, guidelines, and incentives for innovators that encourage development of information and communication infrastructure and applications that serve the long-term public interest.

The synergy between broadband "streets and highways" and the provision of information access and electricity as public goods represents a rich opportunity for our communities and society.

6 Energy use and efficiency of communication

An emerging issue surrounding the increasing growth of, and dependency on, communication networks relates to their use of energy. The dramatic growth—some would say "explosion"—in electricity consumption associated with the operation and manufacture of all forms of communication networking (approaching 5–10% of world electricity supply)[54] has raised questions about the sourcing and projected growth of electricity demand and dependency. It is ironic that an advanced technological global information and communication technology (ICT) system is dependent on an inefficient, polluting, and archaic energy source—coal. This circumstance has been characterized by the statement, "the cloud begins with coal" (Mills, 2013).

And lest one believe that the ultimate usage of "dirty" fossil fuel-based electrical power associated with small mobile devices is minimal, consider the following:

> The average iPhone uses more energy than a midsize refrigerator, says a new paper by Mark Mills, CEO of Digital Power Group, a tech investment advisory. A midsize refrigerator that qualifies for the Environmental Protection Agency's Energy Star rating uses about 322 kW-h a year, while your iPhone uses about 361 kW-h if you stack up wireless connections, data usage, and battery charging (Lobello, 2013).

It is important to understand where and why this energy use occurs. Mills lists the following factors as primary:

- Data centers that have become warehouse-scale supercomputers unlike anything in history
- Ubiquitous broadband wired and wireless communications networks
- The myriad of end-use devices from PCs to tablets and smart phones to digital TV
- The manufacturing facilities producing all the ICT hardware (Mills, 2013, p. 3)

Writing in his blog, *Low-tech Magazine*, Kris de Decker suggests that some kind of "speed limit" for the Internet is needed (de Decker, 2015). In exploring this argument, researchers at Lancaster University made the following observations:

> Putting to one side consideration of how such limits might be achieved, it is intriguing to examine the claim that the energy used by the Internet will continue to grow until the availability of energy itself becomes problematic, that is, unless some other kind of checks or limits to growth are imposed first.
>
> …Current estimates suggest that operation of the Internet (powering devices, networks and data centres) amounts to around 5% of global electricity use; yet this is growing faster (at 7% per year) than total global electricity consumption (3% per year). In other words, the Internet is consuming an increasing portion of global electricity supply.
>
> …how large a portion of global electricity could this represent before such limits might be imposed? Some predictions suggest that production and use of information and communication technologies might grow to around 20% of global supply by 2030, or as much as 50% in a worst case scenario (Hazas, *et al*, 2016, p. 1).

Wired network transmission is more energy-efficient than wireless, but the issue is complex. Data centers and the "cloud" serve wired and wireless networks, with both technologies embedded in the way access networks are being built. End-use devices, their applications, and the way homes and buildings are designed have become major determinants of energy use and

efficiency. The following sections will consider data center energy, transmission and access network energy, and energy use by end-use devices, applications, and the IoT.

> *"It is ironic that an advanced technological global information and communication technology (ICT) system is dependent on an inefficient, polluting, and archaic energy source—coal."*

6.1 Data center energy use

The cloud is a metaphor for a shared pool of computing resources (e.g., networks, servers, storage, applications, and services) that end users can access, configure, and release on demand. Cloud services are hosted on servers that reside in data centers—centralized clusters of computers and supporting network, storage, and power resources. Some of these data centers are enormous in size and consume prodigious amounts of electricity.

The cloud progressively offers an alternative to customer premises computing and storage. The argument has been made that "cloud services appear to be intrinsically more energy efficient than traditional desktop computing" (CEET, 2013, p. 8).[55]

> One key advantage of cloud computing is that it enables resources and infrastructure to be shared between many users, and returned to a resource pool when not needed. This offers economies of scale in data provision, computation and storage, while allowing users to gain easy access to computing resources far more powerful than that provided by a single desktop computer. Data centres are undeniably significant consumers of energy, but can be optimised for efficiency and as a result, cloud services are often promoted as sustainable alternatives to desktop processing (CEET, 2013, p. 4).

In spite of, and often in opposition to, the positon that the cloud is energy-efficient is a body of analysis demonstrating that the wireless network's consumption of energy is more prodigious than commonly understood and is rapidly-growing.

In 2010, the organization Greenpeace began issuing a series of reports over several years highlighting the carbon footprint of cloud computing and the IT industry's data centers. In 2013, the National Mining Association and the American Coalition for Clean Coal Electricity sponsored a 45-page report titled *The Cloud Begins With Coal: Big Data, Big Networks, Big Infrastructure, and Big Power—An Overview of The Electricity Used By The Global Digital Ecosystem* (Mills, 2013). This report showed dramatic growth in IT energy consumption and noted that the situation was growing so fast that current statistics were difficult to find (p. 22).

The IT industry responded in a number of ways. An international standards committee, ISO/IEC JTC1 Subcommittee 39 (SC39) on "Sustainability for and by Information Technology" was established to deal with energy issues relating to data centers and other IT applications.[56] Bell Labs and the University of Melbourne Center for Energy-Efficient Telecommunications issued a report, *The Power of Wireless Cloud* (CEET, 2013), which noted:

> Greenpeace has highlighted the carbon footprint of cloud computing but focused on data centres as being the biggest contributor to energy consumption. When considering the energy consumption of the wireless cloud, all aspects of the cloud ecosystem must be taken into account, including end-user devices, broadband access technology, metro and core networks, as well as data centres. (CEET, 2013, p. 8)

The CEET report pointed a finger at wireless access networks as the main culprit—a point made repeatedly in their report:

> Our energy calculations show that by 2015, wireless cloud will consume up to 43 TWh, compared to only 9.2 TWh in 2012, an increase of 460%. This is an increase in carbon footprint from 6 megatonnes of CO2 in 2012 to up to 30 megatonnes of CO2 in 2015, the equivalent of adding 4.9 million cars to the roads. Up to 90% of this consumption is attributable to wireless access network technologies, data centres account for only 9% (p. 3).

> Public debate continues to focus on the energy consumption of data centres and the savings available to industry. However, there is a broader issue of energy consumption in the cloud computing environment not restricted to data centres. Accessing cloud services via wireless networks is also an issue (p. 8).

The CEET report points out that "There needs to be a focus on making access technologies more efficient and potentially a reworking of how the industry manages data and designs the entire global network" (p. 3).

6.2 Transmission and access network energy use

The Internet's core networks are entirely based on optical fiber, including almost all private/enterprise, telephone, and cellular backhaul networks. However, the local access network (LAN)—the last hop to the home or business—is a much different story.

> A wired connection (DSL, cable, fibre) is the most energy efficient method to access the network. Wireless access through WiFi increases the energy use, but only slightly. However, if wireless access is made through a cellular network tower, energy use soars. Wireless traffic through 3G uses 15 times more energy than WiFi, while 4G consumes 23 times more. Desktop computers were (and are) usually connected to the internet via a wired link, but laptops, tablets and smartphones are wirelessly connected, either through WiFi or via a cellular network.

> Growth in mobile data traffic has been somewhat restricted to WiFi "offloading": users restrict data connectivity on the 3G interface due to significantly higher costs and lower network performance. Instead, they connect to WiFi networks that have become increasingly available. With the advance of 4G networks, the speed advantage of WiFi disappears: 4G has comparable or improved network throughput compared to WiFi. Most network operators are in the process of large-scale rollouts of 4G networks. The number of global 4G connections more than doubled from 200 million at the end of 2013 to 490 million at the end of 2014, and is forecast to reach 875 million by the end of 2015 (de Decker, 2015, p. 3-4).

"In spite of, and often in opposition to, the positon that the cloud is energy-efficient is a body of analysis demonstrating the that the wireless network's consumption of energy is more prodigious than commonly understood and rapidly-growing….

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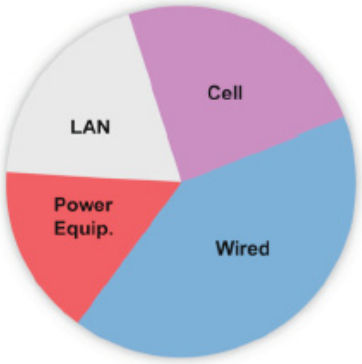


Figure 6.2— Where networks use electricity (Mills, 2013, p. 22)

Figure 6.2 shows the proportions of energy consumption attributed to wired and wireless networks and supporting facilities. This shows that wireless infrastructure, which on the chart is comprised by portions of the LAN and Power Equipment sectors plus the entire Cell sector, accounts for roughly a third of total energy consumption by communication networks.

6.3 End-use devices, applications, and the Internet of Things

Where is the data generated by all of this energy going and what is driving growth in terms of end use? Several categories and trends are involved in consuming this bandwidth (de Decker, 2016, p. 4). Data traffic and storage is driven by manual and by increasingly automated processes.

6.3.1 Manual processes and energy consumption

Manual processes include those that are initiated deliberately using devices and applications, many of which are familiar to everyone. These might be considered discretionary energy use, or are visible to and largely under the control of the user. Some examples are shown below.

- Portable devices - wireless
  - Laptops—WiFi moved computers from office to living room
  - Smartphones—not as much for talking but more and more for video; not an adequate substitute for a computer
  - Tablets—better images and video; intended for wireless so Ethernet plug was removed requiring extra adapter
- Applications
  - Images—photography, personal libraries, and exchange
  - Music and video—use up spare "dead time;" watch videos on *You Tube*™ or *Vimeo*™
  - More personal time online—texting, email, and social media, etc., but people have limited time to spend/waste:

    "…we are now connected anywhere and anytime, using our increasingly energy efficient devices for longer hours…"(DeDecker, 2016, p. 4)
- More wireless video—the biggest network energy user of all:
  - Three pages of text = 0.3 megabytes
  - One high resolution JPEG image = 3 megabytes

"It can be concluded that the rapid growth of automated processes generate more and more Internet traffic and energy use that is invisible to users and beyond their control… Can such functions be accomplished more efficiently, safely, securely, and privately with hard wired localized control systems and a homeowner-controlled gateway that manages any external access to the data?"

    - One 8-minute *YouTube* cat video = 30 megabytes
    - In 2012 video traffic was 57%; In 2017 video is expected to be 69% and 72% by 2019
    - Interactive video/audio requires higher network performance (energy) to avoid latency/ delay
- Does Internet save energy vs. conventional means? May or may not save any energy.
    - DVD movie distribution
    - Newspaper distribution
    - Travel to meetings vs. teleconferencing as a substitute

6.3.2 Automated processes and energy consumption

Automated processes, such as those listed below, constitute a relatively new category of network use and energy consumption. These may be largely invisible to human users but are rapidly increasing and not easily amenable to control or limitation (Hasaz *et al*, 2016, p. 4).

- Automatic updates or backups
    - Recent studies found unexpectedly high levels of communication between apps and cloud, even when specific applications were not in active use.
    - Software updates: 6% of download traffic
    - 10% of traffic if computer game downloads and updates are included
    - Automatic operating system updates (e.g., iPad)
    - Automatic backup of application data and digital photos
    - Unobserved, uncoordinated, unmanaged, and unmanageable
- Software development tools
    - Tool chains and business models are driving the mobile eco-system and push the design of software as "thin clients" to powerful backend cloud services
- Internet of things (IoT) and Machine-to-Machine (M2M)
    - Smart "things" in homes, workplaces, and civic infrastructures
    - Growth that is dissociated from the limits associated with direct Internet use
    - Presently 6.4 billion devices; estimated to be 21 billion by 2020
    - Some estimates put M2M communication as 45% of Internet traffic by 2022
    - Claimed to be "low footprint," but some are not (e.g., cameras, cars, medical devices).
- Advertising botnets
    - Estimated to be 33% to 50% of all Internet traffic today (Hasaz et al, 2016, p. 4)

In regard to the growing use of automated processes, some researchers have concluded that,

> The automated updates, cloud syncing, offloading of storage and computation to the cloud, that are an increasing feature of the design of applications, [are]… endemic to the tools and pervading technological culture that is bringing these about.
>
> Further, the Internet of Things is set to trigger a whirlwind of investment and connected infrastructure growth that has the massive potential to grow operational electricity use and energy of the Internet. Despite sometimes questionable benefits and motivations, the IoT is currently under construction, in many different ways (Hasaz et al, 2016, p. 4).

It can be concluded that the rapid growth of automated processes generate more and more Internet traffic and energy use that is invisible to users and beyond their control. In any case, what is the value of having connected toasters, or a dishwasher that spies on you when most of the network traffic and data is for the benefit of data jackals in the advertising food chain. Can such functions be accomplished more efficiently, safely, securely, and privately with hard wired

localized control systems and a homeowner-controlled gateway that manages any external access to the data?

6.3.3 General systems principles apply to energy use improvement

A set of energy system design principles has been proposed to rethink and envision a sustainable Internet architecture for the future. These include efficiency, sufficiency, and self-sufficiency (Hasaz *et al*, 2016; Hilty, 2015; de Decker, 2015). Among these, the *rebound* effect is of particular importance. Rebound denotes a circumstance wherein efficiency gains are lost to the increased demand that is stimulated by efficiency improvements. This category includes the following types:

- Efficiency—ratio of useful output to input
    - Hardware and energy are inputs, Internet services are outputs
- Sufficiency—when inputs and output are "good enough"
    - Keeping input/consumption within certain limits, while maintaining satisfactory output
    - A sufficient system can improve its outputs or inputs only by improving its internal efficiency
    - e.g.: Mobile devices have reached a state of sufficiency with regard to electricity input
- Self-sufficiency—reducing some inputs to zero
    - Inputs and outputs are balanced and internalized
    - e.g.: A pocket solar calculator is self-sufficient with regard to electricity

Sufficiency is probably the most difficult concept to understand and apply, and it is often in conflict with business goals. For example "better" is the enemy of "good enough." Sufficiency is usually imposed by some external limit. In the case of mobile devices as described above, the external limits that have developed apply to size, weight, usefulness, and battery life that are good enough for the consumer. Better often takes the form of upgrades or other factors that render the product obsolete (e.g., planned obsolescence) and force the purchase of additional hardware and/or software. Instead, technical and business focus should be on finding better solutions only to those that are not already good enough. How these principles might be applied will be considered in a later section.

Efficiency seems to be a laudable principle, but unless carefully implemented, associated gains can suffer the paradoxical and perverse side effect of rebound—stimulating increased demand that cancels the gains and may worsen the problem. An example would be the tendency for building and widening highways to stimulate suburban growth, in turn increasing the demand for more highways and so on.

6.4 Conclusions about energy

Industry groups such as CEET, tend to focus on developing more efficient wireless technology, and in some cases propose entirely new technologies such as 5G wireless. It has been demonstrated in earlier parts of this paper that wireless access suffers from a number of inherent limitations vis à vis wired access that cannot be remedied. Accordingly, wireless will likely remain insufficient. In the section that follows, it will be shown that wired access deployment has been not so much limited by technical limitations as encumbered by regulatory politics and corporate business strategies.

The following observation made in a CEET report analyzing energy consumption by the wireless cloud should be taken seriously by the IT industry:

> There needs to be a focus on making access technologies more efficient and potentially a reworking of how the industry manages data and designs the entire global network (CEET, 2013, p. 3).

As far as the public is concerned, the best approaches to implementing this suggestion might be to deploy municipal optical fiber networks (e.g., FTTx) nationwide, as close to consumers as possible, before resorting to wireless methods and to limit the emphasis on wireless to devices and products that require mobility or cannot otherwise be wired. The quality of service associated with wired access will always be superior to wireless, and it will likely be more than sufficient well into the future.

A parallel approach to the above CEET suggestion (of more efficient access) would be to consider the sustainability analysis suggested by Hilty (2015) and de Decker (2015) with regard to efficiency, rebound, sufficiency, and distributed data centers as a potential solution, thus creating some limit to the growth of energy consumption without having it imposed by external circumstances, such as a climate crisis.

6.4.1 Recommendations

Following are recommendations to improve the energy use of communication networks.

- Deploy municipal optical fiber networks (FTTx) as close to consumers as possible before resorting to wireless methods.
- Apply wireless primarily to devices or products that require mobility or cannot otherwise be wired.
- Move to sustainable distributed data centers (DDCs) through standards, policies, and incentives. DDCs can be seen as a possible trend attributable to energy and environmental constraints. Thus the evolutionary history would be: timesharing > pc > cloud> DDC). Possible strategies to bring about DDCs might include:
    - Localized generation and storage for DDCs
    - Flexibilization (spatial and temporal) of DDCs
    - Utilization of appropriate technology in DDCs

"...Wireless access suffers from a number of inherent limitations vis a vis wired access that cannot be remedied. Accordingly, wireless will likely remain insufficient. In the section that follows, it will be shown that wired access deployment has been not so much limited by technical limitations as encumbered by regulatory politics and corporate business strategies."

7 Policy failures, issues, and business strategies

This chapter deals with the public policies and public issues that affect telecommunications and broadband access. Many of these political issues have been discussed in earlier chapters with regard to specific technical and economic circumstances. This chapter looks at the big picture from a public policy perspective, examining public issues and concerns relating to net neutrality, the digital divide, municipal and community fiber networks, security, and privacy. The chapter also deals with the Internet industry's inordinate focus on advertising; the consequences of this commercialism; the needs for critical infrastructure, disaster resilience, and a sustainable society; and concerns about wireless proliferation as a public and environmental health hazard.

7.1 National policy

Perhaps the most significant problem associated with national broadband policy over the past two or three decades has been that legislation and regulation have intermingled issues relating to delivery of bits with issues relating to content and services. As previously discussed, the *Telecommunications Act of 1996* tried to deregulate based on the assumption that alternate modes of delivery or access (e.g., fiber, copper wire, cable, wireless) would provide alternate avenues for competition, thus allowing the market to compensate for the law's provisions allowing monopolies to form within each category defined by a specific transmission mode (i.e., cellular, wireline, satellite, cable, etc.). Subsequent federal policy in the form of the *National Broadband Policy* (NBP) reinforced this failed approach.

> The US market is a duopoly at best for most consumers and competitive pressures all but disappear for high-capacity connectivity. The future market for advanced digital services is a lightly regulated monopoly for most households. (Crawford & Scott, 2015, p. 3)

The FCC tried to remedy this tendency toward monopoly and duopoly as part of its net neutrality debate, and 2015 decision, and through the Commission's *Municipal Broadband* decision. These FCC actions and related decisions and consequences will be dealt with in greater detail in the subsections that follow.

The *Telecommunications Act of 1996* and the FCC considered wireless (such as from Verizon or AT&T) to be a "competitor" with wired (such as from Comcast or Century Link). Why has this not turned out to be the case? The situation is complex and these have become highly consolidated and entrenched institutions, but the answer is simply that they are not offering the same services—or services that can be directly substituted. Wireless is not a substitute for wires. The subsections that follow explain further why that is the case.

7.1.1 Policy roots

Two historical characteristics of the U.S. political economy go a long way toward explaining how America has uniquely structured and regulated its telecommunications and electric power industries. First is the widespread belief that the best way to serve the public interest is to serve private interests and to allocate decision making, control, and authority to economic decisions by producers, often to the point of guaranteeing and subsidizing their profitability.

The second characteristic derives from the much-touted American distaste for taxes, to which the institutional response has been to hide the full costs to the public of infrastructural development so these costs are not easily recognizable. In most countries telecommunication and carriage industries were formed as governmental functions, recognized as public utilities and "natural" monopolies, and largely capitalized as tax-supported projects. In America's entrepreneurial culture, however, creative and persuasive individuals such as Theodore Vail (in the case of the Bell System) and Samuel Insull (in the case of the Edison electric companies) convinced the politicians of the time (c. 1907–1920) that a privatized investor-owned monopoly regulated by state public utilities commissions (PUCs) would be a politically-palatable way to raise the large amounts of capital needed to build and operate these infrastructures.[57]

By assuring monopoly enterprises generous double-digit returns on cost of service and capital assets, the costs to the public were buried by regulators in complex rate structures and kept off the taxpayer's annual bill. This contributed to the myths that Americans enjoyed lower taxes than more socialistic Europeans, and that America was, in turn, more business-friendly. The reality however, was arguably that costs ended up higher, and the industries more entrenched, than they would have otherwise been. In any case, the technology of telecom and electricity have changed dramatically and older financial strategies may no longer be appropriate.

7.1.2 Investing in public infrastructure

The history of U.S. communication infrastructure increasingly supports the proposition that it is unrealistic to expect private monopolies, duopolies, or triopolies—regulated or unregulated—to make the long-term investments necessary to build the enduring and sustainable public broadband fiber information highway that the country needs. Corporations will invariably seek the cheapest, quickest, and most profitable path, which has led to the current emphasis on wireless. Even the ambitious *Google Fiber* project abruptly backed away from its goal to introduce fiber-to-the-premises service throughout the United States and attempted to find cheaper (to build) wireless alternatives to fiber.

7.1.3 National broadband plan—looking for a cheap fix?

The *National Broadband Plan* (NBP) (FCC, 2010) was an exhaustive report by the FCC that attempted to lay out a path to national broadband access. Noam argued that while "…excellent in its comprehensive overview of a digital ecosystem, [the NBP] 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" (Noam, 2011, p. 471). According to Noam, the NBP overstated the cost by seeming to base its $660 billion "deal-breaker" estimate ($6,000 per household) for fiber on the assumption of "100% penetration by new fiber" (p. 482), and then tried to justify a cheaper approach using wireless. The plan also greatly underestimated the data rate needs of users.

"According to Noam, the NBP overstated the cost by seeming to base its $660 billion "deal-breaker" estimate ($6,000 per household) for fiber on the assumption of "100% penetration by new fiber" (p. 482), and then tried to justify a cheaper approach using wireless. The plan also greatly underestimated the data rate needs of users."

7.2 Delivering the bits—wireless vs. wired access

The NBP suggested minimum access speeds consistent with the recommendations of the cable industry, an industry which may tend to deliberately understate the need for speed in order to maintain scarcity in a market where they have no significant competitors.

> The minimum appropriate speed for every American household by 2020 should be 4 Mbps for downloads and 1 Mbps for uploads. These speeds are enough, the FCC said, to reliably send and receive e-mail, download Web pages, and use simple video conferencing. The Commission also said that it wanted to ensure that by 2020, at least 100 million U.S. homes have "affordable access to actual download speeds of at least 100 megabits per second and actual upload speeds of at least 50 megabits per second."
>
> …Other countries have chosen different goals. The South Korean government announced its plan to install one gigabit (Gb) per second of high-speed symmetric fiber data access in every home by 2012. Japan, the Netherlands, and Hong Kong are heading in the same direction. Australia plans to get 93 percent of homes connected to fiber, ensuring download speeds of 100 Mbps…in the United Kingdom, a 300 Mbps fiber-to-the-home service will be offered on a wholesale basis (Crawford, 2013, p. 262).

The consumer's need for higher data access rates is always growing and tends to outpace what the industry is prepared to offer with its conventional access networks (i.e., DSL, cable, wireless). The reasons for this growth in demand are many, and some have already been discussed in the previous chapter on energy growth. Another reason is related to the role of advertising and will be discussed later in this chapter.

The wireless industry has an incentive to understate the need for speed because they cannot do better, at least at present. This is likely one reason for the industry's push for 5G—to deliver faster access—but it is not clear how well such a technology will actually work and what the unintended consequences may be. In any case, it is hard to avoid the conclusion that optical fiber offers the best and most future-proof solution.

7.2.1 Comparison of wireless and wired access

In the present context, the NBP goals described above seem modest and the 4/1 Mb/ps goal shortsighted and timid. Given economic trends toward disintermediated work and labor[58] and the pressing need for rural economic development, it would seem that gigabit symmetric broadband fiber access should be the national goal.

"The history of U.S. communication infrastructure increasingly supports the proposition that it is unrealistic to expect private monopolies, duopolies, or triopolies—regulated or unregulated—to make the long-term investments necessary to build the enduring and sustainable public broadband fiber information highway that the country needs. Corporations will invariably seek the cheapest, quickest, and most profitable path, which has led to the current emphasis on wireless."

> What does America really need? For starters, most Americans should have access to a reasonably priced 1-Gb symmetric fiber-to-the-home networks…. wireless access works well for small screens carrying low-resolution images but cannot support the data rates that will be needed for each home or business. Only fiber will be able to meet America's exponentially growing demand for broadband access (Crawford, 2013, p. 263)

Noam has extensively evaluated the adequacy of wireless, particularly in regard to rural development, and has assessed the structure, data rates, and growth capacity prospects for wireless networks in comparison with the historical cost curve of wireline-based solutions, stating,

> … wireless is not going to catch up with wireline. Figure [6.1] 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.

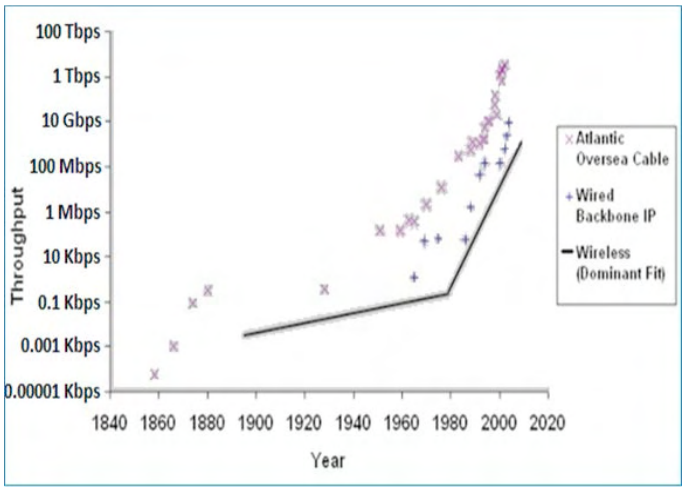


Figure [6.1]: Wired and Wireless Data Throughput Evolution Comparison (Noam, 2011, p. 477)

> 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 (Noam, 2011, p. 476-477).

Noam describes the U-shaped average cost curve of wireless compared to the steadily declining linear average cost curve of wired access. This means that with wireless access, the average cost per user decreases as the number of users increase only to a certain point where it then begins to increase again as more users are added. Noam argues that:

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.

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 (p. 478).

"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. (Noam)"

7.2.2 Can wireless meet the public need?

From a broad perspective, it seems clear that the answer is "no"—wireless cannot deliver the most basic foundation for communications and Internet access that the American public needs. Public needs must be separated from the needs of incumbent providers and the budget priorities of short-sighted governmental agencies and politicians. Moreover, the price tag for a wired system may likely be mitigated by performance improvements associated with new and legacy copper wire and fiber. A hybrid solution may also be possible in many situations based on a fiber backbone with tails of copper wire, coax cable, and fixed wireless by synergies to be gained from increasingly-needed electric power system upgrades. These possibilities will be considered in a later part of this chapter about *Community Broadband Fiber*.

7.2.3 So, why the push for a wireless substitute for fiber?

Verizon and AT&T are currently pushing for wireless as a substitute for fiber (Verizon having put FiOS on the back burner). Before leaving office FCC Chairman Tom Wheeler began a campaign for 5G wireless starting at the National Press Club (Wheeler, 2016), and the FCC has been conducting a reverse auction to free up TV spectrum (Lecher, 2016), as well as allocating new millimeter wave spectrum[59] for 5G wireless phones and/or backhaul (Penttinen, 2016).

Why this push for a wireless substitute for fiber broadband? The arguments put forth assert that fiber is too expensive and takes too long to build out compared with wireless. Neither statement

is compelling or self-evident.[60] The push for wireless arguably has more to do with the greater profitability of wireless for the telecommunications carriage industry as currently comprised and the short-term returns that corporations require.

But, what is in the long-term interest of the public? Noam asks:

> 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 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. 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 (Noam, 2011, 481-482).

The triopoly prefers a solution that fits their commercial strategy and preserves their domination of the broadband space and the current advantageous regulatory situation, while advancing national goals that are put forth as self-evident but cry out for critical examination. The notion of a market-driven shift to reliance on a wired network will be burdened by short-term economic considerations and the current institutional and political context. As mentioned above, even Google Fiber has begun to balk at the time and money needed to install the commodity for which the company is named and is looking increasingly at alternatives.

It is worth adding a note that Google's purposes and strategic goals differ from major broadband carriers, as well as from communities (Nicas, 2016).[61] However, the main point of the above commentary is that among private sector players in the communication infrastructure market, even the mighty Google balks at building out a system it cannot control and monopolize. As noted earlier, communication networks and other infrastructures are public goods, so provision will tend to be underserved by the economic market. Only government will build and/or regulate a wired network in the public interest.

It is time to acknowledge that it is unrealistic to expect private capital to build what the public needs.

7.3 Community broadband fiber

This report, *Re-Inventing Wires* argues that a broadband fiber access network should enjoy the status of basic public infrastructure—comparable to roads, streets, water systems, schools, and electricity—and that all communities should be entitled to build and use these facilities, whether or not commercial interests care to become involved. As discussed in an earlier section, wireless carriers and their lobbyists have influenced governments to stop communities from building community-owned and operated broadband networks. Germanos wrote, "Companies like AT&T, with the help of the American Legislative Exchange Council (ALEC), have pushed through legislation blocking municipal broadband" (Germanos, 2016, para. 7) in about 20 states. The author adds:

> Former FCC Commissioner Michael Copps, now an advisor for advocacy group Common Cause, said the decision harms the public interest. "Let's be clear: industry-backed state laws to block municipal broadband only exist because pliant legislators are listening to their Big Cable and Big Telecom paymasters," he said in a statement. "These corporate providers invest in campaign contributions rather than in deploying high quality Broadband" (para. 9).

The issues of net neutrality and community broadband fiber are closely related. The former deals with the message content and the latter with its physical message delivery. The net neutrality issue involves the question of whether Internet providers should be able to charge Web companies to get their content delivered to customers at faster speeds than available to other content providers and whether all content should be treated equally (Vara, 2015). The community broadband fiber issue deals with the rights of communities and municipalities to build and operate physical networks in competition with private corporations. This section will deal with community fiber and then net neutrality, along with related issues.

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7.3.1 The FCC confronts corporate colonization

On February 26, 2015, FCC Chairman Tom Wheeler announced the Commission's much-anticipated and ultimately surprising decision supporting net neutrality. With this rulemaking, the Commission made access to the Internet a public utility regulated under the *Title II* common carrier rules of the *Telecommunications Act of 1996,* including its non-discrimination provisions.

Interestingly, Wheeler began the day by first announcing a decision that attracted far less attention, preempting laws in Tennessee and North Carolina that restrict municipalities from building their own fiber networks The states in question comprise only two of approximately 20 states that have such laws. (Vara, 2015)

The Tennessee case pertained to the city of Chattanooga, discussed in an earlier chapter, where the municipal electricity utility that built the fiber network was being sued for reaching out to neighboring broadband-deprived communities. The North Carolina case involved Wilson, a small town one hour east of Raleigh, which was similarly sharing access to its community network with neighboring communities. The Commission acted under Section 706 of the *Telecommunications Act of 1996*,

> …which deems that the commission should regularly look into "whether advanced telecommunications capability is being deployed to all Americans in a reasonable and timely fashion." It adds, "If the Commission's determination is negative, it shall take immediate action to accelerate deployment of such capability by removing barriers to infrastructure investment and by promoting competition in the telecommunications market" (Vara, 2015, para. 5).

Wheeler described what he considers "irrefutable truths" when it comes to broadband:

> One is, you can't say that you're for broadband and then turn around and endorse limits on who can offer it. Another is that you can't say, 'I want to follow the explicit instructions of Congress to 'remove barriers'… to infrastructure investment, but endorse barriers on infrastructure investment. I think, as they say in North Carolina, that dog don't hunt. You can't say you're for competition but deny local elected officials the right to offer competitive choices (Vara, 2015, para. 6).

In August, however, a three-judge panel from the U.S. Court of Appeals for the Sixth Circuit struck down the FCC's broadband fiber action in response to suits brought by the state's Attorneys General arguing that the FCC had exceeded its authority in preempting state laws. There is some irony in this argument and ruling given that state legislatures and administrative agencies, acting on behalf of commercial interests, frequently preempt municipal and other local community initiatives that attempt to provide local protection of environment, health, food, agriculture, water, air, privacy, etc., (including preempting local cell-site regulation, and local fracking regulation).

In summary, the above shows the close relationship between net neutrality and broadband fiber access and how they are tied together as basic principles. It also shows how the FCC can finally do the right thing after unsuccessfully trying everything else. This leads to an examination of how equal high-speed access to the Internet can benefit our cities, towns, and communities.

7.3.2 Fiber as basic community infrastructure

The Tennessee and North Carolina cases illustrate that broadband fiber access has become a vital facilitator of health, safety, education, civic participation, jobs, economic development, and the quality of life and well-being for society and its members.

> Some of the areas around Chattanooga and Wilson don't have broadband Internet access at all, or else it exists only at low speeds; parents report driving their children to local churches or to McDonald's so they can get online and finish homework assignments. Such efforts, proponents argue, demonstrate that, although the Internet may once have been a luxury, these days it's a form of infrastructure, not dissimilar to water pipes or roads—and that towns lacking reliable access to it risk falling behind.
>
> "Why should it be the decision of Comcast or any company that the infrastructure that they happen to own in a community is good enough?" Joanne Hovis, the C.E.O. of the Coalition for Local Internet Choice, a group of businesses, cities, and others, told me. "Why shouldn't a community be able to say, 'We will work with another provider or work ourselves to be able to provide better infrastructure'?" (Vara, 2015, para. 7).

Financing community fiber

The financing of fiber installations can be expensive and time-consuming. Local governments can undertake such projects directly, hire a contracting firm, or sign a franchise agreement with an Internet provider. The franchise or public/private partnership approach may reduce some of the up-front risk, but tends to lock communities and subscribers into long-term financial commitments that likely end up being more expensive in the long run than the amortized cost of building and operating community networks—a classic rent versus buy problem. Also, the

private partner or franchise operator may get acquired by Comcast or other monopoly, leaving the community out in the cold with little or no control or influence.

On the upside, governments have the power of taxation, of eminent domain, and of bonding. Often their bond ratings are better than corporations. These resources can be leveraged if data networks are made subject to policies similar to those applicable to public resources such as roads, bridges, water, and sewer systems. For example, an existing local municipal electricity or water utility can usually issue revenue bonds backed by an ongoing revenue stream.

Public-Private Partnerships

With the lack of any meaningful federal broadband policy or funding, the idea of using some form of private investment through public-private partnerships (P3) has been attracting some attention. Three basic business models have been identified with various levels of risks, benefits and control for municipalities (Hovis, et al, 2017).

- Model 1 — Public facilitation, private investment
- Model 2 — Public funding, private execution
- Model 3 — Shared investment and risk

The basic idea is that a city can get some level of private funding behind constructing a network by trading some opportunity to make money. The general P3 concept is not new, although as applied to broadband, it is new and largely untested. Presumably the city can grant a contract or franchise to build and operate the network over some period of time and collect fees from customers or from the city. There are a number of examples, but they vary widely and there is no "standard" template. There are many trade-offs and "risks" involved for both sides.

Challenges of P3

A basic difficulty with all the P3 models is that there is an inherent conflict of interest between the partners. Private investors need 1) profits (usually sooner rather than later) and they need 2) an exit strategy. These are adverse to the city's need to get cheap Internet access equally for all and to not end up stuck in a monopoly situation as most cable or telephone customers, with no control over price, terms, or service. A forewarning is provided by a look at the history of the cable industry which began with small entrepreneurs who exited over time by selling out to larger entities (e.g., ultimately Comcast, Time Warner, etc.). Public policy goals are to keep prices affordable and service neutral and open, and available equally to all. Other goals may also include principles of "open access" where the network is open to competitive service providers, but what is meant by *open* can be problematic.

Risks of P3

It is argued that private funding reduces financial "risk" to the city. However, while the city may not issue bonds, the "…partnership financing may be considered by auditors, state authorities, and the bond markets as counting against the public sector entity's borrowing capacity" (Hovis, et al, 2017, p. 21). Also, unlike some other city facilities, some city residents may not want or choose to subscribe to the service, thus raising the cost per user. Another risk with partnerships

is that the partner or service provider will fail or leave. This risk may relate to the business plan being used and its profitability.

The business plan

There are several business approaches that can be considered for operating the local fiber access network. The options can be roughly broken down into two categories: 1) the *open access* model, aka *wholesale* model, in contrast to 2) the *direct services* model, aka *retail* model. In the case of the wholesale model, the municipality might build the fiber network and then allow multiple service providers to use it. In this case the municipality would have little or no control over the service quality or prices that the ISPs charge, and would be subject to collusion between them to vary or fix the prices. In the case of the retail model, the municipality would operate the entire network and be the sole ISP dealing directly with its retail customers. It might choose to offer some services by allocating to a specific partner (e.g., voice, TV, etc.).[62]

The wires and poles

Perhaps the biggest factor of all in the feasibility of municipal fiber is whether the municipality already owns its electricity utility. If so, adding fiber to the existing "wires and poles" is relatively straightforward and can be funded by relatively inexpensive revenue bonds. If not, making adequate right-of-way arrangements can be quite expensive, if not impossible. If public financing requires a public vote, incumbent broadband providers may spend heavily to oppose the election.[63]

Fiber infrastructure—benefits and motivation

The most important resources to be leveraged are those of localized democratic governance and self-determination in the creation and operation of communication infrastructure. To strengthen public resources, cities and towns can collaborate with neighboring communities. In an age when state and federal institutions have come to be increasingly compromised by politics and corporate money, responsibility and impetus lies with local governments to facilitate and ensure the welfare of community members. At the risk of advocating a return to feudalism, one might argue in favor of cities and communities stepping up to defend their citizens from colonization of rightfully-public communication resources by modern-day corporate brigands and robber barons.

7.3.3 Electricity grid synergy with broadband fiber

Many cities and localities, particularly in rural areas, have established locally-governed and managed electricity municipals, co-ops, and rural electric associations. Often these are ideally suited to deploy broadband fiber because they already use and control the local wires and poles, deal with local customers and users, and have a billing and service infrastructure. Additionally, these utilities are often not-for-profit organizations that can act in the interests of their members and users, rather than of stockholders. On the other hand, unfortunately they can be "captured" by local elites that can become even more impenetrable than investor-owned utilities.[64]

Energy transformation

There are emerging systemic benefits in combining electricity and broadband fiber. The technology of generating, storing, and distributing electricity is undergoing a dramatic transformation. The century-old centralized and capital-intensive model of generation,

"Community-based and municipal electric utilities are well poised to take advantage of synergy between fiber networks and local electricity distribution grids. Many of the same facilities can be shared and customer relationships are already in place. Utilities are also accustomed to financing their own capital improvements."

transmission, and distribution is being challenged by a consumer electronic mass commodity model. The new model takes the form of distributed rooftop solar photovoltaics (PV), batteries, and smart power electronics (e.g., inverters, chargers, energy management systems, smart appliances, etc.). Instead of a one-way flow of electric power from a centralized utility company to each consumer, every electricity consumer becomes a potential producer, or *prosumer*. Technologies are emerging that will enable community-based prosumers to trade clean and efficient solar electricity with other prosumers within their local community distribution grid (Schoechle, 2015).

Community electricity networks

To enable this transformation to a system of community electricity prosumers, a fast and reliable fiber network will be needed so that automated energy management system (EMS) controllers in each home or business can coordinate and trade with each other. The resultant automated local electricity trading system is envisioned by the U.S. Department of Energy as *transactive energy* (TE) and offers to make the electricity grid far more clean and efficient.[65] Community municipal fiber networks would facilitate moving electricity distribution grid supply/demand management to local premises-based communication gateways and allow the creation of energy management systems (EMS), the implementation of variable electricity rates[66], and the replacement of conventional, superfluous, external wireless meter-reading networks (e.g., AMI)[67] with a premise-based metering function integrated with the premises EMS (i.e., a next-generation AMI that we could call "AMI 2.0") based on high-speed fiber communication.

Synergy between "highways"—electricity and Internet

Community-based and municipal electric utilities are well poised to take advantage of synergy between fiber networks and local electricity distribution grids. Many of the same facilities can be shared, and customer relationships are already in place. Utilities are also accustomed to financing their own capital improvements. Larger investor-owned utilities may find it difficult to work with a *prosumer* distributed model because their century-old business is based on generous double-digit profits earned on investments in large capital assets—usually centralized coal, hydro, or nuclear generating plants and large transmission lines. Many large utilities are stuck with long-term investments in centralized generation and transmission facilities that may become obsolete and *stranded* before they are paid off. This situation may worsen in the face of both economic and climate crises as the urgency of shifting to solar and other renewable energy increases.

7.3.4 Economic development

In any case, any community that already controls its own electricity provision might want to consider adding fiber and Internet to its system, as have Longmont and Chattanooga. As discussed in an earlier section, Chattanooga has enjoyed very significant economic growth from its broadband access for both businesses and individuals by enabling commerce and education as well as improved efficiency of municipal services. Longmont's new (barely over a year old) system with it's availability of cheap ($49/month), symmetrical, neutral, and fast broadband is already proving to be a magnet for business and real estate development in comparison with neighboring communities.

The 3.5 x multiplier effect

Economic studies have shown the benefit of localization or keeping commercial activity and jobs in the local community. A 2004 U.S. General Accounting Office study of electricity generation (GAO, 2004) showed that local ownership can generate significantly higher impacts for a county. For example, a single 40MW wind project built in Pipestone County, Minnesota would annually generate about $650,000 in new income for the county. In contrast, that same 40MWs locally-owned, would annually generate about $3.3 million in the same county. The GAO evaluation looked at three counties in Iowa and two in Minnesota. For these 5 counties, local ownership provided 2.5 times more jobs and 3.7 times more total local area dollar impact. There are additional environmental benefits and potential technology and business development economic benefits to the local area.

Smart Cities—Next Century Cities initiative

In a previous section, smart cities were discussed as an application and marketing opportunity enabled by broadband fiber infrastructure. Some innovative municipalities across the country recognize the importance of leveraging gigabit speed Internet to attract new businesses and create jobs, improve health care and education, and connect residents to new opportunities. One example is *Next Century Cities*™, a nonprofit coalition formed in 2014 by 32 mayors and has grown to represent 182 communities across the United States. According to its website, its goal is to help other cities to realize the full power of truly high-speed, affordable, and accessible broadband, to represent local leaders' voices in national broadband debates, and to advocate for city rights and choices.[68]

As can be seen in Chattanooga, Tennessee, Longmont, Colorado, and a number of other cities across the country, there can be great economic benefit when cities and local communities can install universally available fast, affordable, and reliable broadband. With the present divided and contentious political climate at the national and state levels, it is increasingly left to local governments and their citizens to act to determine and direct their own future.

7.4 The net neutrality debate

Net neutrality is the principle that all Internet traffic should be treated equally. The term was coined in 2003 by Columbia Law School professor Tim Wu (Wu, 2003) who describes it as follows:

> Network neutrality is best defined as a network design principle. The idea is that a maximally useful public information network aspires to treat all content, sites, and platforms equally. This allows the network to carry every form of information and support every kind of application. The principle suggests that information networks are often more valuable when they are *less* specialized – when they are a platform for multiple uses, present and future. (Wu, 2016, para. 1)

The concept of net neutrality has roots that go back to early regulatory principles and debates, many of which derive from public utility issues that predate the Internet, and some that predate electronic communications media. Net neutrality is a modern application of the centuries-old concept of the *common carrier* as a form of public good.

In introducing network neutrality, Wu opened a 2003 paper with the following ominous presage:

> Communications regulators over the next decade will spend increasing time on conflicts between the private interests of broadband providers and the public's interest in a competitive innovation environment centered on the Internet. (Wu, 2003, p. 1)

Wu's prediction has been borne out over the intervening years as the Internet has become increasingly hypercommercialized and firmly embedded in our personal and economic lives. In recent years, increasing Internet traffic and the associated scarcity of bandwidth has driven conflicts and deals between Internet service providers (ISPs), such as Comcast, Verizon, etc., and content originators and their customers, such as Google, Netflix, HBO Go, Microsoft, YouTube, etc. In one high-profile case that led to litigation, Comcast was accused of "throttling" competing Netflix traffic, following which Netflix made a deal with Comcast for paid prioritization.

It may be difficult to remember that when the Internet dawned on the public consciousness, only two decades ago, debate swirled regarding whether the Internet should continue to be run by the government and to what extent, if any, commercial traffic should be allowed.

7.4.1 Roots of net neutrality

Tim Wu's 2003 landmark paper on network neutrality was part of a larger discussion among legal scholars, technologists, and regulators surrounding the topic of *open Internet*, including open access rules, broadband platforms, vertical integration, and antitrust issues (Farrell & Wiser, 2003). Much of this discussion was about adopting regulatory concepts from the age of telephones (i.e., telecommunications) and broadcast media (i.e., radio and television)—technologies, that the Internet seemed to be displacing.

Policy debates invariably lag technological developments, and technologists rarely have a clear idea of how their inventions will be implemented and used. The original designers of the Internet, contractors to the U.S. Department of Defense (largely university faculty and students), intended to develop a decentralized file transfer and email communications system that was resilient enough to resist nuclear war. Inventions that followed, including browsers (e.g., Mosaic, Netscape, etc.), voice-over-Internet protocol (VoIP), etc. began to morph the Internet into something unforeseen, disruptive, and paradigm-shifting. A classic example of the this tendency lies in the case of how the nascent digital network impacted the telephone system, which was recognized by a renegade Bell Labs engineer, David Isenberg.

The Stupid Network

Engineers in the traditional Bell System (AT&T) labored long and hard during the 1980s to devise a complex digital phone system that could cope with voice, video, and data. The resulting technology came to be known as Integrated Services Digital Network (ISDN) and was based on an elaborate and robust packet-switching system known as Asynchronous Transfer Mode (ATM). David Isenberg, a Bell Labs engineer working on ISDN technology, realized in 1996 that the Internet had made an end run around his team's efforts. In response to this insight, Isenberg wrote a brief but profound paper titled "The Rise of the Stupid Network" (Isenberg, 1996),[69] which was to become a landmark in the field of communications.

Isenberg's epiphany was that the conventional phone system and the new ISDN were similarly based on the concept of an *intelligent network* that connected to *stupid terminals* (i.e., phone sets), while the Internet reversed this arrangement with the concept of a *stupid network* that connected to *intelligent terminals* (i.e., computing devices). He recognized that an unintended paradigm shift was taking place toward a digital communications system far simpler, less expensive, and more adaptable than ISDN. Isenberg pointed to the key Internet design principle of end-to-end data transport, otherwise known as dumb pipes for data. In the model he described for telecommunication, the task of the network service provider came to be understood as delivery of the user's data reliably, promptly, securely, and unchanged.

Regulatory enigma—IP as "neither fish nor fowl"

Shortly after the publication of his article, Isenberg found unsurprisingly he was no longer welcome at Bell Labs. Nonetheless, Internet Protocol/Transport Control Protocol (TCP/IP) soon began to replace the switched telecommunications network infrastructure as regulators and law professors began to grasp how the new network would compel transformation of the regulatory models and principles that had long assured the public of fairness and access to network services. The Internet was neither broadcasting nor telephone—but both—and more.[70]

For most of the 20th century, the FCC regulated telecommunications as a common carrier as codified in the *Communications Act of 1934*, and for much of the second half of the century, the FCC codified the *fairness doctrine* for broadcasting, which implicitly recognized some level of content regulation to be in the public interest for some forms of mass communication. The *Telecommunications Act of 1996*, said to be the "most lobbied bill in history" (Alster, 2015), did however not apply common carrier classification or content regulation to the Internet. But, in the years that followed, broadband Internet came to carry both broadcasting and telephone.[71] The *Telecommunications Act of 1996* not only did not solve this problem but muddied the waters further, by drawing a false distinction between the categories of *telecommunications* services and *information* services, and then placed common carrier regulation in the former category but not the latter.

7.4.2 The FCC's struggle with industry

Years of struggle preceded FCC Chairman Tom Wheeler's February 26, 2015 announcement of the Commission's historic decision supporting net neutrality. The decision finally moved Internet access from Title I unregulated service to Title II regulated common carriage, including both wired and wireless access. Previously the Commission had attempted open access rules within Title I. For example, its *Open Internet Order of 2010* relying on Section 706 of the *Telecommunications Act of 1996* was shot down by the U.S. Court of Appeals in Washington, D.C. in January of 2014. The Court ruled that the FCC had not properly established how Internet service providers (ISPs) could be held to telephone access rules, but the underlying problem was the artificial and incoherent way that the *Telecommunications Act of 1996* attempted to draw a distinction between regulated and unregulated services.

Wheeler's epiphany

By 2015, FCC Chairman Wheeler came to understand that nothing short of Internet reclassification as a Title II common carrier was going to ground effective regulation and

facilitate service in the public interest. One might ask what led Wheeler, a former lobbyist for the telecommunication industry facing millions of dollars spent on lobbing by the triopoly, AT&T, Comcast, and Verizon, to come around to this insight. One might speculate that his epiphany had something to do with the four million Americans who wrote to the FCC in support of net neutrality, along with the protesters camped outside the FCC for days blocking Wheeler's access to his office. The chairman's amazing turn came to be the subject of much speculation. Consider, for example, the following discussion between Tim Wu and journalist Amy Goodman:

> AMY GOODMAN: How did Tom Wheeler get religion? What was—did he—has he talked to you about this epiphany? I mean, we had the images of the protesters in front of his home, not letting him go to work—
>
> TIM WU: Right.
>
> AMY GOODMAN: —saying, "If this is how you're going to work, we don't want you to go to work"; the encampment outside the FCC that went on for many days.
>
> TIM WU: You know, I think it's really important never to typecast people entirely and be like, "This guy is a lobbyist," or "This guy is..." You know, a lot of people were worried, particularly in the progressive movement, that, former lobbyist, he was just going to show up at the FCC and do his former master's bidding or something. But, you know, he's near the end of his career. He's not looking for another job. And, you know, he became a net neutrality advocate over—I think when you get in the job, you start to see sort of the wisdom of this position. (González, 2015).

As anticipated, the decision by the FCC to support net neutrality was followed by what Kang described as:

> … a huge legal battle as cable, telecom and wireless internet providers sued to overturn regulations that they said went far beyond the F.C.C.'s authority and would hurt their businesses. On the other side, millions of consumers and giant tech firms rallied in favor of the regulations. President Obama also called for the strictest possible mandates on broadband providers." (Kang, 2016)

Landmark decision

But the Commission had evidently done its legal homework well. On June 14 of 2016, the United States Court of Appeals for the District of Columbia Circuit, in a 2-to-1 decision, not only upheld the FCC but found that broadband was a "public utility" and applied this category to both wired and wireless networks, finding the Internet to be "an essential communications and information platform for consumers" (Kang, 2016, para. 4).

7.4.3 Internet as common carrier

In response to the FCC's 2015 decision on net neutrality, big telecom providers have argued that applying common carrier rules to the Internet is a throwback to a bygone era that will hinder innovation and dry up investment. At their 2015 annual *Network of the Future* conference, the Telecommunications Industry Association's CEO, Scott Belcher, declared in an opening keynote for the TIA Annual Member Meeting, that Title II rules would create uncertainty, stifle innovation, and "open the door to Trojan Horse regulation" (TIA, 2015).

On the other hand, the decision was strongly supported by a number of Silicon Valley Web companies that want consumers to have unimpeded access to their services. Pro-neutrality policy

"With the frenzied growth and commercialization of the Internet, those who control information technology and data have acquired unprecedented power without accountability. Manufacturers and software developers have assumed the Zuckerbergian ethic of "move fast and break things" (Lynch, 2017, p. 32), abandoning or avoiding consideration of security and privacy—the policy "orphans" of the Internet age."

experts argue that net neutrality would encourage investment and innovation and suggest it has been the dominant operators who have long stifled competition.

> America has gotten stuck on a plateau of adoption, meaning that there is downward pressure on the adoption of advanced digital services among low- and middle-income communities that are an important catalyst of economic growth.
>
> … Although it is often claimed that deregulation in the US high-speed Internet access market caused increased investment in communications infrastructure, market data do not support this claim. The most successful network operators in the US market have reduced capital expenditures (as a percentage of their ever-increasing revenues) in the years since deregulation. Rather, it is consumer demand for high-bandwidth content and services that is highly correlated with investment and increased speed in the access tiers offered by ISPs (Crawford, 2015, p. 3-4).

Going forward, it was predictable that the triopoly would challenge the 2016 court decision upholding the FCC's net neutrality decision and/or try a legislative or political route to remove net neutrality regulation and preserve its market power. In fact, with the 2016 election of Trump as U.S. President and his appointment of Ajit Pai, a former Verizon attorney, as FCC chair replacing Wheeler, the triopoly may (temporarily) get their wish.

However, support for net neutrality by both industry and the public runs deep and strong, and has become so economically vital that support for it is unlikely to acquiesce to an assault. In the longer term, the FCC has an opportunity to build on the Title II classification to at the same time protect consumers and stimulate economic growth.

> The 184-page ruling also opens a path for new limits on broadband providers beyond net neutrality. Already, the F.C.C. has proposed privacy rules for broadband providers, curbing the ability of companies like Verizon and AT&T to collect and share data about broadband subscribers (Kang, 2016).

Traditionally the Federal Trade Commission (FTC) has held primary responsibility for regulation pertaining to information privacy, however, the FCC has always had important responsibilities in the regulation of customer proprietary network information (CPNI) that restricts phone companies from selling customer metadata.

> …dynamics now in place suggest that privacy may be the next great testing ground for the FCC. A new chance, perhaps, to champion public interest. Even before the opportunity for privacy enforcement under Title II regulatory powers, the FCC faces new challenges from phone companies, now itching to monetize their vast consumer data stashes the way Net companies have. The commonly used term is "Google envy" (Alster, 2015, p. 43).

7.5 Policy orphans—security and privacy

Internet security and privacy are sweeping topics that are increasingly becoming an area of conflict between the United States and Europe as the big U.S. IT companies (e.g., Google, Amazon, Facebook, Apple, and Microsoft) launch new services across the world. With the frenzied growth and commercialization of the Internet, those who control information technology and data have acquired unprecedented power without accountability. Manufacturers and software developers have assumed the Zuckerbergian ethic of "move fast and break things" (Lynch, 2017, p. 32), abandoning or avoiding consideration of security and privacy—the policy "orphans" of the Internet age.

A comprehensive treatment of the topics of consumer and institutional security and privacy is beyond the scope of this paper. But it is important to note the growing external tensions and internal contradictions that are emerging as the largely U.S.-based dominant IT companies attempt to exploit global markets and encounter conflicting regulatory paradigms and social norms. Frequently, the technical designers, deceived by hubris, cloaked in a pretense of engineering or scientific neutrality, and driven by the quest for money, shrug off responsibility for the intended or unintended consequences of their technologies and designs. At the same time it should be acknowledged that, in some or many cases, the designers could not have foreseen the massive scale these ventures would attain (e.g., Google, Facebook, Amazon, etc.) and how momentous the impacts they would impose on our economy, society, and culture.

7.5.1 What are *security* and *privacy*?

What is meant by security and privacy? These can be succinctly defined as follows.

- *Security* is being free from danger or threat.
- *Privacy* is being free from being observed or disturbed.

These concepts are closely related, but distinctly different—sometimes they operate in concert and sometimes they are in conflict or tension. Of concern here is the security and the privacy of data and information at personal and organizational levels. Regardless of the huge social and monetary costs incurred by invasive collection and abuse of data, abusive practices continue because the people making technical choices are not the people who must bear the consequences of those choices.

Central to the arguments put forth in this paper is that the differences between wired and wireless media have consequences far beyond those narrowly associated with technical means of transport and that these differences influence the nature and vulnerability of messages transported. Wireless is less reliable, more exposed, more constraining to content, and can never be as secure or private as transmission by wires. Nevertheless, wireless communication enables functions that are simply not possible with wires. Accordingly, it behooves the designers and the market to make the appropriate choices for their users.

7.5.2 Collision of technology with culture

Privacy laws and practices differ significantly between the United States and other parts of the world, and the United States may eventually need to accommodate global privacy standards for reasons related to global trade and markets. A topic as complex as privacy may be defined more easily in terms of what it *is not,* than what it *is*. The significant differences between data privacy norms in the United States compared with Canada, Asia, and Europe can help define and clarify the dimensions of the term.

Different conceptions of privacy are rooted in cultural concepts related to the primacy of commerce, the ownership of data (e.g., property right vs. right to control), the commoditization of information, and the tensions between a sector-specific rules-based approach and an omnibus or comprehensive principle-based approach to privacy. The roots of these differences are historical and complex[72.] and the differences are important because of the global nature of energy and information technology products and markets, as well as because of the evolving

landscape of international privacy and *big data* and *data analytics*. A thorough treatment of these differences is beyond the scope of this report, however a basic issue is that in the United States personal information tends to be viewed as the property of those collecting it, whereas in European culture and in the wider world, due to historical abuses there is a recognition of some right to control information about one's self. This has led to an increasing policy clash between U.S.-based IT corporations and European Union regulators as data-flows and the Internet become more global.

Over the past two decades, the infrastructural foundations of national and global economies, governments, societies, and cultures have moved decisively to the Internet. While this transformation is discussed frequently and extensively, the particulars of how the network is implemented and operated tend to be accepted uncritically, without realizing the full implications for access, inclusiveness, security, and privacy.

7.6 The Internet hyper-advertising bubble machine

Few today know about or remember a lengthy and passionate debate that took place when the Internet came into public use in the late 1990s as a U.S. government-operated facility. At the time, stakeholders debated whether commercial traffic should be allowed on the network. Since then, the Internet industry has come to be highly commercialized and inordinately based on an advertising business model, and this focus has brought a number of unintended consequences.

7.6.1 The rise of the bots

The advertising model and its priorities permeate the Internet and its technology and dominate the user experience. As reported recently by Robert Cookson in the *Financial Times*,

> Global spending on online advertising has almost doubled in the past four years — reaching $159bn in 2015, according to research group eMarketer. This money underpins the internet economy and supports trillions of dollars of equity in media and technology companies.
>
> Google, the biggest player in the online ad industry, generated revenues of $67bn from it last year. As well as placing ads on its own sites such as YouTube, the group also provides technology services such as DoubleClick Ad Exchange, which connect advertisers to millions of third-party websites and apps. The group takes a cut — as much as 45 per cent in some cases — of each ad sale that it facilitates (Cookson, 2016).

By some estimates, over half of Internet traffic is fraudulent. Cookson cites a recent warning from the World Federation of Advertisers (WFA) that, "between 10 and 30 per cent of online advertising slots are never seen by consumers because of fraud… and marketers could lose as much as $50 billion a year by 2025."

"By some estimates, over half of Internet traffic is fraudulent."

Cookson continues:

> The most pernicious and common variety of ad fraud involves computer programs, or "bots", that simulate the activity of a real person browsing the web or using an app. Hackers build an army of bots, known as a botnet, by sneaking the software on to vulnerable household computers.

> The malicious software runs quietly in the background of the infected computer without making its presence known to the owner. Then, under the hacker's remote control, the botnet — which can be rented through blackmarket internet forums — is directed to visit certain websites. The most sophisticated bots are programmed to click from one website to another, watch videos for their duration, and even add items to an online shopping basket (Cookson, 2016a).

The industry approach to the problem is mainly focused on technical fixes, but regulatory intervention is increasingly considered. It is not clear that technical or regulatory remedies will work because incentives for deceptive and fraudulent business practices are inherent in the business model—this sort of behavior is highly profitable, there are typically no penalties, and the costs of fraud and abuse are buried.

> …US senators Mark Warner and Chuck Schumer last week called on federal authorities to address the problem.
>
> "The cost of pervasive fraud in the digital advertising space will ultimately be paid by the American consumer in the form of higher prices for goods and services," they wrote in a letter to the Federal Trade Commission. "It remains to be seen whether voluntary, market-based oversight is sufficient to protect consumers and advertisers" (Cookson, 2016).

The advertising industry appears to be a major part of a systemic problem beyond issues relating to hackers and botnets as reported in another *Financial Times* story by Cookson:

> US advertising agencies are boosting their profits at the expense of clients by cutting secret deals with media companies, according to an investigation funded by big American brands.
>
> The Association of National Advertisers, whose members include Apple, Procter & Gamble and Unilever, said its investigators had found "pervasive" evidence that agencies are taking cash rebates from media companies without their clients' knowledge.
>
> The ANA alleged agencies used a series of "nontransparent" business practices to enrich themselves on the back of their clients' advertising budgets.
>
> The trade body, whose members collectively spend $250bn a year on marketing communications, said the investigation had revealed "a fundamental disconnect in the advertising industry regarding the basic nature of the advertiser-agency relationship (Cookson, 2016a).

Also quoted in the *Financial Times* story, Brian Wieser, analyst at Pivotal Research said, "The findings are generally damning of the whole industry…" (Cookson, 2016a). Cookson continued,

> Accepting hidden rebates creates an inherent conflict of interest for agencies… The seven-month investigation was conducted by K2 Intelligence, a consultancy founded by Jeremy and Jules Kroll which counts former FBI agents among its employees.
>
> The study stated that "non-transparent business practices" were prevalent across digital, print, outdoor and television media, and that such practices were known of and mandated by senior executives at agencies and their holding companies.
>
> …Media buying is the most profitable activity for marketing services groups…, and for years has been their main source of growth.
>
> The ANA's revelations come at a time of rapid change in the media and advertising industries. The rise of the internet has led to new ways of trading media and increased complexity for marketers. (p. 5)

Accordingly, one might ask whether mechanisms such as fraud and botnets are not aberrations or anomalies, but rather are essential elements of the advertising-based business model, which is driven by the giants such as Google and Facebook. The essential and inevitable nature of fraud in Internet advertising is a consequence of the incentives inherent in the system and is demonstrated by the recent case of Facebook's ad-blocker blocker:

> Ad blockers filter out ads by refusing to display page images and other elements that originated with a known ad server. But Facebook has found a way around this…Facebook's ad-blocker blocker works by making it difficult for software to distinguish advertisements from other material published on Facebook, such as photos or status updates.
>
> In the most recent quarter, Facebook made $6.24 billion in advertising revenue, an increase of 63 percent from a year earlier. Mobile advertising (which is not affected…) accounted for 84 percent of this (Ortutay, 2016).

7.6.2 Data traffic behind the screen

Aside from fraudulent practices, the advertising business model also generates a huge amount of invisible data traffic that has become part of normal browser operation and of which most users are completely unaware. By merely clicking on a web link, a user may be unwittingly initiating a sequence of events resulting in the exchange of hundreds of messages involved in analyzing the user's preferences and conducting an online auction for ads that are then downloaded and displayed as part of the target web page—all within seconds or milliseconds.

Web pages cannot finish loading onto user's screens until the ad auctions are complete. This process introduces a performance delay but it is unclear how much of the delay can be attributed to network traffic and how much to the user's access speed. In any case access speed is an issue and it may be another motive behind 5G wireless—how to cram more ads onto wireless devices without over-taxing the patience of the users (Rysavy, 2017).

7.6.3 Consequences of the advertising model

Google and Facebook dominate the Internet advertising market, and the business strategy for Silicon Valley more broadly seems to be to circumvent competition to gain market power. This raises significant public policy issues and questions around the degree to which vital public infrastructure such as the Internet should be dependent on concentrated market power and burdened with excess bandwidth-consuming traffic loading and costs that are tangential and irrelevant to the average user's basic interests and welfare. Also, the process and its supporting infrastructure essentially provides another way to externalize a portion of the cost of advertising onto Internet users as a whole. Waste and fraud end up being paid for by consumers in the price of the products they buy.

Why is advertising a reasonable business model? If market power is inherent, then at what point might Google or Facebook be considered to have become public utilities? If it is not inherent, then how shall it be avoided or dealt with? Is there a better business model for the Internet?

7.7 Electromagnetic radiation and public health

Radio Frequency (RF) wireless technologies (e.g., Wi-Fi, cellphones, etc.) play an increasing role in the telecommunication infrastructure. At the same time, the public health ramifications of the biological effects of electromagnetic fields (EMFs) are not fully understood and have become a matter of public concern and active scientific inquiry. Recently released U.S. government funded cellphone radio frequency toxicology research on animals (Patel, 2016; Knutson, 2016; MN, 2016) has strengthened the case that EMFs constitute a public health hazard, showing a connection with cancer, just as large investments are being made in new generations of wireless phones and services. On publication of partial results of this study, the wireless industry's *Microwave News* declared, "The cell phone cancer controversy will never be the same again" (MN, 2016, p.1). Now seems an appropriate time for the FCC to step up its reevaluation of the basis of its RF exposure guidelines and to seriously consider the petitions and other statements of international groups of scientists expressing concern about the growing body of evidence showing risk. Such a reevaluation would best be accomplished in a formal working group with specialist members from the CDC, EPA, FDA, NIOSH, OSHA and the IEEE—as well as independent researchers. A reevaluation would be especially timely given emerging plans for greater densification of antenna infrastructure closer to where people live and work.

7.7.1 Biological effects of electromagnetic fields

The current established FCC guidelines for maximum permissible exposure to RF radiation are based on the *specific absorption rate* (SAR), a measure of estimated radiation absorption related to tissue heating that is recommended by ANSI and IEEE. SAR is a blunt tool that does not deal with potential non-ionizing or non-heating effects that have come to be of increasing concern[70]; specifically that significant biological and health effects have been indicated in thousands of studies[71] that are occurring at much lower power levels than were previously understood to be possible, as well as from modulation techniques and other signaling characteristics, and having nothing to do with tissue heating.[72]

There is growing recognition among established academic and industry researchers that a better understanding is needed, and that such an understanding is becoming more urgent. According to some well-established interdisciplinary scientists, problems affecting the research community's ability to confirm and identify these effects include historically inconsistent study results, and "…the lack of a generally accepted mechanism, other than heating, by which weak RF waves can modify biological processes, has contributed to the debate on the possible biological effects of magnetic fields, including whether sources such as cell phones, radar pulses or power lines cause detrimental health effects from these fields" (Barnes & Greenbaum, 2014, p. 2).

In 2002, the International Agency for Research on Cancer (IARC) classified extremely low-frequency ELF EMFs (mostly electrical power frequencies) as a Group 2B "possible human carcinogen", mainly due to the positive studies relating to an increase in childhood leukemia. In 2011, IARC also classified RF EMFs as Group 2B, mainly due to findings from mobile phone-related brain tumor studies. The IARC Monographs were produced over several years by groups of independent scientists from around the world.

Other important developments included scientific research that identified key mechanisms that could explain the previous inconsistent, ambiguous, or unexplainable results and point to specific

mechanisms causing health effects. One such mechanism relates to effects of weak EMF on free radical concentrations, which in turn affect cell growth rates (Barnes & Greenbaum, 2016).[73]

Additional research is described in two U.S. government reports from the 1970s to 1980s that provide evidence for many neuropsychiatric effects of non-thermal microwave electromagnetic fields (EMFs), based on occupational exposure studies (Glaser, 1971; Raines, 1981). Many more recent epidemiological studies provide substantial evidence that microwave EMFs can each produce similar patterns of neuropsychiatric effects, with several of these studies showing clear dose–response relationships. Among the more commonly reported changes are sleep disturbance, headache, depressive symptoms, excess fatigue, attention dysfunction, memory changes, irritability, and EEG changes. Non-thermal microwave and lower-frequency EMFs have repeatedly been shown to be able to cause these effects by activating voltage-gated calcium channels (Pall, 2016).

In addition, other studies and reviews provide evidence for important health-related non-thermal effects of microwave frequency electromagnetic fields, including oxidative stress and free radical damage, cellular DNA damage, leading to chromosomal and other mutational changes, lowered fertility, apoptisis/cell death, an important process in the production of neurodegenerative disease, endocrine (hormonal) effects and sustained elevation of pathophysiological intracellular calcium levels.

Importantly, the complex modulation methods proposed with 5G may present new risks. There is evidence that modulated EMFs are in most cases more biologically active than non-modulated EMFs. Available research on millimeter waves has involved continuous waves, not the complex modulation methods planned with 5G. Researchers are warning that the biological effects of exposure on humans and animals from this novel 5G modulation needs to be studied before wide scale introduction in populations.

7.7.2 National Toxicology Program study—"a game changer"

Awareness of biological and health risks from EMF has been increasing. Several important developments have taken place in recent years. One was the release of partial results of the U.S. government's $25 million cellphone radiation animal toxicology study. "This is a game changer, there is no question," said David Carpenter, M.D., the Director of the Institute for Health and the Environment at the University at Albany. "It confirms what we have been seeing for many years —though now we have evidence in animals as well as in humans" (MN, 2016, p. 3).

Previously, very little U.S. government-funded research had been published since the de-funding of the EPA's bioelectromagnetics laboratory prior to passage of the *Telecommunications Act of 1996*. Due to concern over exposure to cellphone radiation, the U.S. Government Department of Health and Human Services initiated a long-term study by its National Toxicology Program in the early 2000s at the recommendation of the FDA[74]. Although the study was not complete, researchers decided to report their initial findings in May 2016 because the findings at that point were significant and disquieting. Between 70% and 80% of the people who reviewed the study before its release believed the results demonstrated a significant statistical association (NTP, 2016). Knutson reported in *The Wall Street Journal* that:

> The NTP study was designed to expose rats to levels of cellphone radiation that could be considered similar to what humans may experience by using a cellphone at maximum power.

"How far should we go as a society toward locking ourselves into a technological system that risks public health for the sake of a plethora of wireless applications, many of which are amusements, and business models that add risk and instability to the economy? It seems to be time to address these questions seriously."

> "The NTP report linking radiofrequency radiation to two types of cancer marks a paradigm shift in our understanding of radiation and cancer risk," said Otis Brawley, chief medical officer of the American Cancer Society. "The findings are unexpected; we wouldn't reasonably expect nonionizing radiation to cause these tumors. This is a striking example of why serious study is so important in evaluating cancer risk." (Knutson, 2016, p. 4, para. 2–3)

The NTP study found that the link between electromagnetic radiation and cancer is "weak, but positive" (Patel, 2016, para. 1), which given the pervasiveness of such radiation, could result in a staggeringly large number of cancers. As reported in an article in *IEEE Spectrum*, the reason the NTP released the data early was that:

> Given the widespread global usage of mobile communications among users of all ages, even a very small increase in the incidence of disease resulting from exposure to RFR could have broad implications for public health," according to the researchers. Statistics show that the number of mobile phone users will pass the 5 billion mark by 2019… (Patel, 2016, para. 5).
>
> …So what does this all mean? The results are fairly weak and confounding but provide the first positive evidence in animals and will grab the attention of health agencies, says Kenneth R. Foster, a bioengineering professor at the University of Pennsylvania…"This is going to change the rhetoric in the field. People can point to much more hard evidence that [cellphone RF exposure] really is a problem" (para. 9).

To summarize, a highly respected U.S. scientific body (NTP) has found a connection between cellphone radiation and cancer, reinforcing earlier human studies (Russell, 2017)[75]. In addition, a prominent industry standardizing body (IEEE) for wireless (and wired) communications, as well as a vocal skeptic of health effects (Professor Foster) seem to have recognized that there is a problem. This should justify a precautionary approach. Identifying or confirming specific mechanisms of causality is a separate matter for research.

7.7.3 Conclusions and questions about EMFs and public health

Could our growing addiction to wireless technologies be a lurking public health "time bomb" such as was experienced with tobacco, lead, and asbestos? Sometimes the consequences of technologies take decades to reveal themselves as we are now learning about fossil fuels and climate change. The EMF situation is particularly difficult to secure research funding for due in part to the sheer usefulness of wireless and the enormous associated corporate profits. The 5G industry "bandwagon" effect possibly makes research funding even more difficult, but at the same time even more necessary in the relatively unexplored realm of the biological effects of millimeter wave exposures.

As described earlier, Norm Alster of the *Harvard Edmond J. Safra Center for Ethics* has extensively documented conflicts of interest involving the FCC, its commissioners, and its staff, on the one hand, and the wireless industry the Commission is supposed to be regulating on the other. These conflicts of interest apply particularly to the recent Chairman, former CTIA "revolving-door" lobbyist Tom Wheeler as well as the new Trump administration Chairman, former Verizon attorney Ajit Pai. Not for the first time in its history, the Commission appears to illustrate a classic case of regulatory capture—the industry regulator taking on the role of industry promoter. *The Telecommunications Act of 1996* and most subsequent legislation and regulatory actions have placed a strong emphasis on pre-empting efforts by local or state zoning authorities to regulate cell site placement on the basis of health. Accordingly, it would seem that

"Now seems an appropriate time for the FCC to step up its reevaluation of the basis of its RF exposure guidelines and to seriously consider the petitions and other statements of international groups of scientists expressing concern about the growing body of evidence showing risk. Such a reevaluation would best be accomplished in a formal working group with specialist members from the CDC, EPA, FDA, NIOSH, OSHA and the IEEE—as well as independent researchers. A reevaluation would be especially timely given emerging plans for greater densification of antenna infrastructure closer to where people live and work."

the industry had reason to be worried about the health issue from the beginning. According to Alster,

> The FCC in 1997 sent the message it has implicitly endorsed and conveyed ever since: study health effects all you want. It doesn‘t matter what you find. The build-out of wireless cannot be blocked or slowed by health issues.
>
> Now let’s fast forward to see Wheeler on the other side of the revolving door, interacting as FCC chairman with a former FCC commissioner [Jonathan Adelstein, now CEO of the *Wireless Infrastructure Association* (WIA)] who is now an industry lobbyist (Alster, 2015, p. 6).

As Wheeler and the FCC embarked on spectrum clearing and the promotion of 5G wireless, basic questions arose: in view of the NTP study and other research, how long can the health issue be avoided or suppressed? Is it time for the FCC to seriously reconsider its exposure guidelines?[76] Is simply relying on a simplistic SAR radiation absorption estimate (limited to heating effects) no longer good enough? Although the young and the frail are likely more susceptible, everyone may be at risk.

In any case, further reliable and objective research will be needed in order to establish reasonable guidelines for the future. Would it not be prudent public policy to apply the precautionary principle before huge commitments of money, time, and resources are made—and to facilitate a path to broadband that does not rely on wireless?

There may be other good reasons to pull back. There are mental health and brain development issues that have surfaced with regard to infants and children. For example, recently two large investors holding over $2 billion in shares, Jana Partners LLC and the California State Teachers’ Retirement System, called on Apple Inc. to consider and deal with the addiction and mental health effects of their *iPhone* product on children (Benoit, 2018). There is growing electromagnetic smog causing impairment of medical and other important wireless devices that run on low-power wireless protocols. How far should we go as a society toward locking ourselves into a technological system that risks public health for the sake of a plethora of wireless applications, many of which are amusements, and business models that add risk and instability to the economy? It seems to be time to address these questions seriously.

7.8 Summary of conclusions on policy—public needs and business priorities

This chapter has discussed national communication policy, the relative advantages and disadvantages of wireless and wired technologies, community fiber, net neutrality policies, the neglect of security and privacy, the ascendency of advertising as the main driver of the Internet, and lurking known and unknown risks to public health. These topics raise an interesting question: how much of the high-tech “creativity of the market” is really about offering the public something of value and how much is driven by economic incentives to sell chips, gadgets, and software and gain strategic advantage over competitors (real and potential)? Following are some conclusions and observations about public and private policies that influence the relationship between public needs and present business strategies of the companies shaping this sector.

7.8.1 Conclusions—national communication policy

It is unrealistic to expect private capital to develop and build public goods such as communication infrastructure and to invest in a manner consistent with the public interest. Capitalists and corporations are motivated, and their trajectories shaped by, the relentless search for profits and for their share values, and they must accordingly seek unconstrained growth regardless of sufficiency considerations and social and/or public needs. Per a classic economic perspective, profits are never sufficient and are constrained only by resources and capital. The unconstrained profit motive may serve society adequately in some commodity markets when market activity is open, fair, and competitive, but ostensibly free markets often fail when commodities are (partly or entirely) public goods and competition is constrained by natural monopoly.

Two strategic failures underlying the *Telecommunications Act of 1996* were regulation by medium rather than by service, and allowing consolidation (e.g., mergers and acquisitions) and anti-competitive arrangements to develop within each medium justified by the assumption or hope that the other media would provide competitive balance. It did not work out that way.

The IT business model that has developed in media and technology can be described as:

- Sell more chips by embedding them into everything we can think of.
- Sell more software apps, preferably in a manner that locks consumers into a cloud-based subscription revenue model and planned obsolescence.
- Collect more consumer personal data to monetize, primarily through advertising.

This model has transformed the character and trajectory of technical innovation in communications. The guiding principle has become, "we build it because we can"—a model wherein each technology or technical solution seeks a problem and/or market, and entrepreneurs and management are locked in endless and aimless frenetic pursuit of profits. Also, capitalists may search for investments that may be less than profitable if they pump up share values and facilitate a quick asset flip.

In this business environment, much of what gushes from the data cornucopia is not really needed (botnets, ads, noise, etc.) and has led to (among other blessings) a hyper-commercialized Web bubble machine and growing hacking industry. The strategy and model of Silicon Valley entrepreneurial innovation that has evolved (or devolved) has been one associated with the concentration of market power in a few mega corporations (e.g., Facebook, Google, Apple, Amazon, etc.). The result has in some cases reduced entrepreneurial aspirations to the following formula:

1. Drop out of school.
2. Invent a new app.
3. Sell it to Google.
4. Retire to xyz, or back to step 2 (invent another app).

The morphology described above has been characterized as an "innovation illusion" in a new book by that title (Erixon and Weigel, 2016). In a *The Wall Street Journal* review of this book, the authors are quoted as saying, "…there is too little breakthrough innovation…and the capitalist system that used to promote eccentricity and embrace ingenuity all too often produces mediocrity" (Rees, 2016). On a similar theme, a recent series in *The Wall Street Journal*, titled

"Are We Out of Big Ideas" describes the *innovation paradox*, noting that "There is a yawning chasm between what innovation promises the economy and what it is delivering" (Ip, 2016).

7.8.2 Conclusions—wired vs. wireless

When it comes to delivering the bits, copper wire and fiber access networks are superior to wireless in cost and performance. Fiber offers the most stable and future-proof long-term solution. On the other hand, wireless offers mobility that wired cannot. If wired service is made more available, the consumer will have the option to use it and to be less dependent on wireless. They will have the option to use wireless where and when they need it. Wired and wireless are not competitors, but rather they are complementary. The theory embraced by the *Telecommunications Act of 1996*—that wireless would enable a competitive market–has proven to be mistaken.

Accordingly, wireless should not be seen as a substitute for wired networks. FTTH is the first preference, but in principle, the goal should be to bring fiber as close to the user as possible, to use a copper tail for short distances where necessary, and to resort to wireless technology as a last resort. The public interest lies in the establishment of stable long-term physical infrastructure, not in the ephemeral wireless *app du jour* (latest application) or *gen du jour* (latest generation) that are so often associated with wireless systems.

"The public interest lies in the establishment of stable long-term physical infrastructure, not in the ephemeral wireless app du jour (latest application) or gen du jour (latest generation) that are so often associated with wireless systems."

7.8.3 Conclusions—community fiber

The benefits of community-owned and controlled fiber networks as basic infrastructure are well established. It behooves municipalities and communities to take charge, act in their own interests, and break free of the triopoly. Trickledown broadband is not adequate. Cities and communities have no obligation to support planned obsolescence and the relentless pursuit of corporate profits. They can and should localize the policymaking process to serve the health and welfare of the people and their social and economic growth. As described in the previous section, FTTH is the first preference, and in principle, as previously stated, the goals should be to:

1. Bring the fiber as close to the user as possible.
2. Use a copper tail (new or old) for short distances where necessary.
3. Use wireless technology as a last resort or an ancillary service.

7.8.4 Conclusions—net neutrality

Net neutrality is a fundamental principle and a defining issue for the future of the Internet. Business priorities and market power cannot be permitted to preempt the public interest in the

design and implementation of important basic infrastructure. In a recent editorial, *The Seattle Times* clearly addressed this as an urgent issue:

> The FCC and its net-neutrality policies are also a bulwark against the dangers of media and telecommunications consolidation. The handful of companies connecting most Americans to the Internet are buying up media companies, increasing chances they'll manipulate access to benefit their content. Comcast bought NBC, AT&T bought Time Warner and Verizon is buying Yahoo. All have chafed against net-neutrality rules and tested limits, experimenting with schemes to provide discounted, special access to preferred media. (Seattle Times, 2017)

The Internet has become so economically vital to society that it is hard to imagine how preferential service by could be allowed. In any case, a major public political fight over the issue of net neutrality is ongoing.

7.8.5 Conclusions—security and privacy

The present business model for the communication infrastructure does not favor designing products with privacy and security in mind. The situation can be described as:

- Security does not matter much.
- Privacy does not matter at all.
- Time to market is what counts.
- The benefits of data are worth the cost of hacking, especially when someone else bears those costs.

Only by strong public policy, wise legislation, and sound technical standards can the challenges to the public's security and privacy be met. This has largely been the European approach. A similar approach needs to be taken in the United States.

7.8.6 Conclusions—advertising

The Internet has come to be based on advertising and to function as a hyper-advertising bubble machine. According to poet and social critic Anil Dash, the advertising model permeates the technology and dominates the experience:

> Fraud and botnets are not simply aberrations or anomalies, but rather they are essential elements of the advertising-based business model (Dash, 2017).

At least a third, and possibly more than half of the traffic on the Internet has come to be characterized as worthless or bogus, yet increasingly more infrastructure must be built to support it and increasing amounts of energy are wasted by it. Along with network neutrality, forms of regulation, taxation, and technical limitation must be found to counter this burdensome and parasitic trend.

"At least a third, and possibly more than half of the traffic on the Internet has come to be characterized as worthless or bogus, yet increasingly more infrastructure must be built to support it and increasing amounts of energy are wasted by it. Along with network neutrality, forms of regulation, taxation, and technical limitation must be found to counter this burdensome and parasitic trend."

7.8.7 Conclusions—public health

There is growing evidence that our society's growing addiction to wireless technologies could bring a lurking health time bomb such as was the case historically with tobacco, lead, and asbestos. Much of the disproportionate reliance on wireless is driven by policies purported to enable competition and innovation, that, perversely, result in concentration of monopoly market power, promotion of technology for its own sake, and churn of planned obsolescence. Beneficial and vital uses of wireless may be crowded out of radio spectrum or drowned out in the unnecessary radio noise through a proliferation of applications of dubious value. It is time that the FCC reexamine the basis of its exposure guidelines, and the FDA and other public health agencies take seriously the health risks associated with electromagnetic radiation and require pre-market health testing and post-market health surveillance, as would be required for a biologically active drug, process, or procedure.

"Irrespective of federal action or inaction, it behooves local governments to take the initiative and gain control of their own broadband future. State and federal governments need to stop obstructing and preempting local government initiatives—an example of the corrupting influence of money in politics."

8 Conclusion

This inquiry through the wide-ranging, interdisciplinary, and intertwined topic of communication media and networks has highlighted a number of revealing observations, developed guiding principles, and offered reformative recommendations. These suggest a number of ways to look at how today's decisions about communication infrastructure may shape tomorrow's culture and society. Technical choices about electronic communication media made by corporations, governments, and individuals can and will shape the messages that are conveyed and how they are perceived. Often the medium itself becomes part of the message, to quote the ever-relevant Marshall McLuhan (McLuhan, 1964; McLuhan & Fiore, 1967). Technical choices always have unintended consequences. Inventions and new technologies are selectively adopted and re-shaped by social and economic forces and rarely end up to be what the developers intended. So it is with the Internet and with all of the related technologies it has spawned. Thus, it is important for policymakers, designers, and the public to pause to better understand and consider the effects and consequences of their policy choices.

8.1 Key observations and conclusions

8.1.1 Central observation and conclusion

The facts, evidence, and arguments provided in this report bring forward several key observations and conclusions. The central conclusion is:

A high-speed optical fiber-based Internet access network should be available to every community and every member within every community.

Such access should be available at reasonable cost and be governed democratically and/or provided under the operational and financial control of a local public entity (e.g., town, city, county, community authority, etc.) accountable to the public.

In organizing and building community networks, the first preference should be to wired (i.e., fiber and/or copper) access for every subscriber premises, and wireless should be considered as a last resort where wired access is not feasible. Private wireless carriers and services should be considered as adjunct and not primary service. Community wired networks should be financed by public funds, taxes, municipal bonds, and grants from governments or non-profit foundations, and not by private corporate funding and/or partnerships. So-called *public-private partnerships* inevitably tend to introduce inherent conflicts of interest between the public and private for-profit investors. In principle, community networks should be financed, constructed, and managed in a manner analogous to such public infrastructure as municipal water systems, sewers, streets, or libraries.

8.1.2 Additional observations and conclusions

The following additional observations and conclusions are related to the primary conclusion provided above and are interrelated with each other:

1. Communication networks and the Internet have become part of our nation's basic physical and social infrastructure, such that access and availability will play a continuing and probably increasing role in shaping society and culture.

"Wired access networks are fast, safe, quiet, private, secure, can deliver DC power, and are amenable with municipal ownership and operation as a public utility...

Wireless access networking may be useful in some cases, but is laden with risks, technically limiting, undependable, energy intensive, and relatively inefficient, and should therefore be considered to be an adjunct service."

2. Wired communication is largely more "future-proof" and will likely remain more reliable and stable than wireless.
3. Wired access networks should be preferred over wireless, wherever possible or practical.
    a. Wired access networks are fast, safe, quiet, private, secure, can deliver DC power, and are amenable with municipal ownership and operation as a public utility.
    b. Wireless access networking may be useful in some cases, but is laden with risks, technically limiting, undependable, energy intensive, and relatively inefficient, and should therefore be considered to be an adjunct service.
4. Privately-owned, for-profit corporations can be effective for producing products, commodities, and many services in a market economy, but they are usually not effective at producing and maintaining public goods (i.e., goods and services that are shared by the public for which overall benefits are indirect and require long-term investment (e.g., roads, bridges, public transportation, telecommunications, education, healthcare, libraries, basic scientific research, the Internet, etc.)). Private enterprise can produce remarkable technical achievements, but particularly in the case of communication and other infrastructural products and services, they often misdirect the benefits away from those for whom they were intended; i.e., the public.
5. Responsibility for infrastructure and public services is increasingly defaulting to cities and communities as state and federal political systems become increasingly contentious, dysfunctional, and dominated by corporate interests. An account of cities and communities that have seized responsibility for their own public services are described in a recent 236-page report, *Reclaiming Public Services: How cities and citizens are turning back privatization* by the Amsterdam-based Transnational Institute (TNI, 2017).[80]
6. The advertising-based business model that has invaded the Internet over the past two decades, in contrast to what was envisioned by the founders and early users, has now rendered the World Wide Web dysfunctional, vulnerable, and inefficient, and has resulted in concentrated corporate control and influence, reversing the original concept of a decentralized, distributed, open, democratic, egalitarian network providing access to knowledge and public discourse (Perry, 2016).
7. In spite of rhetoric from telecommunication companies and their political allies about the obsolescence of copper landlines, this longstanding infrastructure still outperforms wireless networks through use of VDSL, G.fast, or Ethernet technology as well as provide DC power at the same time. It may be that network operators find reliance on wired infrastructure to be undesirable because, ironically, while these systems offer large cost savings because they are already in place and are subject to effective regulation in the public interest, they cannot be monopolized and confined to the operator's proprietary wireless network protocols and lucrative data plans.
8. 5G wireless is premature and presently unneeded by the public or the market.
    a. Promotional hype surrounding 5G wireless is a technology push likely driven more by planned obsolescence and selling new generations of chips, software apps, and smartphones than by any demonstrated public or market need that cannot be better met by wired infrastructure or still-emerging 4G LTE technology.

b. The promotion of 5G is likely related in large part to the industry's incentive to reallocate and resell millimeter wave television spectrum to reap enormous revenues and profits (Electronic Design, 2016).

9. Internet energy consumption growth is unsustainable.
    a. The main energy culprit is wireless video.
    b. WiFi is more efficient by far than cellular, while wireless providers are pushing 4G and 5G cellular.
    c. As much as half of Internet traffic is fraudulent or unnecessary.
    d. Core and access network architecture needs thorough reworking for efficiency.
    e. Distributed data centers offer a possible direction for improvement.
10. The principal rationale for IPv6 (i.e., the supposed need for larger Internet address space) is fallacious.
    a. The notion that all IoT devices can or should be directly interconnected is erroneous, introduces unnecessary risks, and is fraught with other difficulties.
    b. IPv6 deployment is in large part a solution looking for a problem and a technology looking for a market.
11. Industry and policy makers offer lip service to privacy and security but consistently fail to make the necessary investments and implement the technological solutions required to effectively address these problems because the costs of such risks are not visible or measureable and are not borne by the designers or operators.
12. Evidence of potential public health risks from electromagnetic radiation from wireless devices and infrastructure is sufficiently great to warrant a major effort by industry and by regulators to better understand these risks before committing further to rolling out the technology.

8.1.3 Supporting rationale

The rationale for the foregoing additional observations and conclusions include the following:

Benefitting economic growth

Fast, inexpensive, symmetrical, and neutral Internet access offers to create a platform on which to build economic growth and education. Such a platform could help compensate for disparities of wealth and income in urban and rural communities by enabling commerce and the exchange of ideas.

> As Sanjay Jha, chairman of Motorola said in 2011, a wireless platform is just not big enough to support the huge amounts of video that people want to watch. "That is why the [high speed Internet access—equipped] home will be the central hub" for all the bits people consume. (David Wilkerson, 2011) (Crawford, 2013, footnote 18, p. 312)
>
> A fiber (or cable) wire is twenty to a hundred times as fast as a 4G wireless connection, and those wireless connections will slow down as they are shared by more people (Eli Noam, 2011) (Crawford, 2013, footnote 19, p. 313).
>
> …wireless access works well for small screens carrying low-resolution images but cannot support the data rates that will be needed for each home or business. Only fiber will be able to meet America's exponentially growing demand for broadband access (Crawford, 2013, p. 263).

> In perspective, using dialup, backing up five gigabytes of data…would take twenty days. Over a standard (3G) wireless connection, it will take more than 7 hours; and over a cable DOCSIS 3.0 connection and hour and a half. With a gigabit FTTH connection, it will take less than a minute (paraphrased: Crawford, 2013, p. 263).

Net neutrality will be essential in order to realize the economic growth potential. The Internet is a commons and its value lies partly in that it is not fragmented and allows any user to also be a server. If it were to be colonized by a few large corporations, its value would be inherently limited.

The "triopoly"

Largely through mergers and acquisitions, Verizon and AT&T have essentially divided the wireless market between themselves and now dominate wireless Internet access. They also have taken a strong hold on the old wires by their ownership or acquisition of regulated telephone landline carriers. This report has shown how their domination of regional landlines has been used to systematically decommission conventional phone service and force subscribers into more profitable wireless services, and also use the wires to cross-subsidize their wireless access networks and facilities.

Likewise, Comcast, through many years of mergers and acquisitions in the cable TV industry, now dominates wired Internet access through its fiber and coax-based network. These three corporations, Verizon, AT&T, and Comcast, comprise a triopoly that overwhelmingly dominates Internet access in the United States. This arrangement gives them the market power to limit service and data speeds, maintain artificial scarcity and high prices, and to exercise political power to further limit competition from new entrants, private or public.

Breaking the triopoly—de-monopolization and de-corporatization

The triopoly comprised and institutionalized by these three companies can be broken to some large extent by freeing up community fiber. A major federal policy push along with associated funding could put local people to work building out the fiber infrastructure, and at the same time could enable broad local economic opportunity based on fast Internet access. Irrespective of federal action or inaction, it behooves local governments to take the initiative and gain control of their own broadband future. State and federal governments need to stop obstructing and preempting local government initiatives—an example of the corrupting influence of money in politics.

Wireless is not an adequate substitute for wires

Wireless broadband access is not an adequate substitute for wired access (CTC, 2017). Millimeter wave (e.g., 5G wireless) backhaul is at best an on-the-cheap solution favored by corporations looking for short-term profits. It is wholly inadequate for a number reasons, among which is that it depends on an invasive and unstable complex millimeter wave hardware/software prone to (sometimes-planned) obsolescence. This complex approach contrasts sharply with the simplicity of basic future-proof fiber/hardwired facilities. At the same time, the wireless approach provides fewer jobs (most of its jobs are in the area of technical/software), and is subject to line-of-sight limitations, interference, asymmetric service, slow data rates, congestion problems, and potential public health risks.

"Despite the hype and the lofty stated intentions, what is actually offered and provided tends to be more of the same highly constrained, corporatized, commoditized, and hypercommercialized services, revealing the self-interested monopolistic motivations of the technology industry. Meanwhile, choices that should be made by public policy are left by default to the largesse of corporations and billionaires."

How does wired access differ from wireless?

Wired infrastructure is inherently more future-proof, more reliable, more sustainable, more energy efficient, and more essential to many other services. Wireless networks and services are inherently more complex, more costly, more unstable, and more constrained. Wired networks are simple, fast, and focused on delivering data to browsers with minimal processing other than ad insertion. In contrast, wireless is a much slower shared medium and is constrained by the limited display capabilities which must be formatted for smartphones and tablets, and are managed differently by each carrier according to marketing and data plans. The phones and formats are constantly being obsoleted and "upgraded", as are the networks themselves with new generations of network protocols (e.g., 3G, 4G LTE, 5G, etc.). Planned obsolescence is an inherent characteristic of wireless. This constant change going on in the wireless world makes it an unstable platform for broadband access compared with wired.

"The Internet is a commons and its value lies partly in that it is not fragmented and allows any user to also be a server. If it were to be colonized by a few large corporations, its value would be inherently limited."

8.2 Trends and the future

8.2.1 Infrastructure stimulus

Enabling municipal and community fiber universally could put wireline services back on a par with wireless and put wireless in its proper place (i.e., mostly as a convenience for things that move). We should not expect private companies to pay for and build out fiber networks to, and within, all communities. Private development of communication infrastructure is a path to more monopoly franchises and other encumbrances, as we have seen from the experience of cable video providers. Moreover, public-private partnerships come with costs, often hidden, that more often than not outweigh the benefits. For example, private companies and their investors need profits and exit paths. They could end up being acquired by other companies.

Fiber infrastructure is a basic vital public good that should be publicly-owned and controlled. Google's plan to build out a private network has been subject to numerous fits and stalls because it is too expensive to allow the desired and expected level of profits (Nicas, 2016). Corporations need profits and will always look for short cuts, compromises, and on-the-cheap solutions. A wired communication infrastructure should be funded by the public as basic long-term investment as are water, streets, and sewers. A consistent problem associated with American phone and power provision historically is that monopoly operators endeavored with no small success to hide the full costs to users and communities. Full and accurate accounting of the costs and benefits of private communication networks demonstrate that they cost more in the long run.

Municipal bonding authority is a valuable tool that can help finance community fiber projects. Fiber to the home or premises is preferred, but a copper tail can work for the last hop (150 meters/500 feet) if necessary or efficacious. Also, old copper pair infrastructure can be

repurposed and represents a valuable public right-of-way if speed meets the user's need (10 Mb/s minimum). Copper Ethernet (100 Mb/ps minimum) w/power can be used where needed.

A natural alliance exists between communication infrastructure and municipal electric power. Community ownership of the wires and poles makes sense and sharing them is widely practiced. Community power will be cheaper with solar distributed generation that can be enabled by a fiber connection to every subscriber.

Municipal fiber infrastructure enables economic development and empowers people and their communities. Following are some examples that are often cited in the hype surrounding the notion of smart cities, which actually apply more plausibly to networks based on community-owned and operated infrastructures and are not something new and apart as may be implied in the smart cities rhetoric:

- Public safety and emergency services
- Water systems
- Energy systems—smart grid and clean energy
    - electric power grid management for localization and decentralization solar+storage (transactive energy TE)
    - metering of electricity, water, gas, etc.
- Smart buildings (energy efficient, useful, and friendly)
- Transportation systems (light rail, traffic signals, weather sensors, etc.)
- Health services
- Public services (government information dissemination)
- Education, training, and distance learning
- Work at home enablement
- Voice communication services
- Travel reduction (better video/audio conferencing)
- Small business—connected to customers/resources, trade and commerce

8.3 Recommendations for action

Re-Inventing Wires offers the following recommendations as a guide for policymakers at all levels as they consider policies and principles shaping regulation, legislation, and funding initiatives:

1. Build or upgrade to a wired access network infrastructure for all communities nationwide

Build-out FTTH/FTTx to as close to the user as possible, with copper tails where needed, including Ethernet or old copper wire pair (both provide power delivery today). As a last resort, use wireless tails for things that move or where wires are not possible.

- Build community-based networks—base this build-out on public investment and control rather than private investment and control in order to prevent the conflicts of interest in the provision of basic needs
- Maintain and defend network neutrality—make it the fundamental principle: *equal availability to all users for both access signaling and content.*

1.1 Take advantage of new Ethernet/USB premises wiring inside homes and buildings

Bring wires as close to the application as possible. Use wireless for things that move or where wires are not practical. Take advantage of DC power delivery and Power over Ethernet/USB.

- Use wireless only where hard-wired connections are not possible.
- Prefer WiFi instead of cellular (3G/4G) where possible using local low-power access points at the end of the wire.
- Do not invest in 5G wireless networks (avoid risks and waste of inevitable obsolescence).

1.2 Do not decommission the standing copper phone pair telephone wired networks

- Conventional copper wire pairs can transmit at high speeds (e.g., *VDSL* or *G.fast* gigabit/ps speeds are possible) as a short or interim "copper tail" for fiber networks.
- Conventional copper wire pairs can also still deliver DC power.
- Conventional copper wire pairs represent a public right-of-way to each premises (it is a valuable public good).
- Conventional copper wire network has advantages that include 911 service, traditional DC power delivery, and resiliency.

2. Repeal state laws impeding or preempting municipal broadband networks

State laws preempting or impeding municipal broadband networks serve no public purpose and violate the basic principles of democracy and self-governance. Communities have a basic right to build their own public infrastructure and to local control of issues related to public health, safety, and environment.

3. Combine fiber access networks with local electric power distribution grids where possible

Communities can take advantage of synergies between broadband fiber and modernized electricity infrastructure, especially for integration of localized distributed energy.

- Fiber enables control of community solar and premises solar-plus-storage.
- Fiber can share the poles and wires.
- Consider converting to a not-for-profit independent distribution system operator (IDSO) model for local grid management.
- Fiber facilitates real-time energy management and local sharing of electricity (e.g., demand response, dispatch, storage, distribution automation (smart grid), Transactive Energy, etc.).
- Fiber eliminates the cost of separate wireless metering networks.
- Consider municipalizing the local electricity grid.

4. Implement energy-efficient communications

- Make data centers more efficient by moving to distributed data centers (DDCs).
- Wires should be the preferred choice wherever possible.
- Minimize use of wireless in access networks and prefer WiFi over cellular 4G.

State laws preempting or impeding municipal broadband networks serve no public purpose and violate the basic principles of democracy and self-governance. Communities have a basic right to build their own public infrastructure and to local control of issues related to public health, safety, and environment.

- Avoid the energy-guzzling 5G strategy entirely.
- Apply STEP energy rating program/policies in homes and buildings.

5. Create and support standards for privacy and security

- Utilize open international technical standards for implementation and enforcement of privacy and security gateway standards and practices.
- Adopt product performance requirements for privacy and security standards.

6. Ramp-up scientific study of biological and health effects of electromagnetic fields

- Avoid a possible public health disaster along the lines of tobacco, asbestos, lead paint, etc.
- Get a better understanding of the behavioral effects and consequences of digital media on people and society, including learning and childhood development, sociological impacts, and mental health.
- Apply the precautionary principle in policy choices in the interim, and hardwire as widely as possible.

7. Find a better business model for supporting the Internet and WWW

- The ad-based Internet is broken and wasteful; hyper-commercialization denies the promise of the Internet and WWW. (See Berners-Lee comments in Perry, 2016). An Internet economy based on data collection is unsustainable.
- Avoid centralization and corporate domination.
- Make WWW a platform for public participation and engagement (rather than a platform for excessive and intrusive ads, botnets, hackers, and fake news).

8. Democratic governance demands that digital access be neutral, fast, and cheap

Consider that a democratic society depends on public discourse and on the freedom of the press and of speech. In our present age of increasing concentration of media ownership and of migration to on-line publication, discussion, and social media, the Internet remains for now one of the few open avenues of public access to media. Democratic governance requires that digital access be neutral, fast, and cheap. It is essential to firmly establish and vigorously defend the principle of net neutrality.

"Democratic governance requires that digital access be neutral, fast, and cheap. It is essential to firmly establish and vigorously defend the principle of net neutrality."

8.4 Final words

In June 2016, a gathering called *The Decentralized Web Summit* convened in an old church in San Francisco. The meeting was organized by Brewster Kahle, founder of the Internet Archive, and sponsored by the Internet Archive, the Ford Foundation, Google, Mozilla, and others. Attending were young entrepreneurs and developers as well as some of the original founders of the Internet, including Vint Cerf, one of the original architects, and Tim Berners-Lee, creator of the World Wide Web. The purpose of the gathering was to consider how to restore some of the original vision of a decentralized, democratized network that now seems to be in eclipse. Perry (2016) recorded and summarized comments made at the time by Berners-Lee, who noted "… how far [the Web] has strayed from the original dreams for the technology."

> "That utopian leveling of society, the reinvention of the systems of debate and government—what happened to that?" he asked. "We hoped everyone would be making their own web sites—turns out people are afraid to."
>
> But even the basic things people want to do aren't possible, because instead of being a true, interconnected web, it has become a collection of silos. "People have their friends on Facebook and some photos on Flickr and their colleagues on LinkedIn. All they want to do is share the photos with the colleagues and the friends—and they can't. Which is really stupid. You either have to tell Flickr about your Facebook friends, or move your photos to Facebook and LinkedIn separately, or build and run a third application to build a bridge between the two." (Perry, 2016, p. 1, para. 5)

Berners-Lee had hoped that users would be empowered to create their own websites rather than be drawn into centralized sites and serices (e.g., Facebook). He also criticized the model of trading privacy for free access to things on the Internet, and said it doesn't have to be so.

> The deal the consumer makes is a myth," he said. "It is a myth that it has to be, it is a myth that everybody is happy with it, it is a myth that it is optimal" for anybody, the consumers or the marketing machine. (para. 6)

The meeting discussed a number of approaches and initiatives that could be taken by Internet and WWW software application developers and other groups. Additional to such activities, which could play a vital role in the re-democratization of the Internet, this paper advocates as an essential element the nationwide establishment of fast, inexpensive, symmetrical, and neutral Internet access networks, allowing escape from the walled gardens and silos constructed by our wireless and cable industries.

Afterword by Magda Havas, PhD

Re-Inventing Wires: The Future of Landlines and Networks by Timothy Schoechle, PhD is a critically important work. It offers a comprehensive overview representing four years of research on why the current wireless trajectory has failed to adequately serve and protect society, the technical advances of wired technology, and how government officials and the public have been misled about the adequacy and desirability of wireless communications. The report provides an informed plan for advancing communications without sacrificing what we hold most dear: a healthy population, prosperous local economies and a thriving planet.

As Dr. Schoechle describes, the Telecommunications Act of 1996 resulted in extreme concentration of market power among cable and wireless carriers, which he calls the 'Triopoly'. This concentration of power has led to the short-term profitability interests of these providers shaping the availability, quality, content, and media of high speed internet access in the United States, and to favoring wireless access over the establishment of a sound and significantly faster, safer, more secure, more reliable and more energy-efficient hard-wired communications infrastructure.

The 'wake-up call' is that the U.S. has fallen to #17 of the top 20 among developed countries in fixed broadband penetration (29.71 subscriptions per 100 inhabitants), with similarly poor performance in speed of access, and an ever-widening 'digital divide', while other countries are increasingly investing in fiber to the premises and committing to high speed broadband access for all.

Policymakers and local communities would best listen to the important recommendations in *Re-Inventing Wires: The Future of Landlines and Networks*. This careful analysis and historical perspective is especially timely, given the wireless industry's widely publicized plans for aggressive 'antenna densification', or the widespread dissemination of 4G LTE and new millimeter wave 5G antennas. It has been evident for a very long time that ever-increasing wireless pollution portends catastrophic and unsustainable outcomes for human health and the environment. On this basis alone, wireless communications should not be the technology of choice, when far safer options exist.

On several other equally important grounds, Dr. Schoechle explains that wireless technologies should not be the basis of our communications infrastructure. Wireless communications can never approach the speed and reliability of wired networks, and importantly, wireless has negative economies for speed compared to wired alternatives, meaning that as we move to higher speeds, using wireless makes less and less economic sense. Also, wireless communication uses vastly more energy than hard-wired technologies.

Local governments' rights also are at stake in the race to blanket the nation in wireless antennas. Dr. Schoechle describes legislation being introduced in many States today that would force municipalities to permit placement of wireless industry antennas on utility poles, street lamps,

street signs and other municipal infrastructure, pre-empting local governments' authority on behalf of private, corporate interests. Unless citizens and local governments proactively oppose these bills, locally elected officials will be unable, in the very near future, to protect their communities from the expected health and environmental consequences of high-intensity antennas, or from the unattractive aesthetics of densely placed antenna infrastructure outside homes. Democracy is being eroded as states legislators and lobbyists enact this kind of disempowering legislation.

Just as with 'smart' meters and the 'smart grid', inferior wireless technology is being promoted to the public and policymakers as an 'advancement', while more prudent investment in safer, faster, more secure, more reliable, less wasteful and more enduring technology languishes.

Re-Inventing Wires also highlights legislation, passed in 20 States, that preempts or impedes municipal broadband networks. This, again, violates principles of democracy and self-governance, while depriving communities of tremendous economic benefits from municipal fiber, a magnet for businesses, as well as fast, high-quality, neutral and inexpensive internet access for residents. It is becoming increasingly clear, as Dr. Schoechle explains, that private, for profit companies have inherent conflicts of interest; and are not well-suited to providing infrastructural public goods.

Another important reality in need of careful examination, explained in *Re-Inventing Wires*, is the exploding demand for streaming content, mainly for entertainment, that is placing a tremendous drain on inefficient wireless systems and leading to the need for more cell towers and antennas to support them. In late 2017, the wireless industry announced the need for hundreds of thousands of new cell towers to be located across the United States within the very near future. *Re-Inventing Wires* explains how wireless data streaming will never be able to compete with the speed and efficiency of wireline delivery, which is the most viable solution for providing the unlimited data content the public desires.

Re-Inventing Wires: The Future of Landlines and Networks astutely recommends that communities:

—Build or upgrade to wired access networks, and take control of their broadband future;

—Repeal laws impeding or preempting municipal broadband networks, that keep prices high, and quality of service low;

—Create and support standards for privacy and security, the 'policy orphans' of the wireless age;

—Disallow decommissioning of wired copper phone pair networks, presently being dismantled. Copper has a very important role to play due to better voice quality than VOIP, where sound is compressed to free up bandwidth for more profitable data and video applications. Use of copper is also essential in combination with fiber, offering the option of copper "tail" into premises. New advances in copper signaling technologies allow copper to outperform wireless, and this valuable national asset should be fiercely protected.

—Minimize use of wireless, as it is laden with risk, technically limiting, undependable, energy intensive, relatively inefficient, and presents important public health risks.

—Find a new business model to support the Internet and WWW that lessens incentives for hyper-commercialization, fraud and waste, and today's situation where the pursuit of money drives most activity and innovation, and as much as 50% of internet traffic is described as being driven by botnets, and thus illegitimate. Instead, communities should tap the potential of this extraordinary communications platform for the public good, as well as find a way to put an end to the ever-accelerating waste of energy in the invisible, and difficult to measure and control, automated processes that support the internet marketing machine.

—Encourage use of wired local premises "gateways", that can eliminate data privacy risks by providing firewalls, filters, and policy servers, that can define and enforce privacy policies, while putting the user in control of the data flowing in and out of the home, protecting security and privacy;

—Acknowledge the wireless 'cloud' is not energy-efficient at all, as is often suggested in the push to get people to use it. Dr. Schoechle cites a report demonstrating from 2012-2015 the wireless cloud added in carbon footprint the equivalent of 4.9 million new cars to the road, or an increase in energy use of 460%. Up to 90% of this energy consumption is attributable to wireless access networks, with only a fraction attributable to data storage.

—Acknowledge wireless devices, antenna networks and data centers are consuming an ever-increasing portion of the global energy supply, based largely on coal, and is growing at 7% a year, versus 3% generally. Understand plans for a wireless Internet of Things (IoT), connecting potentially trillions of electronic devices, is a highly irresponsible pursuit in this regard. Commitment to wired communications infrastructure, for internet access and the IoT is the only sensible direction.

—Finally, *Re-Inventing Wires* touches on the far-reaching implications of intentions to remake the Internet into a timed, synchronized system, which Dr. Schoechle describes as reminiscent for some of an Orwellian global control network, and the oppressive, computer-controlled world in George Lucas' 1971 film, THX1138. It would behoove citizens and local governments to understand present ambitions in technology industries to make sure the world being shaped by technology is the world we want to live in.

In *Re-Inventing Wires: The Future of Landlines and Networks* Dr. Schoechle has provided an extremely valuable, multi-faceted analysis of our present situation within an historical perspective, as well as recommendations for a better future, which are critical for citizens and local governments to understand.

Society is at an important choice point. We can either squarely face the inadequacies of the present wireless communications trajectory, and see the irresponsibility of imprudent decisions now being made on behalf of society by technology companies, or leave a legacy of irresponsibility to the next generation.

The good news Dr. Schoechle brings to our attention in *Re-Inventing Wires* is that a great renaissance in copper and fiber is truly now at hand. Optical fiber and copper signaling advancements, new turbo-charged Ethernet connectors, along with updated wiring and cable standards provide superior alternatives to wireless antennas. Premises "gateways" on the horizon are being standardized, and will soon offer citizens control over what data leaves the premises, and thus the privacy we all deserve.

We owe to ourselves a wired solution that guarantees fast, affordable, health-safe, secure and sustainable Internet access for everyone. As stakeholders, it is our responsibility to see that this vital area of our society is aligned with our values, and that solutions to the many problems created by wireless communications are addressed. Fortunately, as Dr. Schoechle explains, most of these problems are eliminated or greatly diminished using wires.

In great appreciation for this most insightful report,

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Endnotes

[4] Although Marconi is generally credited with the invention of radio, there is evidence that Nicola Tesla was experimenting with radio data transmission in New York City in the early 1860's (Jonnes, 2003, p. 314).

[5] Metadata is data about or describing the message data (*e.g.,* phone numbers, times, dates, field identifiers, *etc*.).

[6] Inventions seldom if ever end up being what the original inventor intended. This is because as they are applied by society they are morphed by market and cultural forces into other forms and purposes. For example, Alexander Graham Bell intended to invent a hearing aid and did not envision the vast socio-technical system that his telephone became. How this happens is a field of study and body of scientific literature known as the "social construction of technology."

[7] The use of copper wire for telegraph and later telephone networks was introduced by Theodore Vail, founder of the Bell System. His role is discussed in more detail later.

[8] Known as Asynchronous Transfer Mode (ATM), part of the Integrated Services Digital Network (ISDN) standards

[9] WiFi, being very short range wireless, is closer to wired (Ethenet) service than 3G/4G mobile phone service, although is some respects these two may be converging to some extent with regard to portable devices (to be discussed later).

[10] Internet (TCP-IP) has now largely replaced ATM in many telecommunication networks. This transition was heralded in the landmark paper, *The Rise of the Stupid Network* (Isenberg, 1997).

[11] "LTE", the term for 4G (4th generation) wireless, is an acronym for long term evolution. It is ironic in that "long term" means "until the next new new thing gets cooked up"—or about a decade.

[12] *Ethernet* is a commercial tradename for a family of wired local area network (LAN) technologies standardized in 1983 by the Institute of Electrical and Electronics Engineers as IEEE 802.3. It was first introduced in 1980, with a data rate of about 3 Mb/s over coaxial cable.

[13] *WiFi* is a commercial tradename for the 802.11 family of wireless *Ethernet* protocols that use the 2.4 gigahertz (12 cm) ultra high frequency (UHF) and 5 gigahertz (6 cm) super-high frequency (SHF) industrial, scientific and medical (ISM) radio bands. A 1985 ruling by the U.S. Federal Communications Commission released the ISM band for unlicensed use. These frequency bands are the same ones used by equipment such as microwave ovens and are subject to interference.

[14] The core or backbone networks are largely based on Internet protocol (IP), but also include a large number of other protocols, both legacy and new.

[15] An exabyte is 10^{18} bytes. For comparison, a gigabyte is 10^{9} bytes, a terabyte is 10^{12} bytes and a megabyte is 10^{6} bytes.

[16] Also included in this list could be any number of other wired and wireless LAN protocols such as USB™, Bluetooth™, HomePlug™, Z-Wave™, ZigBee™, and many others.

[17] FiOS, is an acronym for Fiber Optic Service, a bundled Internet access, telephone, and television service that operates over a fiber-optic communications "fiber-to-the-home" (FTTH) network to over 5 million people in nine states. Verizon is a former regulated New York regional bell phone company *NYNEX* that expanded into unregulated business areas including nationwide LTE wireless services (*Verizon Wireless*).

[18] The history of perverse consequences of deregulation is told by Robert Horwitz in *The Irony of Regulatory Reform* (1989).

[19] For example, the *Act* did not anticipate much of the competition that has developed, such as wireless service

competing with both local and long distance wireline service, VoIP competing with wireline and wireless telephony, IP video competing with cable television.

[20] According to surveys by the ITU and the OECD, the United States ranks 22nd in Internet access by percent of population, and 15th by average connection speed (Crawford, 2013, p. 271).

[21] It is well established that regulators are susceptible to chronic "regulatory capture" by those that they regulate (Peltzman, 1976), and that public officials have a tendency to serve their own interests rather than those of the public (known as "public choice" theory). Regulatory capture and public choice theory are well-developed topics in policy research. A comprehensive review of the academic literature on regulatory capture has been prepared by Dal Bó (2006).

[22] Alster (2015) compares telecom to the tobacco industry, identifying a number of parallels including:
- refusal to examine the public health evidence
- hyper-aggressive legal action and bullying
- stonewalling PR
- undermining credibility of scientific experts
- cutting science funding
- publishing contradictory science
- trivializing highly credible dissenters
- misleading about scientific consensus
- light regulation
- industry control of congressional committees
- revolving door between industry and regulator
- spending large sums on direct lobbying and associations
- spending on both hard and soft money contributions

[23] An example of such industry-driven preemption of local municipal regulation is SB 649 that was adopted by the California legislature but vetoed by the Governor following vigorous objection from municipalities and the public (Kushnick, 2017).

[24] Gary Bolton, VP of Global Marketing of ADTRAN, commented during a panel discussion on Smart Cities, that 32% of fixed downstream traffic was produced by *Netfilx* and *You Tube* (TIA, 2015).

[25] Comment by Sprint Research Scientist Nick Baustert during a morning TIA keynote panel, June 3 (TIA, 2015).

[26] The address allocation is inefficient because in the early days of the Internet, there were a very limited number of users—mostly universities—who were assigned an inordinate amount of space. It was not forseen how the Internet would be used.

[27] IPv4 uses a 32-bit address and provides approximately 4.3 billion addresses. IPv6 provides 7.9×10^{28} times as many addresses as IPv4. Both a source and destination address reside in the header at the beginning of every IP message packet. As a result, IPv6 adds both packet length and processing time—a burden to simple low-cost devices.

[28] A gateway is a formal term for an interface between two networks, and it involves some protocol and application language translation process at the top (application) layer of the protocol stack. In this process, the message would be completely re-packaged, and any device-level IPv6 addressing would be irrelevant.

[29] Simple sensor networks often employ various localized application- or medium-specific protocols and addressing schemes that do not use IP (e.g., Zigbee,™ Bluetooth™ Z-wave™, HomePlug™, Modbus, CAN-bus, etc.).

[30] On-line software update processes are not a good fix because they simply open up new security vulnerabilities and require even more processing power.

[31] For example, IEC Guide 110 Edition 2, Home control systems – Guidelines relating to safety (1998, revised 2012) produced by the International Electrotechnical Commission (IEC) ACOS (Advisory Committee on Safety).

[32] For example, ISO/IEC DIS 14543-3-10:2012 *Information technology — Home Electronic Systems (HES) — Part 3-10: Wireless Short-Packet (WSP) protocol optimized for energy harvesting — Architecture and lower layer protocols*, developed by ISO/IEC Subcommittee 25, Interconnection of IT equipment, Working Group 1 on Home Electronic System (HES).

[33] *Normal* accidents are *system accidents*, where due to complex interdependencies, apparently trivial events can cascade through the system in unpredictable ways to cause a large event with severe consequences. The classic work on the subject is *Normal Accidents* by Charles Perrow (1981), inspired by the Three Mile Island nuclear reactor accident. Typical examples of susceptible complex systems are electric grids, nuclear power plants, air traffic control systems, spacecraft, and financial trading systems.

[34] In May of 2011, a review of the research by WHO's International Agency for Research on Cancer (IARC) found evidence that mobile phone users display significantly increased incidence of glioma and acoustic neuroma brain cancer (Dellorto, 2011). IARC then classified radiofrequency radiation as a Class 2B "possible carcinogen"—thus listing cell phone use, and other RF emitting devices and equipment, in the same "carcinogenic hazard" category as lead, engine exhaust, and chloroform.

[35] Many states have outlawed cellphone use without "hands-free" equipment and car-makers call them a safety feature, but ironically, studies show that it is not the driver's hands that are the problem, but rather their brain.

[36] The landmark decision (known as the MFJ or Modified Final Judgment) by the Federal District Court for the District of Columbia under the jurisdiction of Judge Harold Greene, grew out of an antitrust suit by MCI, a long distance provider, originally filed in 1974, and joined the same year by the U.S. Department of Justice.

[37] The Telecom Act of 1996, like most legislation, left much to the discretion of regulators and administrators who are inevitably influenced by politics and money—and by "regulatory capture" and "revolving door" career paths.

[38] An example was the spin-off of MediaOne from US WEST and the career of Gary Ames, CEO of US WEST who became CEO of MediaOne. Ames later sold MediaOne to Comcast and became Executive Vice President. Sol Trajillo moved up from the ranks within US WEST to take over as CEO, then a few years later, sold US WEST to QWEST, leaving with well over $100 million in severance to head a telecom venture in Australia.

[39] Section 704 of the *Act* specifically prevents local governments from limiting antenna placement on environmental grounds (interpreted legally to include health reasons). More recent legislation (e.g., *Mobile Now Act*, California *SB.649*, etc.) sought to preempt local governments further with regard to antenna placement on utility and other infrastructure.

[40] See previous footnote regarding US WEST.

[41] The historical path chosen in the United States for both electricity and telephone infrastructure development is an exception from that chosen by the rest of the world. Americans seem to have preferred to have their "taxes" (or costs) hidden behind the mythos of "free enterprise"—choosing regulated private monopolies and inflated rates over outright public ownership and taxes. In the case of electricity, the history has been thoroughly recounted by Rudolph and Ridley (1986), and in the case of telecom, by Horwitz (1989).

[42] In March of 2010 the FCC issued its 300-page *National Broadband Plan*, called for by a congressional stimulus bill and created under Obama's new FCC Chairman, Julius Genanchowski. The Plan did not focus on structural changes, but rather on subsidies to "…provide at least 100 million homes in the U.S. affordable Internet access at download speeds of 100 megabits per second and upload speeds of 50 megabits per second" (Resende, 2010).

[43] In essence, the FCC's approach in the NBP was to attempt to buy or "bribe" their way to public connectivity rather than come to grips with the underlying structural problems and market failure that were preventing build-out of fiber access networks.

[44] DOCSIS was developed by Cable Labs, a technical research and development consortium of cable firms. It was standardized by the ITU-T.

[45] In actuality, the channel frequency assignments were shifted because of varying local channel assignments and to accommodate the many more channels being offered. This required a "cable box" to translate the cable channel frequencies to the conventional TV receiver channel frequencies. This created a conflict between TV manufacturers and the cable industry over how the receivers could be made "cable ready". The cable box need created an additional revenue stream for the cable industry. This conflict was never totally resolved and continues to be a matter of contention with the FCC.

[46] Telephone predated widespread availability of electricity, so it needed its own power to operate a subscriber's phone. This has turned out to be an advantage of landline phones over wireless cordless and cellular phones in cases of power grid failure.

[47] Early phone pair installations terminated with simple screw or clamp terminations at the subscriber's end, but today most equipment using phone pairs use modular RJ-11 style phone jack to terminate "wires" with up to 4 pairs (8 conductors).

[48] According to researchers at *ASSIA, Inc*. (formerly with *Bell Labs/Telcordia*) "As (non-PON) fiber systems improve speeds to the fiber/copper interface, new DSL standards known as G.fast, 212 MHz G.fast, and G.mgfast increase speeds up to 800 Mbps, 2 Gbps, and 5-10 Gbps, respectively [6]. G.mgfast should encompass point-to-multipoint transmission to many in-home devices, and if there are 2 or more twisted pairs to the home the so-called phantom-vectoring methods can be used to transmit 10's of Gbps (Gatherer, 2017).

[49] Initially *Ethernet* was a serial communication network protocol developed for internal control messaging within a Xerox copy machine. Other "winning" technologies that came out of the Xerox Palo Alto Research Center (Xerox PARC) were the mouse, icon graphics, and laser printers—all ultimately commercialized by others such as Apple Computer and Microsoft.

[50] *Ethernet* is standardized primarily by the *Institute of Electrical and Electronic Engineers* (IEEE) 802.3 committee, and internationally by *International Organization for Standardization* and *International Electrotechnical Commission* ISO/IEC SC 25 (joint technical committee for Interconnection of Information Technology Equipment).

[51] Infrared light has a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves—typically from about 800 nanometers to 1 millimeter.

[52] The term "signaling" refers to the (hardware) modulation techniques used to encode information on a (metal, glass, or air) medium. "Encoding" refers to the (software) method used to impose digital information onto the signals.

[53] A terabit is a million million (10^{12}) bits per second, or a thousand gigabits (1000×10^9) per second.

[54] According to Hazas *et al* (2016, p. 1) citing 2014 figures, "Current estimates suggest that operation of the Internet (powering devices, networks and data centres) amounts to around 5% of global electricity use; yet this is growing faster (at 7% per year) than total global electricity consumption (3% per year)".

[55] Although perhaps tangential to the energy discussion, some advantages for cloud service providers include customer lock-in, subscription recurring revenue streams, and customer data mining opportunities. Some disadvantages for consumers have been discussed here earlier.

[56] SC39 consists of two working groups: WG1 "Resource Efficient Data Centres,"and WG2 "Green ICT."

[57] Theodore Vail (1843-1920) was a visionary industrialist that served as the President of American Telephone & Telegraph between 1885 and 1889, and again from 1907 to 1919. He had also previously worked for Western Union and introduced the use of copper wire in telephone and telegraph lines. He saw telephone service as a vital public utility and a natural monopoly, conceptualizing it in the slogan "universal service" (in contrast to the "dual service" of redundant systems of the time) under which he sought to consolidate all U.S. telephone service under the Bell system.

Notably, Vail believed that the role of private enterprise and the corporation in society was much broader than making money. He championed the concept that profit maximization was not necessarily the primary objective, and although necessary to insure the organization's financial health, it was only one factor in a complex socio-technical equation

where the corporation could serve a beneficent function in modern technological society.

[58] Much is said and written recently on the "Uberization" of commercial activity and the "gig economy". These themes would seem to rely heavily on a gigabit level of broadband access.

[59] The new allocated spectrum includes the 28 GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz), and 39 GHz (38.6-40 GHz) bands, as well as a new unlicensed band at 64-71 GHz (Electronic Design, 2016).

[60] New trenching, termination, and installation techniques have greatly improved wired installation costs.

[61] Google's initial purpose in its *Google Fiber* project was to exemplify and stimulate fiber build-out for high-speed broadband access to get "…other companies to take its approach to the rest of the U.S. (Barr, 2014). Its main business depends on the widest possible access to its Internet search (and advertising) engine.

[62] The "direct services" model is being employed by Longmont, Chattanooga, and every other successful broadband muni fiber system, and is planned in Fort Collins. The "open access" model is risky and has failed in some notable attempts (e.g., Utopia, Utah). No successful examples have yet been identified in this research.

[63] For example, in November of 2017, voters in the City of Fort Collins, Colorado, voted overwhelmingly to approve more than $100 million in bonding authority to finance a municipal fiber build-out by its municipal electric utility—in spite of over $500,000 spent by the local cable providers in opposition compared to less than $10,000 spent by local citizen advocates.

[64] For a more thorough discussion of the topic, a series of case studies has been provided by Denise Fairchild and Al Weinrub (2016), eds., in *Energy Democracy: Advancing Equity in Clean Energy solutions*.

[65] Transactive energy (TE) is a dynamic electricity pricing technology and tariff initiative under development by the *Pacific Northwest National Laboratories* and the *GridWise Architecture Council*.

[66] Variable rate structures such as TE could be designed to operate in a predictable, fair, and equitable manner to accommodate the needs of low-income customers while also enabling dynamic customer generation and storage within the local distribution grid and the community sharing of electricity.

[67] AMI is an acronym for an electricity remote meter-reading standard developed in the early 1990s as ANSI C.12 and later ironically named "advanced metering infrastructure." It can no longer be considered "advanced."

[68] Next Century Cities <http://nextcenturycities.org>

[69] A newer version of Isenberg's paper, "The Dawn of the Stupid Network," was originally published as the cover story of *ACM Networker 2.1* in 1998 (Isenberg, 1998).

[70] It should be noted that transporting voice and video over IP is not without significant technical difficulty. Voice service in particular is *isochronous* data (i.e., timing dependent) and subject to severe quality problems if packets are missing or delayed, so IP is does not fully replace conventional switched voice service from a quality or reliability standpoint. "There's a lot of complexity here at a technical level that is absolutely lost in the policy conversations," says Fred Baker, a distinguished engineering fellow at Cisco Systems and former chair of the Internet Engineering Task Force. Getting the technology right is crucial for the future of the Net" (Hecht, 2015, p.1)

The fundamental technical challenge is getting the net to carry traffic it was never meant to handle… Voice and video signals must come fast and in a specific sequence. Conversations become difficult if words or syllables go missing or are delayed by more than a couple of tenths of a second…Our eyes can tolerate a bit more variation in video than our ears can tolerate in voice, on the other hand, video needs much more bandwidth (p. 1)….congestion is most serious on wireless networks (p. 2).

[71] The FCC had already eroded the fairness doctrine and obligations in broadcasting with "regulatory reform" during the 1980s (Horwitz, 1989).

[72] A more thorough discussion of the differences in privacy laws and practices has been provided by Schoechle (1995 and 1995a). The historical and cultural roots of these differences can be explained in part by American Exceptionalism (Lipset, 1996), and the consequences of such differences can be seen in relation to differing standardization practices between the United States and the international standardization system (Schoechle, 2009, p. 18–41).

[73] SAR measures the ratio of power to weight (watts/kilogram) at a given frequency above 100 kHz for a given period of time. Although the SAR may be useful in a laboratory situation to measure single source, single frequency exposures on mannequins, it bears little relationship to the real-world environment.

[74] As far back as 1971, the Naval Medical Research Institute identified over 2,000 references on the biological responses to RF and microwave radiation (Glaser, 1971).

[75] The FCC guidelines do not recognize the effects of RF exposure on pregnant women, infants, children, people with medical implants, the infirm, or wildlife. They also do not recognize the effects of cumulative, long-term or combined exposures.

[76] Another mechanism has been proposed by Dr. Martin Pall, Professor Emeritus in Biochemistry and Basic Medical Sciences, Washington State University. According to Pall, EMFs act to produce non-thermal effects by activation of the voltage gated calcium channels, or VGCCs. EMFs act directly on the voltage sensor of the VGCC, the part of the VGCC protein that detects electrical changes and can open the channel in response to electrical changes. Excessive calcium in the cells results from this activation, leading to a wide range of biological and health effects (effects that have been shown to be reversed with calcium channel blockers, confirming the VGCC role) (Pall, 2013).

[77] https://ntp.niehs.nih.gov/ntp/htdocs/chem_background/exsumpdf/wireless051999_508.pdf

[78] Santa Clara County health official Cindy Russell, MD (2017), founder of *Physicians for Safe Technology*, provides a current survey of proposed mechanisms and references. <http://www.sccma-mcms.org>

[79] It is important to understand that the FCC does not have a duty or interest in protecting public health. See below:
- Promoting competition, innovation and investment in broadband services and facilities
- Supporting the nation's economy by ensuring an appropriate competitive framework for the unfolding of the communications revolution
- Encouraging the highest and best use of spectrum domestically and internationally
- Revising media regulations so that new technologies flourish alongside diversity and localism
- Providing leadership in strengthening the defense of the nation's communications infrastructure

https://www.fcc.gov/about-fcc/what-we-do

[80] The TNI report is based on research involving 1,600 cities in 45 countries that have chosen public ownership over corporate ownership, especially of their energy and water systems. The report concludes, "These (re) municipalisations generally succeeded in bringing down costs and tariffs, improving conditions for workers and boosting service quality, while ensuring greater transparency and accountability." (p. 11) The report challenges the ideas that governments are ineffective service providers, that private companies are more efficient, and that austerity budgeting and reductions in public service are inevitable.

"In an age when state and federal institutions have come to be increasingly compromised by politics and corporate money, responsibility and impetus lies with local governments to facilitate and ensure the welfare of community members. At the risk of advocating a return to feudalism, one might argue in favor of cities and communities stepping up to defend their citizens from colonization of rightfully-public communication resources by modern-day corporate brigands and robber barons."

National Institute for Science, Law and Public Policy

Bringing Science and Law Together to Create Intelligent Policy

The National Institute for Science, Law and Public Policy (NISLAPP) is a 501(c)(3) non-profit that was founded in 1978 to bridge the gap between scientific uncertainties and the need for laws protecting public health and safety. Its overriding objective is to bring practitioners of science and law together to develop intelligent policy that best serves all interested parties in a given controversy. Its focus is on the points at which these two disciplines converge.

The constantly evolving nature of scientific research, together with the accelerated pace of technological advancement, has drawn into question the reliability of the information on which decision makers in both government and industry rely. Many of the innovations that have led to the development of new products and processes have also raised significant new health, safety, and efficacy issues for consumers. NISLAPP's mission is to help reconcile the historic and political vagaries of the legal process with the absence of "absolute" scientific answers in addressing immediate and long-range consumer concerns. Rather than attempting a definitive resolution of such problems, this approach is aimed at encouraging honest interplay to help promote autonomous arrangements in areas of health and public safety. NISLAPP serves as a source of enlightenment to the consumer movement, industry and public policymakers alike by applying commonsense criteria to common-good concerns. It is NISLAPP's intent to forge dialogue between parties who may see themselves as diametrically opposed to each other's interests, and reconcile legal and scientific concerns in the formulation of intelligent, safe and sensible public policy.

To support our work, please contact James S. Turner, Esq., Chairman (jim@swankin-turner.com) or Camilla R. G. Rees, MBA, Senior Policy Advisor, National Institute for Science, Law and Public Policy (CRGR@aol.com)



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