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The Internet Adopts Two-Way Radio

by HENRY H. PERRITT, JR.[1]

Abstract

The Internet, having displaced conventional correspondence with email, having displaced traditional libraries with online ones, having revolutionized shopping, having uprooted television and movies, now is absorbing police, fire, ambulance, and public utility two-radio systems.

Digital radio technologies combine with Internet switching of transmitters, receivers, and networks, so that a police officer can talk to an ambulance driver or a train dispatcher across the state or across the country. Specialized cellphones are becoming indistinguishable from walkie-talkies. Cellular telephone channels replace two-way-radio air links.

Integration of "private mobile radio" into the Internet is the result of specific advances in radio and networking technology that now draw

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Mr. Perritt was a member of President Clinton's transition team, focusing on the Federal Communications Commission, and subsequently advised the White House on its regulatory philosophy for the Internet. He and his law students set up one of the first Internet servers providing access to governmental information in 1992 at Villanova Law School. He served on the National Academy of Sciences Computer Science and Telecommunications Board. He has written 15 books and about a hundred law review articles, many on technology and law and on entertainment and law, including the recent *Uber Television: Internet-Only Television Stations*, 23 UCLA ENT. L. REV. 65 (2016), and *Keeping the Internet Invisible: Television Takes Over*, 21 UNIV. OF FLA. J. TECH. L. & POLICY 121 (2017), both addressing the relationship between the Internet and commercial television.

He is a commercial helicopter, private instrument airplane, and remote drone pilot; co-owns a drone company focused on newsgathering; and is an extra class radio amateur (K9KDF). A number of radio amateurs around the world have contributed thoughts about the future of digital radio, in hundreds of "QSOs" with the author, many of them on one of three digital radio modes used by amateurs: DStar, DMR, and System Fusion.

He appreciates suggestions and editorial improvements from his student and friend Albert J. Plawinski and from his friend and helicopter instructor, Eliot O. Sprague.

Congressional approval in FirstNet, which provides a framework for writing the specifications and selecting the vendors for a new first-responder network that ensures interoperability.

This is occurring as the public switched telephone system converges with the Internet, so that the two no longer are separate or reflect different architectures.

Public officials and stakeholders must be vigilant to ensure that this initiative does not unduly limit competition in the equipment market or impair ordinary civilian uses of the communications infrastructure.

Introduction

On December 5, 2016, I was sitting at my computer editing a law review article. I heard the following on my handheld radio transceiver receiving on 439 Megahertz: "VK2EBH listening." Curious about the heavy British accent, I responded, "K9KDF." A 25-minute conversation ensued in which Brian, the operator of VK2EBH, told me he was a retired aluminum smelter technician in Newcastle, Australia, north of Sydney, and proceeded to answer my questions about aluminum smelting technology. Before we had concluded our conversation, another station, G4EGH, joined us. Stan told us that he was located about 40 miles southeast of London.

The radio transceivers we were all using had five watts maximum power and yet they were able to communicate all the way around the world. All three of us had our radios tuned to frequencies on the 400 MHz band, where the radio propagation is strictly line of sight and incapable of traveling beyond the horizon.[2]

2. PMR uses multiple bands of frequencies in the radio spectrum. The FCC divides each of these bands into specific frequencies that PMR users and their contractors may choose subject to frequency coordination. Radio missions are one type of electromagnetic radiation. Though they all travel at roughly the same speed, 186,000 miles per second, radio signals at different frequencies travel differently through the atmosphere. Very low frequencies penetrate the earth and are useful for naval communications with submarines. Medium wave frequencies, where the AM broadcast band is, travel across the Earth's surface well, following its curvature 400 miles or so in the daytime. HF, or "short wave" frequencies, can travel across the surface of the earth but also can be reflected by different layers of the ionosphere so that they skip great distances, sometimes around the world. Skip distance depends on the ionization of different levels of the ionosphere, which varies according to the 12-year sun-spot cycle and the time of day. In daylight, more sun ionizes the lower layers of the ionosphere. Typically, the frequencies at the lower end of the HF range, from 1.6 MHz to about 10 MHz, travel couple of hundred miles in the daytime, but a couple thousand miles at night. Frequencies in the middle of the HF band, ranging from about 10 MHz to about 21 MHz, can travel several thousand miles in the daytime but have much less range at night, when they simply penetrate the ionosphere and go out into space. Frequencies at the top of the HF band have highly variable propagation characteristics, depending on conditions of the ionosphere. They may be strictly line of sight or they may be able to travel great distances due to skip.

The frequencies from 30 to 300 MHz are known as the VHF band, those from 300 to about 800 MHz as the UHF band, and above 800 MHz, as microwave frequencies. The boundaries between VHF and UHF and, especially, between UHF and microwave are ill defined. One sometime sees 900 MHz labeled as UHF or as microwave.

None of the frequencies about 30 MHz skip, and they do not follow the curvature of the earth. In other words, they are limited to line up, 8 miles if a transmitter and receiver are at sea level, increasing according to the formula r=1.4 times square root (height of antenna). As frequencies increase into the upper part of the UHF band and beyond, the signals experience more attenuation from the atmosphere, atmospheric phenomena such as precipitation and clouds, vegetation, and human structures. Eventually, as frequency increases further, radio emissions begin to behave light. Radar waves, for example, transmitted in the 2- to 4 GHz band for air traffic control, begin to behave more like light waves, reflected by any object that can be seen.

Early radio technologies could use only low frequencies. Below the AM broadcast band and above 1 MHz was a reach for the first vacuum tube transmitters and receivers. The useful spectrum began to encompass low VHF frequencies by the end of the second world war, and this band became popular for the first public safety radio uses. Transistors and miniaturization associated with integrated circuit devices made higher and higher frequencies useful, so that, today, almost everyone occasionally uses frequencies in the 2.4 and 5.7 GHz band where WiFi operates.

Communications like this occur hundreds of times per day, not only in amateur radio service, but regularly in public safety, railroad, electric and gas utility, and other private mobile radio band services.

This is possible because communications that used to be carried only by radio, and subject to its limitations of range and interference, now can complete a significant part of their journeys enclosed in Internet packets,[3] moving seamlessly between radio repeaters[4] at the edges of the Internet.[5]

Radio engineers designing two-way radio systems[6] now have a broader range of choices than they used to. They still must pay attention, of course, to transmitter power, receiver sensitivity, antenna radiation patterns, and frequency selection in order to avoid interference. The last mile remains a radio link[7] to allow mobility of system users. Now added to these traditional tools of radio engineers is an Internet gateway, and they now must understand how the voice traffic is encapsulated in the Internet's IP, TCP, and UDP and other, higher level, protocols to navigate from origin to destination.

This migration of two-way voice radio communication to the Internet implicates not only the technologies of electromagnetic radiation[8]and global computer networks; it also raises important, but also often overlooked, microeconomics questions involving standard-setting, network effects, and monopoly power. The move of two-way radio to the Internet has not only been accompanied by a replacement of traditional command and control

3. A "packet" is a cluster of digital bits communicating information because of its standardized structure. Most packets traversing the Internet are framed by the Internet Protocol ("IP").

4. A *repeater* is a radio transceiver that receives radio signals on one frequency, amplifies them, and retransmits them on a different frequency at higher power. Repeaters' received and transmitted frequencies are paired. A *transceiver* is a radio device that combines the functions of a radio receiver with those of a radio transmitter.

5. An "edge" of the Internet is where Internet traffic leaves (or arrives at) the Internet and enters another part of the communications infrastructure, such as a radio access net (RAN) in a cellular telephone network, or a LAN.

6. The formal name for the radio systems discussed in this article is "Private Mobile Radio," *see* 47 C.F.R. § 2.1 (definition of mobile radio services, as distinguished from fixed radio services), commercial mobile systems (public telephone systems), 47 C.F.R. § 20.3, aviation radio, 47 C.F.R. § 87.5, maritime radio, 47 C.F.R. § 80.5, and amateur radio, 47 C.F.R. § 97.3. The term "two-radio" is a common colloquial term for these services.

7. Engineers frequently refer to it as an RF (radio frequency) link, and vendors sometimes call it an "air link."

8. RF signals are one type of electromagnetic radiation. Light is another.

regulation by the FCC with a privatized approach more closely resembling the regulation of the Internet. Private standard-setting organizations have always played an important role in communications regulation, but now private organizations are allocating frequencies, developing and administering licensing exams, and performing virtually every aspect of regulation, while the FCC merely puts its stamp of validity on private decisions.

These trends will continue and accelerate because the Internet is a superior communications ecosystem compared to thousands of proprietary and incompatible private radio systems, sometimes linked together with ad-hoc wired, microwave, or optical fiber.

Four aspects of the adoption process are occurring more or less simultaneously.[9] The first is the replacement of analog PMR[10] systems with digital systems that link base station transceivers together through the Internet. The second is the migration of the public telephone system away from circuit switched technologies to the Internet, with the replacement of its switches with the Internet's traditional packet routing.[11] The third is the push to provide interoperable public safety communications through the cellular telephone system rather than through physically separate VHF and UHF radio systems. The fourth is the diversion of two-way radio communication into the public switched telephone system, so that the links between base stations and repeater transceivers are effected through channels provided by the telephone company instead of channels provisioned privately by public safety communications vendors. As that occurs, the

9. To be faithful to the metaphor in the title and to promote efficient discussion, the article uses the concept of "adoption" to refer to the multifaceted transition that is integrating PMR into the Internet and into the public telephone system.

10. Terminology and conflicting acronyms potentially confuse discussion of the trends. Many industry literatures refer to "LMR"— and mobile radio—while the legal term is "PMR," which distinguishes private networks from those intended to serve the general public. *See* HAMLET SAROKHANIAN & NEWBURN, EXPANDING COVERAGE AND CAPACITY THROUGH LAND MOBILE RADIO NETWORK INTEROPERABILITY 4 (2016), https://www.business.att.com/content/dam/attbusiness/reports/push-to-talk-white-paper.pdf (using the term "LMR" in describing the conversion from P25 to AT&T's PoC offering in Fairfax County, Virginia). This section uses "PMR." Cellular telephone service is CMRS—commercial mobile radio service—a subject of public mobile radio. CMRS includes cellular service. 47 C.F.R. § 20.3 (defining "commercial mobile radio service") Mobile radio services that do not meet the definition of CMRS are presumed to be PMR services. 47 C.F.R. § 20.3 (defining "private mobile radio service").

11. Strictly speaking, Internet routers *are* switches. But the text follows the conventional distinction between physical circuit switches and packet routers.

Internet channels between base station and repeater resources already common for digital radio modes can simply be those of the public telephone system.

These changes have implications for the design of mobile hardware. Portable radios are unlikely to look like a typical PMR handset walkie-talkie in 2017. They also are unlikely to look like an iPhone 6s. They will be hybrids, less bulky than PMR walkie talkies,[12] but more substantial than cellphones, and they will have prominent push-to-talk buttons.

This article begins by explaining the basic technologies. It explains how they are deployed to meet the communications needs of different PMR services. Then, it reviews the history of the Internet's expansion, identifying the characteristics that drove the folding of one communications mode after another into this ubiquitous network of networks. It analyzes key regulatory developments aimed at providing adequate space for new technological architectures to be developed rather than constraining them by legacy engineering prescriptions for communications devices and interconnections. It evaluates the benefits and risks of the new, freer and more private, organizational and regulatory landscape. It considers the perils of private self-regulation and security vulnerabilities and concludes that the major trends toward the Internet as the dominant communications infrastructure for the world are sound and will continue. The deadweight of committee regulation typifying many standard-setting initiatives would benefit from being replaced by something more closely resembling the Internet Engineering Task Force RFC system.[13] The article notes that overly aggressive understandings of intellectual property reinforce monopolistic practices that stultify innovation and argues that many of the concerns about security are overblown.

It includes amateur radio users as well as public safety and commercial/ industrial users. Historically, amateur radio operators ("hams") have tested new radio technologies and shown how the use of commercial products can be extended. They continue to do that with digital radio. Thus, some of the features not yet marketed to public safety and commercial industrial customers may be in actual use by hams.

12. Motorola invented the term "walkie talkie" as a colloquial term for the first portable radios. They were used in the U.S. armed services early in World War II.

13. See *infra* Section III.F.

I. **Architectures**

Advances in communications technology are causing the integration of private mobile radio ("PMR"), the cellular telephone system ("CMRS"), and the Internet. Historically, the architectures of the three systems were quite different. They share the fundamentals, but each has its own terminology. Transmitters and receivers exist in every communications system, often combined in the same piece of hardware, called a "transceiver." Some kind of "circuit" or "channel" ties them together. How rapidly they can talk, or how much data they can exchange depends on the "bandwidth" of the channel.[14] They must have some way of finding each other to set up a communications session.[15]

A. Private Mobile Radio

Private mobile radio systems typically comprise one or more base stations, one or more repeaters, and a multiplicity of mobile units. The mobile units communicate with each other, and with repeaters and base stations via radio. The base stations and repeaters communicate with each other through a fixed microwave, wire, optical fiber, or Internet links.[16] Historically, the radio signals among stations have been analog, but the FCC's refarming initiative[17] is forcing users to digital radio[18] in order to meet increasingly stringent bandwidth limitations. The analog systems mitigate

14. The bandwidth of a channel is like the diameter of a pipe. As more water can flow through a bigger diameter pipe, more data can flow through a bigger diameter channel.

15. The calling party may dial a 10-digit telephone number associated with the called party; it may transmit a voice call on a shared channel; or it may send a packet with an IP address in it.

16. As *infra* Section I.C explains, the physical layer of the Internet may comprise radio, optical fiber, or wired connections. The text distinguishes between links involving the Internet as a routing mechanism and links involving no routing or proprietary routing mechanisms.

17. The refarming initiative requires radio hardware to be capable of operating on channels with reduced bandwidth. *See Private Land Mobile Radio Services,* FCC (May 17, 2016), https://www.fcc.gov/wireless/bureau-divisions/mobility-division/private-land-mobile-radio-services (briefly describing refarming initiative).

18. The analog radio signals modulate the radio carriers with an audio waveform directly. By contrast, digital radio, first, digitizes (and usually compresses) the analog signals and, then, modulates the carrier with the digital representations.

interference by assigning different clusters[19] of users to different frequencies.[20] Digital systems achieve the same result by assigning users to different clusters on the same frequency.[21] Repeaters frequently are tied together to extend coverage of their RF[22] footprints.[23] The frequencies used for PMR are in the part of the spectrum known as VHF or UHF,[24] which are limited to line of sight, meaning that a typical transceiver with an antenna at head height can communicate no more than 2 or 3 miles. An antenna 100 feet above the surface enables communication up to about 12 miles. Because the communication range increases with height, repeater antennas typically are placed on towers at points of high elevation such as hills or mountains or on the tops of tall buildings. Links between repeaters can take the form of wires, optical fibers, or point-to-point microwave channels. The wires and optical fibers can be overhead or buried, and any of the three types of links can be installed privately or leased from third parties such as a telephone company or a specialized provider of antenna towers and facilities for cell phones and PMR.[25]

Systems may involve multiple base stations and repeaters. With that architecture, all the base stations, like the mobile stations, transmit on the same frequency, and the repeaters receive that transmit frequency, again like the mobile stations, but transmit on another frequency. Otherwise, the base and mobile station signals would interfere with the repeater signals. Base and mobile stations must be tuned to two different frequencies: the frequency on which they transmit and the frequency for the repeater, which they receive. It is more straightforward for the system to treat the base station just like any other node that is handled by the repeater.

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19. This article uses the term *cluster* to refer to a group of radio users virtually connected to each other.

20. The receivers distinguish signals according to their frequency. Therefore, when the signals are on the same frequency, the receivers are unable to distinguish those signals, and interference occurs.

21. The different modes use different terminology for the clusters. DMR calls them “talkgroups,” DStar calls them “reflectors,” and Fusion calls them “rooms.”

22. Radio-frequency.

23. “Footprint” refers to the range of radio-frequency signals, considering terrain and other factors that may limit the range.

24. VHF frequencies range from 30 to 300 MHz; UHF frequencies range from 300 MHz to 1 GHz.

25. American Tower, Crown Castle, Digital Bridge, and InSite Wireless Group are the examples of communications infrastructure companies.

On the other hand, multiple repeaters serving the same system must operate on different frequency pairs; otherwise, their transmissions would create dark spots in the coverage area when the signals from the different repeaters transmitting on the same frequency are out of phase and, thus, cancel each other out.

The core call-routing functions performed by a cellular telephone system considered in Section I.B are quite similar to the functions performed in a wide-area PMR system.[26] The core functions include setting up calls that involve more than one repeater or cell phone tower. Specialized functions, however, are different.

Most PMR networks use legacy analog techniques to allow one unit to establish a communication session with another unit. The calling unit knows what talk group the desired unit is likely to be connected to and simply makes a voice call: "Illinois State Police District 10 Dispatcher, this is Shelby County Sheriff Unit Two." Most digital PMR products allow the unit to make a direct call to another unit by sending a digital representation of the called unit's number. Unit numbers are proprietary.

Cell phones, of course, are reachable by imputing their telephone numbers in a familiar 10-digit form, possibly preceded by a country code. Internet locations are reachable by sending a TCP handshake packet to an IP address, which is often hidden behind a domain name or email address.

Trunking is a design of radio network that allocates frequencies on an as-needed basis. Working frequencies in a trunked system are clustered around a control channel. A radio user wishing to set up a communications session sends a data message on the control channel. The logic supporting the control channel selects one of its frequencies that is not in use, assigns it for the session, and informs the requesting user and the other members of the current talk group. The users' radio automatically switches to the working frequency and communicates directly with each other. Trunking often is confused with digital radio. Digital radio doesn't need trunking, and trunking can occur in an analog radio system.

Trunking and roaming capabilities are distinct from the basic features of digital radio and Internet routing. Roaming involves the ability of a mobile transceiver to determine the closest ground base transceiver, either repeater or base station, and to shift its communication to that facility, instead of one

26. This article uses the term wide-area PMR system ("WAPMRS") to refer to a system in which fixed radio facilities, repeaters or base stations, are tied together through fixed links.

that is receding as the mobile unit moves. This is accomplished by straightforward comparison of signal strengths from different antennas.[27] Both trunking and roaming provide additional functionality to system users, but they are more expensive and complex, trunking more than roaming.

B. Cellular Telephony

The cellular telephone system is a mesh of interconnected, relatively low power radio transmitters and receivers that are almost always combined into *transceivers.* The transceivers and their antennas are grouped and placed on cell towers with their power and propagation characteristics assigned to cover a limited amount of territory that is rarely more than ten square miles.

The cellphone system shares frequencies by dividing its coverage area into multiple cells.[28] Each cell has a cluster of VHF or UHF frequencies for communication and a control channel. Adjacent cells use different frequencies to prevent interference.[29] Cell towers contain multiple antennas and radiate relatively low power signals from a multiplicity of transmitters, one for each frequency, and receive transmissions from the individual cell phones. When the signal from a cell phone becomes stronger in an adjacent cell than the signal from the cell to which the cellphone is connected, the Mobile Telephone Switching Office ("MTSO") hands off the customer to an adjacent cell.[30] This is an example of roaming.

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27. Roaming is possible only when the ground stations operate on different frequencies; otherwise, the mobile station cannot distinguish one from another and cannot decide which one has the stronger signal.

28. *See* NAT'L ASS'N OF BROADS., ENGINEERING HANDBOOK 594–595 (Edmund A. Williams et al. eds., 10th ed. 2007) (explaining architecture of cell networks).

29. *See* Karthikeya Boyini, Comment to *Cellular Architecture*, TUTORIALSPOINT (Sept. 28, 2018), https://www.tutorialspoint.com/cellular-architecture (last visited Feb. 16, 2019) (explaining that different cell sites of each carrier use different frequencies).

30. Peter Steenkiste, 18-452/18-750 Wireless Networks and Applications Lecture 18: Cellular: 1G, 2G, and 3G (Spring Semester 2017), slide #5 (functions of MTSO), slide #19 (identifying handover function), https://www.cs.cmu.edu/~prs/wirelessS17/handouts//L18-Cellular.pdf.

The Base Station Controller ("BSC")[31] and Radio Network Controller ("RNC"),[32] which are subsystems within the MTSO, are responsible for detecting when a customer wants to make a call and then sending an *attach* message on a cell's control channel, which connects the mobile unit and the call to an available frequency within the cell.[33] This is an example of trunking. The same subsystems keep track of all cellphones within the range of a cell and signal them when they receive calls.[34] 4G and LTE systems, representing more advanced technology with higher data rates and greater capacity,[35] have somewhat different architectures,[36] but the principles for beginning and terminating call, handoffs, and accounting are the same.

The MTSO connects mobile calls to the public switched telephone system ("PSTN"). Data exchanges, as contrasted with voice conversations, are routed by the MTSO to the Internet cloud,[37] rather than to the PSTN. The MTSO also is responsible for accounting for call minutes or data used and for roaming—handing off a customer to another provider when the customer is outside the coverage area of the provider to which she is subscribed.[38]

Wireless providers increase the capacity of their networks through a variety of techniques. First, they decrease the height of cell towers, thereby reducing the range of each, resulting in smaller cells and increased frequency

31. *GSM – The Base Station Subsystem (BSS)*, TUTORIALSPOINT, http://www.tutorialspoint.com/gsm/gsm_base_station_subsystem.htm (last visited Feb. 16, 2019) (listing functions of BSC such as handling radio channel setup, frequency hopping, and handovers).

32. *UMTS – A New Network*, TUTORIALSPOINT, http://www.tutorialspoint.com/umts/umts_a_new_network.htm (last visited Feb. 15, 2019) (depicting a relationship between RNC and BSC).

33. Mobile Telephone Switching Office, WIKIPEDIA, https://en.wikipedia.org/wiki/Mobile_Telephone_Switching_Office (last updated May 1, 2018) (explaining attachment and handoff procedure).

34. *Id.*

35. The increased capacity results, not because the signals move faster; they do not. Capacity increases because bandwidth of the signals increases.

36. *See* Robert Triggs, *4G vs LTE – What is the Difference?*, ANDROID AUTHORITY (Nov. 10, 2018), http://www.androidauthority.com/4g-vs-lte-274882/.

37. "Cloud" is a common metaphor for the Internet, to distinguish it from the parts of the communications infrastructure beyond the Internet's edge. It is a good metaphor because it captures the idea that the applications that connect to each other through the Internet do not need to know what is inside the "cloud." They just connect to it, confident that it will provide a connection to the desired application at the other edge.

38. Robert D. Keith, *How Cell Phone Work*, http://iml.jou.ufl.edu/projects/fall04/keith/Works.htm (last visited Mar. 2, 2019) (explaining roaming and accounting functions of MTSO).

reuse. Eventually, however, demands on the capacity results in congestion and deteriorating performance. The answer is to subdivide each of these macrocells into smaller sub-cells, known as *small cells*, comprising micro- and picocells.[39]

Small cells use the same frequencies as their macrocell parents but provide higher received power to user devices than the macrocells, causing the user devices to select them. "Backhaul"—the signals and messages tying all the sites together, is provided ideally by optical fiber links, but, when necessary, the system uses microwave links implemented on higher frequencies, in the 18 and 23 GHz bands and even millimeter wave in the 60 and 80 GHz bands, affording greater available bandwidth through larger slices of spectrum, at the expense of greater atmospheric attenuation, which does not matter as much given their smaller size.

Small cell sites achieve greater density than macrocells by closer spacing, possible because of lower output power and lower height. Typically, 14 small cell sites serve each macrocell. Small cell transmitters provide stronger signals to user devices close to a small cell than their associated macrocells, causing the user devices to connect to the small cells instead of increasing the load on the macrocells.

Finding locations for small cells is a constraint. Providers must make use of light poles, utility poles, billboards, and building façades, and eventually they run out of space.

Capacity requirements can be increased further by deploying the cell infrastructure's equivalent of multicasting. Multicasting often is associated with broadcast entertainment,[40] but it also is useful for distributing radio transmissions intended for groups of users, as for a police precinct, or a group of railroad trains receiving the same track access instructions.

Cells define the physical layer at the edge of the Internet, blending with user provided Wi-Fi points of presence using unlicensed spectrum beyond the edge of the Internet.

3G LTE systems, which represent the dominant technology in the United States, handle everything in digital form, including voice. Voice and data may be distinguished for billing purposes, but both types of information move through the infrastructure as IP packets.

39. MICHAEL ALFAKER, *An Efficient Approach to Small Cell Design* (Dec. 2015), https://www.aglmediagroup.com/wp-content/uploads/2018/06/AGL-Small-Cell-Mag-Dec 2015.pdf.

40. *See* Henry H. Perritt, Jr., *Keeping the Internet Invisible: Television Takes Over*, 21 UNIV. OF FLA. J. TECH. L. & POLICY 121, 141-142 (2017) (explaining multicasting).

C. Open Systems and the Internet

Reference to the Open Systems Interconnection ("OSI") model facilitates talking about communications and computer architectures, including the Internet; the Internet is the most prominent example of an OSI-compliant system. The OSI model is an abstract way of representing the interaction among different layers of any communication system. At the bottom is the *physical* layer, which comprises wires, optical fibers, laser beams or radio channels over which communication signals actually travel. At the top is the *application* layer, which comprises user-oriented functions typically implemented in software. In between lie the data-link,[41] network,[42] transport,[43] session, and presentation layers which specify how information gets packaged for moving over the physical layer, how the resulting packets comprising one communications session get associated with each other so that a user has the illusion of a continuous stream of information making up of a conversation, and how the resulting streams get presented as inputs to the application software. OSI permits designers of system components to specialize in fewer than all of the layers and to write open specifications only for the interfaces with adjacent layers. Thus defined, their products can interoperate successfully with other vendors' products.

The Internet is the most pervasive realization of the OSI concept. The Internet is not a thing, or a single product. It is, instead, a collection of millions of computer programs and computer hardware devices all tied together by implementing open standards at each of the layers of the OSI stack. Some of its service providers are huge, like AT&T, which provides optical fibers, wires, and RF circuits at the physical layer. Some are tiny, like the author of this article, who provides circuits at the physical layer in the form of a cable modem and Wi-Fi points of presence. The IP routers included inside these two boxes also function at the network layer.

The devices at each end of a communications link perform functions at all of the layers, accepting inputs at the physical layer and processing them upward through the intermediate layers so that they emerge in usable form

41. Ethernet has physical layer functions but is primarily a data-link protocol.

42. The Internet Protocol ("IP") is a network layer protocol.

43. Transport Control Protocol ("TCP") and Uniform Data Protocol ("UDP") are transport layer protocols.

at the application layer. The computers on which this article mostly was written runs application, presentation, session, transport, and network layer software and is tied into edge of the Internet through its wireless ethernet card functioning at the data-link layer.[44]

The process of moving information through the layers is like taking a message written on a piece of paper and progressively enclosing it in one envelope, then another, and then another as it moves down from the application layer to the physical layer. The message enclosed in its multiple envelopes traverses the physical layer and then, software at the receiving end removes each envelope as the message moves up to the application layer,[45] where it is subject to further processing. For example, audible speech, represented initially by an analog waveform, gets digitized at the presentation layer,[46] segmented into UDP and IP packets at the session and transport layers, and associated with data indicating the identity of the sender and the address of the receiver there. Routers in the network layer send it towards its destination. The routers are tied together by Ethernet network interface cards at the data-link layer and by optical fibers, wires, or radio links in the physical layer.

The Internet also expresses a philosophy, core principles of which are:

1. Simplicity;
2. Indifference to the content of end-to-end communications;
3. Relegation of specialized computation to the edge, in the application layer, rather than in the core, at lower layers;
4. Acceptance of anyone who wants to connect, as long as he adheres to the Internet's technical standards;[47]
5. Resilience to damage.[48]

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44. The Ethernet card itself is wired into the computer; it controls access to the wireless channel, which uses a distinct protocol at the physical layer.

45. Each envelope has its own address, formatted in accordance with the protocol at that particular layer. A TCP envelope, for example, has the "port" corresponding to an application.

46. The function of particular layer may be performed in different hardware. The digitization of voice, for example, may be performed in the microphone itself, or the microphone may send an analog waveform to other devices, which digitize it.

47. *See* RFC, COMMENT NO. 3439, SOME INTERNET ARCHITECTURAL GUIDELINES AND PHILOSOPHY (2002), https://www.ietf.org/rfc/rfc3439.txt.

48. The Internet was designed so that if one "link" in the system goes down (in case of a nuclear attack), packets would be automatically re-routed over other links and reach their destination.

The fact that the technical standards are open to the public and available without cost to everyone does not imply that the information content is similarly open; users of the Internet are perfectly free to use proprietary standards known only to them at the edge, in the application layer, and they might use the secure socket layer Internet standard, which permits them to encrypt communication and reserve access to it only to those who possess a private encryption key.

The capacity of the Internet is determined by a combination of router processing speed, link bandwidth, and the number of alternative pathways from each origin to each destination. If there are six pathways from one server to one client, each router need have only 1/6 of the processing power that it would need if there were only one path.[49] Likewise for link bandwidth. Router processing power must be matched to link bandwidth. A very fast router can function no faster than the capacity of the links connecting it. A slow router cannot fill the bandwidth of a high capacity link.

The Internet has a physical reality, of course. The electrons and photons that carry the signals representing digital bits move over optical fibers; coaxial cables; and radio, in the form of microwave transmissions, UHF cellphone transmissions, and satellite transmissions.[50] Typically, Internet service providers[51]lease optical fiber or radio capacity from entities that specialize in providing such connectivity, but some entities, like cable MVPDs and the telephone companies, provide their own physical connectivity. They often have physically buried their own cable or established their own transmitters. Multiple types of Internet service providers use this physical capacity. Tier 1 providers handle the largest volumes of Internet traffic,[52] and peer with each other.[53] Tier 3 provides last-

49. The data is divided among six paths, each with one router. So, each router gets only one-sixth as much traffic to process.

50. This part of the Internet corresponds to the physical layer of the OSI stack.

51. Anyone who provides a service comprising the Internet is an "Internet service provider." Discussions of the Internet, however, usually distinguish between "ISPs" who connect customers at the edge to the cloud, and "backbone" providers who handle large volumes of traffic between ISPs. And, of course, there are multiple levels or "tiers" of backbone providers.

52. Earl Amijewski, *A Baker's Dozen, 2013 Edition*, ORACLE DYN (Jan. 9, 2014) http://research.dyn.com/2014/01/bakers-dozen-2013-edition/ (reporting that in 2013, the top tier one backbone providers were Level 3, NTT, Telia Sonera, GTT, Cogent, Taga, Spring, Verizon, Tel. Italia Sparkle, TCCW, China Telecom, XO, and Hurricane Electric).

53. *Peering*, in contrast to *transit*, involves exchanging traffic without paying each other. Transit connections provide access to any place on the Internet for a fee. Networks with roughly

mile connectivity to users. Tier 2 providers are intermediate in size. Some enterprises participate in all three tiers.

Since the turn of the 21st-century, content delivery networks (CDNs) have arisen.[54] CDNs combine load sharing, caching, and network connectivity.[55] They store content on a multiplicity of large servers placed geographically near the edge to serve expected demand. The multiple servers provide greater reliability through redundancy and greater efficiency by offloading repeated requests for the same content from one central server.[56]

The physical architecture is simple. A connection, say an optical fiber, connects to routers at each end. Peering and transit sites, called Internet Exchange Points,[57] are simply large routers. The mesh has considerable flexibility. A content producer or programmer may want to carry its traffic closer to where its viewers are.[58]

It can arrange to lease its own optical fiber, buy its own large-scale routers, and make peering or transit arrangement with other backbone providers closer to where the largest groups of viewers are.[59] Or, if it does not want to be in the physical networking business, it can hand off its traffic

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equivalent traffic levels usually peer; networks with disparate levels of traffic usually enter into transit arrangements.

54. *See* Mustafa Aljumaily, *Content Delivery Networks Architecture, Features, and Benefits*, RESEARCHGATE (April 2016), https://www.researchgate.net/publication/305722381_Content_Delivery_Networks_Architecture_Features_and_Benefits (describing content delivery networks).

55. *See In the Matter of Protecting & Promoting the Open Internet*, 30 FCC Rcd. 5601 15-24, ¶197 at 88 (2015) [hereinafter 2015 ONO]. (noting that CDNs enter into both transit and peering arrangements with backbone providers).

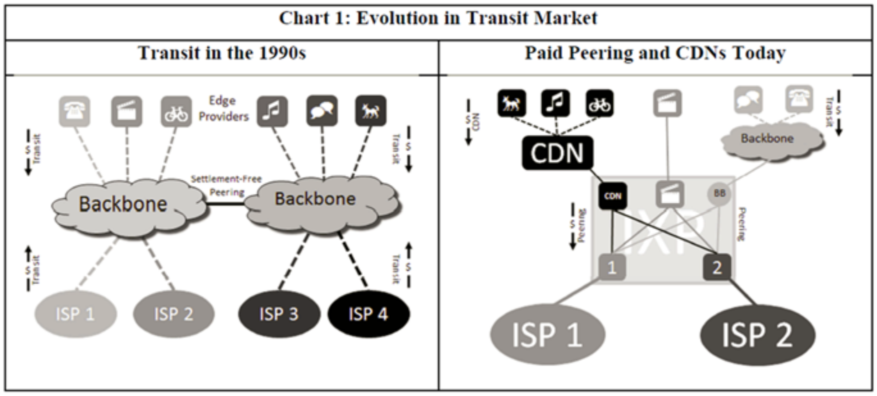
56. "ISPs regularly cache popular content—anything from simple text to streaming video—so that when a subscriber requests such content it can be retrieved more quickly (and with less load on the network) than would occur if the request were sent to its specified destination. And it's not just an ISP's own servers that cache content; an entire industry of content delivery networks have sprung up to move content closer to Internet users to improve performance" *Id.* at 355 (Pai, dissenting).

57. An Internet exchange point typically is configured as ethernet ring in a single facility to which each participating carrier attaches a gateway router. *See* ANDREW BLUM, TUBES: A JOURNEY TO THE CENTER OF THE INTERNET 109–118 (Ecco, 2012) [hereinafter Tubes] (explaining Internet exchange points, with examples).

58. Building a pipe that terminates close to be edge reduces the number of hops packets must take from their origin to their destination. Reducing the number of hops minimizes delays and increases effective bandwidth.

59. *See* 2015 ONO, *supra* note 55, ¶ 198 at 88 (noting that AT&T, Comcast, Time Warner Cable, and Verizon have built or purchased their own backbones).

further upstream to a third-party backbone provider or to a CDN which will hand it off to backbones are multiple points further downstream.



The chart compares the Internet architecture of the 1990s to that of now, emphasizing the role of CDNs.[60]

The Internet protocols are becoming the norm for video distribution. Television programmers are harmonizing their internal exchanges on IP. Eighty percent of telephone MVPD providers use IPTV.[61] Cable Internet access providers are embracing a decentralized infrastructure that looks like the Internet's multicasting. The Internet's core virtue is that it is invisible. Producers and consumers of information have the illusion of dealing directly with each other. Each has a broad choice. Any consumer can deal with any producer, and all producers have access to all consumers The dominant policy goal is to keep the Internet invisible, in this sense.

D. Station Finding

Any form of communication requires that the participants in a communication session both have access to a channel through which the content will pass between them. The channel can be as informal and physical as a pause in a group conversation around a dinner table. It can be a discrete radio frequency to which both transmitter and receiver are tuned. Analog radio communications between a police unit and a dispatcher are an example

60. 2015 ONO, *supra* note 55, at 89.

61. *In the Matter of Annual Assessment of the Status of Competition in the Mkt. for the Delivery of Video Programming*, 32 FCC Rcd. 568 (2017).

It can be an electrical circuit defined by wire pairs connected by switches. A voice telephone circuit is an example. It can be an electrical circuit to which multiple stations are connected, allowing access by each depending on digital codes exchanged. Ethernet is an example. The transition addressed by this article involves a shift from the second and third types of channels to the fourth.

Although useful communication can take place on direct instances of the second and third type of channel, as by direct radio communication between transmitters and receivers within radio range of each other, or buy a simple intercom, most communication systems of any significant functionality require chaining multiple channels. In the public telephone system, for example, the calling party has a wire pair connected to the local "central office." That comprises one circuit. A switch in the central office selects an available trunk line—another wire pair—connecting that central office to another center office or to a long distance wire center, comprising a third circuit. Then, at the destination, an incoming truck wire pair connects to the central and a "last-mile wire pair connected to the called party.[62] The Internet replaces the switched circuits, one for each communication session, with intermingled Internet packets, each representing a small piece of a communication session. Routers route each packet to its destination according to addresses in the header of the packet.

In order for units to communicate with each other they must know where to attempt contact. In the legacy telephone system, that is not a problem; each subscriber has one wire pair and one telephone number connecting his telephone to the network. In an analog PMR system, calling and called parties find each other primarily by selecting the appropriate frequency and then by calling the desired station orally. For example, a municipal police unit wishing to communicate with a deputy sheriff for the county enclosing the municipality might switch to a sheriff's department frequency different from the municipal police frequency and call the station. If the station is listing on that frequency, it would respond, and the communication session would begin. The infrastructure for station finding relies almost entirely on frequency assignment, although technologies exist to allow selective calling, in which a call to a particular station is preceded by a series of audio tones

62. Modernization of the telephone plant has replaced many of these physical wire pairs with virtual circuits, in which individual channels are multiplexed on wire pairs, coaxial cables, or optical fibers.

associated with the called station.[63] Every station on a particular frequency ignores calls unless they are preceded by that station's audio tone.

In the public telephone system, station finding depends upon a set of unique telephone numbers, assigned by telephone service providers. The FCC coordinates the set of available numbers through its North American numbering plan.[64]

The Internet depends for station finding on a set of unique IP address, mostly associated with equally unique domain names. The coordination of the system is the responsibility of the Internet Assigned Names and Numbers Authority (IANA).[65]

II. Digital Radio Modes, and How They Work

Digital radio modes comprise two distinct technologies : one for the RF link between the user's transceiver and the gateway;[66] the other for routing communications between gateways, implemented almost entirely through the Internet in the current state-of-the-art. Each technology can exist without the other. Digital radio can be implemented on a local repeater not connected to the Internet. Internet routing of radio communications can occur when the RF communications are analog. But the current digital radio modes, TETRA, P25, DStar, DMR, dPMR, System Fusion, and NXDN employ both.[67] Digital radio functionality is divided between hardware and software. Much of the software runs on general purpose computers connected to the Internet.

63. *Continuous Tone Coded Squelch System*, RADIOREFERENCE.COM, http://wiki.radioreference.com/index.php/Continuous_Tone-Coded_Squelch_System (last visited Mar. 24, 2019) (explaining CTCSS, a system for activating units on a frequency only when a transmissions is preceded by a particular code).

64. NANPA, *About NANPA,* https://www.nationalnanpa.com/about_us/index.html (explaining NANPA's contract with FCC); Henry H. Perritt, Jr., Digital Communications Law § 8.07[D] (assessing NANP*).*

65. IANA, *About Us*, https://www.iana.org/about (2019*). See also* Henning Schulzrinne, Transitioning the PSTN to IP, www.ietf.org/proceedings/86/slides/slides-86-iab-techplenary-4.pdf.

66. The *gateway* is the specialized computer that connects a radio device like a repeater to the Internet.

67. LENNY GEMAR, DMR AND DIGITAL VOICE MODES (Aug. 14, 2017), http://www.k7id.org/presentation/20170814.DmrAndDigitalVoiceModes.pdf (basic explanation of digital radio modes).

A. Communication Patterns and Network Topologies

The basic element of a PMR network is a *talkgroup*.[68] Talkgroups mimic the group of users tuned to the same analog frequency at the same time; in digital radio, members of one talkgroups may be communicating to the system on different frequencies, and different talkgroups may operate on the same frequency without hearing each other.

Talkgroup configuration depends upon the activities to be coordinated by radio communication. Two aspects of activity are relevant, interdependence of distinguishable activities, and their spatial proximity. No reason exists, for example, for the ushers inside Amtrak's Union Station in Chicago, who assist passengers and control their access to the gates to be in the same communications cluster as the dispatchers and train-and-engine crews approaching the station on the myriad of tracks outside. The communications within each of these two groups is irrelevant to the other group. Sheriff's deputies in Alachua County, Florida ordinarily have no need for radio communication with the trucks of Florida Light and Power Company or the engineers operating CSX trains in the county.

Public safety agencies differ among themselves with respect to their communications needs. A police agency needs to connect officers on patrol by themselves are in pairs with a dispatcher. Groups of officers responsible for the same territory need to be able communicate with each other smaller communities, particularly, have four more informal mutual aid package in which the officers from one agency assist the officers from another on a routine basis. They need to be able to communicate with each other and then for tactical crises, like mass shooters, natural disasters, or mass accidents, officers from dozens or hundreds of different agencies need to be able to communicate with each other. Depending on the size of the area, officers may need multiple repeaters to retain communication.

Another aspect is spatial. A law-enforcement or fire suppression activity needs to cluster field units within proximity to the situation they feasibly can handle, given their mobility. A cluster intended to coordinate the activities of foot patrolmen will be smaller spatially than one intended to coordinate the activities of motor vehicles, which in turn will be narrower in scope than one intended to coordinate the activities of helicopters. Radio amateurs and research engineers often want to test their ability to communicate with

68. Talkgroups are called "reflectors" in amateur radio's DStar and "rooms" in amateur radio's Fusion.

anyone around the world, but that desire for maximum range is rare for other users of PMR systems.

Good talkgroup design sets an upper limit on the number of users. If too many users are assigned to a particular cluster, congestion is more likely, making it more difficult to deliver messages timely. In other words, a system designed to cover a whole state would likely to have too many users; one for a rural militia district would be small enough that congestion would not likely be a problem.

The basic design decision for a particular group of users is to determine the appropriate talkgroup size and define the kind of activities to be coordinated and the geographic scope.[69] All the digital radio modes offer flexibility in defining talkgroups and interconnecting them, a feature heretofore lacking in two-way analog radio systems with repeaters hard wired to each other. The only way to redefine a cluster in those systems is to change how the repeaters are connected by changing wired connections or fixed microwave links and by changing radio frequencies on users' radios.

Once a talkgroup is defined in the abstract—train and engine personnel on the Alabama Division of Norfolk Southern—the system needs some means for determining who has access to it, who is a member of it at any particular point in time. This necessarily is a centralized function. Typically, a specialized server performs the task by maintaining tables for each cluster, with entries for each member The server sends messages to the affected members of a cluster whenever the status of the table changes. Typically, these messages include Internet addresses for every connected user, permitting cluster members to exchange traffic directly with each other rather than having to pass it through the central server. When a user links to a cluster to which he has privileges, the server issues him a virtual admission ticket and enters his IP address or mode index number in the cluster table, sending a message identifying the user to the cluster owner. These cluster memberships can be transitory, as commonly is the case for amateur radio, where operators come and go from various clusters as they seek interesting contacts. Or, they can be more or less permanent, as for police officers assigned to a particular precinct or to taxicabs operating in a particular city.

In understanding this configuration, it is important to recall that the individual users do not directly connect to the Internet; they have RF links

69. *See Talkgroup Design*, P25 BEST PRACTICE, http://www.p25bestpractice.com/specifying/talkgroup-design/ (last visited Mar. 24, 2019) (recommending local, regional, global interoperable, and specific mutual aid channel talkgroups).

to a repeater. They have radio transceivers; all they need to know is what frequency do use to communicate with a repeater or node, and that's already programmed into the transceiver. It's the repeater that needs a gateway to the Internet, and only it needs to know the Internet addresses of other participants in the cluster. The mobile units in one police precinct may need to use the Internet links to other repeaters rarely, for example when a one user is out of range of the repeater another user is connected to but within range of a second repeater in the same cluster.

On the other hand, a system designed to dispatch inspection and repair crews for a power line, pipeline, or railroad would need to be substantially more extensive in scope. Digital radio systems vary in the flexibility they offer users to reconfigure their topologies- the definitions of talkgroups and the ease of switching between them. DMR repeater managers determine a relatively small number of other repeaters to which they connect, the interconnected group of repeaters constituting a *bridge*. In DStar and Fusion, individual users can alter repeater connections simply by transmitting a new reflector or repeater number (DStar) or a new room number (Fusion).

Most of the modes allow an arbitrarily large number of inbound connections and limit the number of outbound connections. Limiting the number of outbound connections to one means to each talkgroup manager retains control over the scope of his talkgroup. He can deny inbound connections on a case-by-case basis, and if he is assured that no inbound connection will have any other outbound connection except the one to him, he knows that his members are not, and cannot expand the scope of his talkgroup on their own. At the same time, he can expand the scope of his talkgroup arbitrarily as long as he can attract new inbound connections.

When one individual needs to communicate with multiple repeaters as he moves around, *roaming* is a desirable function. Roaming is essential for railroad, pipeline, and electric transmission-line applications.

Mobile transceivers typically are programmed with a multiplicity of talkgroups: at least one for the smallest geographic unit, a small municipality or a police district or precinct in a larger one. The dispatcher communicates with individual officers on this talkgroup. A second talkgroup at the same geographic level may permit "car-to-car "communication" between two users who switch to it once the dispatcher gives permission. Typically, countywide and statewide talkgroups each would be represented by the frequencies for a nearby repeater, along with the designation of a talkgroups reflecting the geographic coverage for that channel geography. An agency's coverage for the different channels can be changed relatively easily simply by reprogramming the servers that link the repeaters. This is as easy as changing the configuration file for the server; no adjustments need to be made to individual transceivers. Trunking is attractive when the level of congestion resulting from putting all of the traffic on one channel is unacceptable. Most agencies, however, find it desirable for all of the personnel working a particular geographic area to be able to hear each other's communications, at least communications between the dispatcher and individual officers or pairs of officers.

B. Access to the Network

All of the systems require a transceiver seeking an additional connection to a fixed station such as repeater to send a credential, usually a registration number or call sign issued by why the particular digital mode a database of registration numbers or call signs typically is maintained a nice central global database for that mode.

so, a repeater receiving a signal from the transceiver not already connected to that repeater send the credential through the Internet to the database and get a confirmation that the connecting transceiver is known.

C. Radio Hardware

Eight digital modes are available in the marketplace: Tetra, P25, DMR, DStar, Fusion, dPMR, and NXDN. DStar and Fusion are amateur radio modes; the others are both PMR and amateur radio modes. Because P 25 was designed by the public safety community, its market penetration is greater in that community than that any other mode. DMR and NXDN enjoy greater penetration bed in the commercial and industrial service. Tetra and P25 are the oldest, Tetra being a European approach to trunked radio and P25 being the first open standards joint undertaking by the U.S. public safety and radio trade groups. DStar was the first mode developed explicitly for amateur radio operators. Its unveiling by the Japanese Amateur Radio League was roughly contemporaneous with the release of P25.

DMR is an open European standard that was embraced by Motorola and other US vendors and has, probably, the dominant market share in the United States after P25.[70] Motorola has a disproportionate market share in the

70. DMR was opened up the amateur radio use by a number of equipment vendors and amateurs working as Motorola engineers, who developed a system of servers and repeaters that parallels public safety and commercial repeaters developed by Motorola.

equipment market, but the availability of inexpensive DMR handheld transceivers beginning in 2016 are shifting the market structure. dPMR was developed as a less expensive alternative to DMR with essentially the same features, including, importantly, the 6.25 kHz bandwidth. dPMR achieves that bandwidth, however, by frequency division multiplexing rather than time division multiplexing like DMR and P25. Kenwood and Icom have developed a slightly proprietary version of dPMR called NXDN. NXDN is assured of significant market share because the railroad industry has adopted it for voice communication in its $8 billion Positive Train Control ("PTC") program, mandated by the United States Congress. System Fusion is a proprietary Yaesu product aimed at the amateur market. It is such a close derivative of DMR, that some transceivers accept both DMR and Fusion transmissions without adjustment.[71]

All eight are similar in their use of patented analog-to-digital conversion, and the way in which their voice-over IP packets traverse the Internet. They differ in their interfaces, their terminology, and whether they use frequency- or time-division multiplexing to achieve the 6.25 KHz signal bandwidth goal of the FCC's refarming initiative.[72] This is how DMR implements the communications patterns analyzed in Section II.A.

Suppose M1, M2, M3, and M4 are police units in a small municipality. M1 is the dispatcher; the others are mobile units. C1, C2, C3 are deputy sheriffs in the county surrounding the municipality. S1, S2, and S3 are state police units. RM1 is the UHF repeater for the municipality, RC1 and RC2 are repeaters for the sheriff's radio system. RS1 through RS 12 are repeaters for the state police. Each repeater operates on a different frequency pair.

M1 through M4, and other units associated with the municipal police department are grouped together as Talkgroup 56. The county sheriff units are grouped as Talkgroup 12. The state police units are grouped as Talkgroup 2. All the communications from any member of Talkgroup 56 are simply re-broadcast by the repeater, thereby reaching all other members of the Talkgroup. At this level the DMR links don't change much from how it would work in an analog environment.

71. Handheld and mobile transceivers for P25, dPMR, and NXDN capable of operating on the amateur frequencies are available, but few repeaters are deployed for these modes on the amateur bands.

72. *See Private Land Mobile Radio Services,* FCC (May 17, 2016), https://www.fcc.gov/wireless/bureau-divisions/mobility-division/private-land-mobile-radio-services (briefly describing refarming initiative).

Any communication from a member of Talkgroup 12 is rebroadcast by both RC1 an RC2, which are linked together through the Internet. Any broadcast by a member of Talkgroup 2 is rebroadcast by all of the state repeaters, RS1 through RS 12, which similarly are linked through the Internet.

In addition to these three talkgroups, each defined by and limited to a single law-enforcement agency, several other talk groups exist. TG 3 is a statewide tactical talk group to which all of the state police repeaters, all of the county sheriff repeaters, and all of the municipal repeaters are linked. This talk group is a sure-fire way for any police unit in the state to talk to any other police unit in the state. It must be used selectively, however, because unacceptable congestion easily could result if too many users are trying to use it at the same time. TG 3 links the two sheriff repeaters and all of the repeaters for municipal police units with in the county.

The municipal police radios would be programmed as follows. Each of the Talkgroups would be listed as a "contact." The municipal repeater would be listed several times, each listing constituting a "contact." The several contacts would have the same frequency pair for the municipal repeater but each of the different Talkgroups. So, if M1 needed to communicate only with M2, M3, M4, she would select channel 1 on her radio. Her signal would be rebroadcast by the municipal repeater to everyone else on channel 1. If M2 needed to talk to a deputy sheriff, he would switch his walkie-talkie to channel 2 or channel 3. Then, the transmission from his walkie-talkie would go into the municipal repeater and be routed through the Internet only to the county repeaters, if he has selected channel 2, and to the county repeaters plus all the other municipal repeaters in the county, if he has selected channel 3. By switching to channel 4 or channel 5 he can communicate with the any state police unit in Talkgroup 2 or with any police unit in the state in Talkgroup 3. In all cases, his radio transmissions are going only to the municipal repeater. The other units he communicates with on the other talk groups are communicating via radio only with their repeaters. The repeaters are interconnected through the Internet.

Users of private mobile radio systems enjoy a variety of features not commonly found in cellphone systems, and these capabilities influence hardware design: *push-to-talk* is one obvious difference; *talkgroups* enable all units in a cluster to communicate with each other. *Receive lists* permit them to monitor multiple clusters. The lists, of course, can be implemented at the precinct, fire district, countywide, or any other arbitrarily chosen collection chosen by the system designers. Often, in the implementation of digital modes like DMR, users can change the group to which they are connected at any point, much as an analog user can do by switching frequencies.

Talk through in simplex PMR systems enable individual users to communicate directly with each other; they are not dependent on establishing an RF link with a central point. There may be many circumstances in which RF communication with a simple repeater is interrupted. That does not result in the communication blackout if the units can talk to each other. Radio discipline obligates them to get permission from a dispatcher before they communicate directly, or to switch to a car to car frequency, but nothing about the technology limits direct communication

Many digital PMR systems have a *solo worker* feature, which can trigger periodic beeps to users working my themselves. If a user does not respond to the beep, the transceiver sends an alert to the dispatcher. Closely related is a *man down* feature. If injured or otherwise incapacitated, a can summon help simply by pressing an each to reach button.

All digital PMR hardware must perform three functions: analog to digital conversion, compression, and modulation.

1. Analog to Digital Conversion

All of the modes, except TETRA, use the AMBE protocol as the analog-to-digital converter.[73] Two basic approaches to analog to digital conversion exist. One takes a, usually complex, analog wave form, samples it and profiles the waveform with digital bits. The three steps in this process are customarily known as quantization, digitization, and compression.[74] The other approach, speech modeling, reduces sound to its individual elements—phonemes or allophones in the case of speech,[75] pitch, duration, rhythm, and

73. *See AMBE-2020™ and AMBE-2020™*, DIGITAL VOICE SYSTEMS, INC., http://www.dvsinc.com/products/a20x0.shtml (last visited Mar. 24, 2019). AMBE is a trademark for improved multiband excitation. *See* Multiband Excitation Patent, *infra* note 76 (explaining multiband excitation).

74. *See* HENRY H. PERRITT, JR. & ELIOT O. SPRAGUE, DOMESTICATING DRONES: THE TECHNOLOGY, LAW, AND ECONOMICS OF UNMANNED AIRCRAFT 86-90 (2016) (explaining process).

75. Phonemes are speech sounds each of which has a different meaning in a given context. The H sound and "ham" in the J sound and "jam" are phonemes. Allophones are different vocalizations of the same phonemes, representing variations among speakers and among dialects of the same language.

timbre for music, and has some system for encoding the elements in digital form.[76] The difference between the two approaches for speech is roughly analogous to the difference between digitizing the audio waveform representing combinations of vocal and instrumental music and representing pitch, direction, timber, and rhythm in something like the MIDI format.[77]

The AMBE approach to speech compression uses the same techniques used in speech synthesis. Mathematical models of the vocal cords and the speech cavity are encoded as pitches, and acoustic properties these low-level models of the components of speech then can be activated and shaped by the voice of a speaker as the input.[78] At the receiving end, the same models are used as a voice synthesizer with parameters that bring the synthesized speech close to the properties of the original speech. The quality never can be as good as a digital representation of the original waveform with high levels of quantization and digitization, because no model of speech is capable of replicating the defining characteristics of each person's unique voice quality. But the combination of compression efficiency and fidelity is much greater than can be obtained by direct quantization and digitization followed by lossy compression.

Because all of the digital radio modes use the AMBE vocoder, the inherent limitations on their fidelity are the same, although other features of their hardware and software can degrade or enhance the quality available from AMBE. What the user hears comes out of a speaker or earphone, which has received an analog signal, likely amplified, after it left the AMBE.

2. Modulation

Modulation is the superimposition of intelligence on a carrier. The intelligence can be human voice, music, photographic images, or other representations of the physical world. Analog waveforms or digital bits can encode what sensors see, hear, or feel. The information is the *baseband*. The

76. *See Joint Quantization of Speech Subframe Voicing Metrics and Fundamental Frequencies*, U.S. Patent No. 6,199,037 (Mar. 6, 2001) (John C. Hardwick, applicant) [hereinafter Multiband Excitation Patent].

77. *See About MIDI-Part 4: MIDI Files*, MIDI ASSOCIATION, https://www.midi.org/articles/about-midi-part-4-midi-files (last visited Mar. 24, 2019) (explaining how MIDI models music rather than digitizing sound files).

78. *See* Multiband Excitation Patent, *supra* note 76.

carrier is an electromagnetic emission capable of propagating through space. Modulation is the combination of the two.[79]

The first radio signals used digital modulation. The Morse code is a binary digital encoding scheme. A current or an electromagnetic signal is either present or not, an absence signifying a space, and a presence signifying a mark—a dot or a dash. The basic modulation technique, even with the earliest spark gap transmitters,[80] was simply to turn the signal on and turn it off. Because dashes are three times as long as dots, duration of the signal matters as well presence or absence. So, transmitting Morse code also involves pulse-width modulation, with the longer pulses representing the dashes and the shorter pulses representing dots. The same basic modulation technique has been used 110 years.[81]

Encoding more complex forms of information, such as speech and images, in a digital form creates lots of bits, which, for many applications, including radio communications, must be transmitted in real time. Because bandwidth requirements are directly proportional to the rate of information transfer, under the Shannon theorem,[82] spectrum for digital radio involving voice or images must be shifted to higher frequencies, where more bandwidth is available, and the number of bits used to represent each informational artifact must be minimized. The result is that most digital radio for voice communication is assigned to VHF and higher bands, with constant pressure to increase the frequency further as the lower VHF and UHF bands become more congested.

Parallel pressures cause radio engineers and computer scientists to develop quantizing, digitization, encoding, and compression techniques that reduce the number of bits required for each a particular kind of baseband

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79. *See Domesticating Drones* at 88-90 (explaining modulation).

80. *See Spark Gap Transmitter History*, ELECTRONICSNOTES, https://www.electronics-notes.com/articles/history/spark-gap-transmitters/history.php (last visited Mar. 15, 2019).

81. Other modulation techniques are available for Morse code. Frequency shift keying ("FSK") maintains a continuous signal and shifts its frequency by a small amount to represent marks and spaces. Audio frequency shift keying ("AFSK") shifts the audible frequency of an audio signal and uses AM single side band or FM modulation to modulate a carrier signal. *See* ARRL, THE ARRL 2015 HANDBOOK FOR RADIO COMMUNICATIONS § 8.3.2 at 8.11-8.11 (ARRL, 92nd ed. 2014) (explaining FSK); *id.* § 8.3.5 at 8.14 (explaining AFSK).

82. *See* Larry Hardesty, *Explained: The Shannon Limit*, MIT NEWS (Jan. 19, 2010), http://news.mit.edu/2010/explained-shannon-0115; *Shannon's Theorem*, FREIE UNIVERSITAT BERLIN, http://www.inf.fu-berlin.de/lehre/WS01/19548-U/shannon.html (last visited Mar. 24, 2019).

signal. Radio engineers work to develop modulation techniques that are more efficient.

The more complex modulation techniques used in the digital radio modes addressed in this paper achieve greater efficiency by allowing each symbol to represent multiple bits, thereby increasing the amount of information that can be represented by each symbol. A decimal number is a *symbol*, capable of taking on one of ten values. A byte is a symbol, capable of taking on one of sixteen values.

The efficiency comes at a price, however. Circuit complexity and tighter tolerances for signal values are not the only cost; more complex modulation schemes also have greater vulnerability to noise Digital radio exhibits the paradox that low levels of noise can simply be filtered out, leaving a clean demodulated baseband signal where analog modulation techniques would pass along the noise. With weaker signals, with a higher level of background noise – producing a lower signal-to-noise ratio, a threshold is reached where the receiver is no longer able to demodulate the signal. No intelligence is transmitted at all beyond this point, unlike an analog-modulated signal might still be readable, albeit with difficulty. The problem is not the corruption of a bit here and there in the payload; that can be fixed by forward error correction algorithms. The problem is the corruption of meta-information such as synchronization flags or bits that leave the receiver in the position of trying to make sense of apparently random bits.

All voice radio transmitters contain modulators, and all receivers intended to receive their transmissions contain demodulators. In most two-way radio communications, the modulation and demodulation functions are performed by the transceivers and repeaters.[83]

Miniaturized devices to perform the modulation and demodulation functions without performing other transmitter and receiver functions also exist. A USB modem is a modulator/demodulator device that can be plugged in to a gateway computer through its USB port. As the name suggests, the modem is responsible for modulating a carrier wave at the designated frequency with the baseband signal, comprising the digitized voice signal. On the receiving end, the modem extracts the baseband digital signal from the carrier. The baseband signal is proprietary so the gateway computer's software must understand its structure so it can extract routing information and process it further. Modems can operate on any frequency and pass

83. The repeater may not need to demodulate a received signal; it may simply amplify it and rebroadcast it.

through any kind of baseband signal. Thus, Wi-Fi modems can be designed to operate on the Wi-Fi frequencies. Broadband wireless modems such as those offered by Verizon and AT&T operate on cellphone and broadband wireless frequencies, and other modems operate on VHF, UHF, and low microwave frequencies.

A digital radio user out of range of a repeater can use one USB modem tuned to the transceiver frequency to receive signals from his transceiver over relatively short distances–hundreds of yards–and through another USB modem tuned to the WiFi or broadband wireless frequencies, connect put the signal into the Internet routing arrangement compatible with the transceiver. Very small general-purpose computers such as the Raspberry Pi[84] can serve as the gateway computers.

This arrangement makes it easy to construct and deploy portable repeaters or nodes, assuring coverage for incidents, regardless of repeater location.

III. The Internet's Adoption Record

In its first twenty years, the Internet emerged from Defense Department and academic labs to become the world's predominant information infrastructure.[85] Once it was available for commercialization, the Internet gradually, over 20 years, absorbed written correspondence, commerce for tangible things, music and then video entertainment, and virtualized the performance of many services, especially those centered on information processing and communications. Consistently, the features that attracted users were its ubiquity and the associated network effects and its open architecture. The Internet allowed anyone with access to a computer and a phone line to make use of resources around the world, without being tied to the particular vendor that had sold them a service. The barriers that fell one after another were processing speed, especially the speeds for access at the edge of the Internet, searching and finding aids, so that almost anyone who made resources available through the Internet could be found without too much trouble, and compression algorithms allowing large audio and video files to be transferred to the Internet without too much loss in fidelity or interruptions in play.

84. *See generally* RASPBERRY PI, www.raspberrypi.org (last visited Mar. 24, 2019).

85. *See* Henry H. Perritt, Jr., *The Internet at 20: Evolution of a Constitution for Cyberspace*, 20 WM. & MARY BILL RTS. J. 1115 (2012), http://scholarship.law.wm.edu/wmborj/vol20/iss4/5.

Of course, each major step forward took a while to be widely available. Technology alone is not sufficient for a successful product launch; technology must be molded around consumer tastes and habits. Entrepreneurs had to work out how new technology should be used and develop business models that were sustainable.

The Internet allowed information network designers—and sometimes their customers—to reconfigure networks at will, globally, without being tied to topologies defined once and for all by wires and the physical placement of antennas. The flexibility to define network topology is obviously important for communication systems, but it also was important to e-commerce funders like Amazon and information resource providers like Google. Amazon could put an order fulfillment warehouse anywhere it wanted and plug it into the Internet, suffering no disruption of customer service because of the move.[86]

One might be tempted to call the amalgamation of these activities with the Internet, "conquests." A better term would be "assimilation," "absorption," or as the title suggests, "adoption," because the Internet is not imperial; it does not deal with its new acquisitions by subjecting them to command-and-control direction. It allows their cultures and behavioral patterns to continue as they have in the past. The article uses the term adoption in the family law sense. Metaphorically, the Internet represents a new and better parent for activities that are being orphaned by the development of new technologies or whose current parents' proprietary attitudes stunt the development of their offspring. These current parents are being forced to relinquish some of their parental rights as the Internet adopts their products.

The following sections describe and analyze the instances in which the Internet has adopted an activity that was going on before the Internet arrived. It excludes activities, such as social networking, that arose for the first time out of the Internet's availability.

A. The Internet Adopts Correspondence

The Internet took over correspondence because of the convenience of nearly instant communications and because of huge network effects. In 1990, email was a curiosity for individuals and businesses. It existed, in the form

86. *See* Tubes, *supra* note 57, at 78–81 (explaining how connections to the Internet are established).

of Western Union's Easylink and MCI's MCImail, along with a handful of other proprietary systems, but the users of each system were isolated from the users of other systems. This was the world of dial-up bulletin board. One typically sent an Easylink or MCImail message by dialing a call to the email provider's local access number, which connected one to the email server, and then sent the email to the server over the telephone line. At the receiving end, the emails accumulated in the addressee's mailbox until he dialed into the server to retrieve them.

Somewhat later, America online and CompuServe offered their own email systems, and their eventual scale shifted market share away from the other specialized providers to them. The network effects were enormous, of course. If one had to make only one connection to exchange email with anyone in the world, transaction costs significantly declined. As the Internet spread in the private sector, it naturally squeezed out the fragmented services.

Early doubters claimed that email was not sufficiently private, misunderstanding how it worked. Many thought that it was a store and forward system, in which each email messages rested for a time on one or more intermediate servers, where it could be read by anyone. In fact, email is sent directly from the sending email server to the receiving email server—both then and now.[87]

B. The Internet Adopts Libraries

The Internet absorbed libraries, beginning with specialized libraries, such as law libraries, when three things occurred: the scanning and digitization of content, improvements in download speed, and improvements in printer speed so that it took no longer to print a downloaded document than to photocopy a physical one. The scanning and digitization of content accelerated as more entities such as courts and legislatures routinely kept their documents and reports in electronic form rather than printing them conventionally.

87. *See* Simplified Mail Transfer Protocol (SMTP), the widely used Internet standard for email. See RFC 821 (1982), https://tools.ietf.org/html/rfc821 (original definition); RFC 5321 (2008), https://tools.ietf.org/html/rfc5321.

Once the basic decision was made to privatize and commercialize the Internet,[88] and once the PSTN was opened up by the Telecommunications Act of 1996, key technological developments increased the momentum through the 1990s and 2000s. The first barrier to fall allowed access speeds to increase.[89] When the Internet was unleashed in the early 1990s, access was possible through dedicated lines leased from the telephone company or through dial-up modems connected to ordinary voice telephone lines.[90] By the early 2000s, penetration of cable television infrastructure, development of cable modems, and modification of cable networks to handle traffic in both directions, revolutionized bandwidth available at the edges of the network. Somewhat later, new technologies deployed by the telephone companies, principally Digital Subscriber Lines (DSLs), allowed data rates on retail telephone lines to increase commensurately.[91] By the end of the twentieth century, major telephone service providers, having mainly crushed the threat of competitive local exchange carriers (CLECs), [92]committed

88. *See generally* Brian Kahin, *Commercialization of the Internet: Summary Report,* RFC 1192 (Nov. 1990) (reporting on workshop held by the Science, Technology and Public Policy Program of the John F. Kennedy School of Government, Harvard University, March 1-3, 1990, for the purpose of planning the commercialization of the Internet). The author participated in the workshop and wrote two articles about the legal challenges that would be presented by the Internet. *See* HENRY H. PERRITT, JR., MARKET STRUCTURES FOR ELECTRONIC PUBLISHING AND ELECTRONIC CONTRACTING ON A NATIONAL RESEARCH AND EDUCATION NETWORK: DEFINING ADDED VALUE, IN BUILDING INFORMATION INFRASTRUCTURE (Brian Kahin ed., 1992); Henry H. Perritt, Jr., *Tort Liability, the First Amendment, and Equal Access to Electronic Networks*, 5 HARV.J. LAW & TECH. 65 (1992).

89. Use of the word "speed" is potentially misleading. All electronic signals move more or less at the speed of light-186,000 miles per second. The rate at which data can be handled, however, depends on bandwidth. An ordinary telephone voice circuit provides about 4 KHz of bandwidth, limiting data rates to 56 Kbps with advanced modulation techniques. *See* MARGARET LEVINE YOUNG, INTERNET: THE COMPLETE REFERENCE 10 (2d ed. 2002). "Speed," as used in this text, refers to the speed of data transmission.

90. Typical bandwidth was 1.4 to 1.5 Mbps on a leased T1 line or 56 Kbps through a dial-up modem. *Id.* at 13.

91. DSL, developed at Bellcore in the mid-1980s, demonstrated the feasibility of inserting broadband digital signals on the wires designed for baseband analog voice signals. *See* Gareth Marples, *The History of DSL Internet Access: A Race for Technological Speed*, SPEEDGUIDE.NET (May 4, 2004), https://www.speedguide.net/articles/the-history-of-dsl-internet-access-1414.

92. The Telecommunications Act of 1996 allowed competitive local exchange carriers to compete with incumbent local exchange carriers by allowing CLECs to use their infrastructure. *CLEC*, WEBOPEDIA, http://www.webopedia.com/TERM/C/CLEC.html (last visited Mar. 24, 2019).

substantial capital to improve their networks[93] by deploying optical fiber beyond central offices,[94] often directly to residences and commercial premises, and marketing DSL service to all of their customers.

One of the impediments to widespread use of the Internet was the need to know the domain name (URL) of a desired destination. Search engines evolved as a kind of automated index to URLs. One of the most successful early search engines was AltaVista, developed by Digital Equipment Corporation and introduced in 1995.[95] By the beginning of 1999, Google began to emerge with a more refined search engine algorithm, [96] and by the mid-2000s it dominated the search engine industry.[97]

Another significant development came in the form of compression algorithms that facilitated the distribution of music and videos. Internet distribution of music exploded with the introduction of the MP3 compression algorithm and associated hardware and software known as codecs.[98]

C. The Internet Adopts Shopping

Although Internet enthusiasts were trumpeting the arrival of e-commerce by 1995, they were still outnumbered by skeptics who believed e-commerce could not flourish until a new form of money was developed

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93. Widespread availability of DSL required telephone companies to remove loading coils from the part of the network that connected central offices to residential and commercial customers. Loading coils extend the reach of voice signals by reducing the capacitance of longer lines. *See Load Coils?*, DSLREPORTS, http://www.dslreports.com/faq/657 (last visited Mar. 25, 2019). Capacitance is an undesirable feature of a communications channel because it smooths out the oscillations in an analog signal. *See id.* Loading coils, however, also block higher frequency signals, making DSL data transmission impossible. *Id.*

94. Widespread deployment of an optical fiber infrastructure has made it possible for the Internet to accommodate exploding demand for higher bandwidth. Signals transmitted over optical fiber experience much less attenuation and interference than the same signals transmitted over copper (or other metallic) wire. An optical fiber offers orders of magnitude, higher bandwidths, and longer link distances than copper wire.

95. *AltaVista: A Brief History of the AltaVista Search Engine*, WEBSEARCHWORKSHOP, http://www.websearchworkshop.co.uk/altavista_history.php (last visited May 1, 2012).

96. *Google Inc.,* CO. HISTORIES, http://www.company-histories.com/Google-Inc-Company-History.html (last visited Mar. 2, 2019).

97. *Google: A Brief History of the Google Search Engine*, WEBSEARCHWORKSHOP, http://www.websearchworkshop.co.uk/google_history.php (last visited May 1, 2012).

98. Mary Bellis, *The History of MP3*, THOUGHT.CO (2012), https://www.thoughtco.com/history-of-mp4-1992132.

for e-commerce transactions.

E-commerce had existed since the 1960s through dedicated communication circuits and Electronic Data Interchange (EDI) standards that permitted disparate proprietary computer systems to make sense of the data that was sent and received.[99] Electronic funds transfer, ATMs, and point-of-sale credit card terminals were widely accepted by the end of the 1980s.[100] The spread of the Internet made an easy-to-use interface available in the form of web browsers, and simplified the processes of establishing computer-to-computer connections.

In 1995 Jeff Bezos launched Amazon.com, making it a pivotal year for the development of the internet and e-commerce.[101] The impact on perceptions of e-commerce was almost as dramatic. If so, many people were willing to buy books through the web, they might be willing to buy other things. Earlier, Dell and Cisco had begun using the Internet to interact directly with customers and allowed them to configure the products they wished to buy and then to order them directly over the Internet.[102]

By mid-2011, few types of consumer goods were not sold online. E-commerce flourished despite early concerns about payment systems, lack of consumer trust, consumer reluctance to incur transaction costs of using the web, and the reluctance of service or product suppliers to risk their intellectual property. Most of these concerns proved unwarranted. In the mid-1990s, many argued that e-commerce would require the development of entirely new payment systems.[103] I disagreed and argued that the existing

99. *See* C. J. Anumba & K. Ruikar, *Electronic Commerce in Construction-Trends and Prospects*, 11 AUTOMATION CONSTRUCTION 265, 267 (2002) (noting the impact of EDI); Janine S. Hiller & Don Lloyd Cook, *From Clipper Ships to Clipper Chips: The Evolution of Payment Systems for Electronic Commerce*, 17 J.L. & COM. 53, 55 (1997) (noting that the evolution of the internet began in the 1960s).

100. Anumba & Ruikar, *supra* note 99, at 268.

101. Amazon enjoyed explosive growth. Sales revenue grew 838% from 1996 to 1997, and customer accounts grew 738% in the same period. Letter from Jeffrey P. Bezos, Founder and Chief Executive Officer, Amazon.com to Shareholders (1997), http://media.corporate-ir.net/media_files/irol/97/97664/reports/Shareholderletter97.pdf.

102. *See Acquisitions by Year*, CISCO, https://www.cisco.com/c/en/us/about/corporate-strategy-office/acquisitions/acquisitions-list-years.html ("In September 1995, Cisco acquired Internet Junction Inc.") (last visited Mar. 24, 2019).

103. *Compare* Sarah Jane Hughes, *A Case for Regulating Cyberpayments*, 51 ADMIN. L. REV. 809, 813-14 (1999) (noting the demise of most cyberpayment systems as e-commerce developed), with Hiller & Cook, *supra* note 99, at 98 ("[T]o the extent electronic commerce grows, it is certain that it will not flourish unless acceptable systems for payment are available."), and Kerry Lynn

credit card systems would prove perfectly adequate and acceptable to consumers.[104] By 2000, adequacy of existing payment systems became clear,[105] largely because of the dispute resolution system built into credit card transactions.[106]

Concerns about inconvenience were mitigated by one-click shopping, popularized by Amazon, beginning in 1999.[107] The one-click method reduced the number of steps a consumer took to order an item from an e-commerce site, and relieved a consumer from having to reenter all his basic information, such as name, address, and credit card information.[108]

On the other hand, the easy replication of information in digital form undermined traditional business models in some industries, particularly those for music and video entertainment. The result was a war over enforcement of copyright on the Internet, which still clouds the future of e-commerce.

D. The Internet Adopts Entertainment

The demise of the CD as a medium for music along with the bankruptcies of Tower Records and Blockbuster dramatized the movement of music and video to the Internet and away from physical recordings. The introduction of

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Macintosh, *How to Encourage Global Electronic Commerce: The Case for Private Currencies on the Internet*, 11 HARV. J.L. & TECH. 733, 738-39 (1998) (arguing that the Internet needs its own private electronic currencies), and Robert F. Stankey, *Internet Payment Systems: Legal Issues Facing Businesses*, *Consumers and Payment Service Providers*, 6 COMMLAW CONSPECTUS 11, 12 (1998) (arguing that the percentage of credit card transactions will decline as e-commerce grows).

104. Henry H. Perritt, Jr., *Legal and Technological Infrastructures for Electronic Payment Systems*, 22 RUTGERS COMPUTER & TECH. L.J. 1, 2 (1996); Henry H. Perritt, Jr., *Payment Infrastructures for Open Systems*, 3 DATA L. REP. 1, 20 (1995).

105. Henry H. Perritt, Jr., *Dispute Resolution in Cyberspace: Demand for New Forms of ADR*, 15 OHIO ST. J. DISP. RESOL. 675, 676 (2000) (explaining why intermediary-provided dispute resolution, such as credit card charge-backs and escrow arrangements, prove more attractive in practice than independent third-party mechanisms such as arbitration or mediation).

106. *Id.* at 690-94 (explaining credit card charge-back system).

107. Ronald J. Mann & Travis Siebeneicher, *Just One Click: The Reality of Internet Retail Contracting*, 108 COLUM. L. REV. 984, 1002 (2008) (noting Amazon's "renowned" one-click patent).

108. Amazon.com, Inc. v. Barnesandnoble.com, Inc., 239 F.3d 1343, 1348 (Fed. Cir. 2001) (suggesting Amazon's patent for one-click ordering might be invalid).

mpeg-4 in 1998 similarly facilitated Internet distribution of full-motion video files.[109]

In intervening years, video entertainment has become an Internet-dominated phenomenon, as demonstrated by the rise of Netflix, Hulu, and the entry of Amazon and Google into the video production business.[110] The advances in compression and download speeds that permitted the Internet to absorb music have done the same thing with video entertainment. Additionally, improvements in mobile access to the Internet are causing more and more people to "cut the cord."

Increasing bandwidth and connection speeds have been engines of Internet expansion since the widespread adoption of email. Load sharing and high-speed wireless access are only the most recent developments and have profound implications for entertainment. Load sharing was widespread by 2000, enhancing the capacity of popular websites.[111] As e-commerce exploded, the traffic to popular websites exceeded what any individual server could handle.[112] A protocol was needed that could share the burden among multiple servers controlled by the same entity and providing essentially the same information.[113] The result was "load sharing," which "balance[s] the load across a bunch of physical servers . . . mak[ing] those servers look like one great big server to the outside world."[114]

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109. *A History of Success – A Future in Innovation*, MPEG LA (2019), http://www.mpegla.com/main/about (stating patented technology that is licensed by MPEG LA).

110. *See* Henry H. Perritt, Jr., *Technologies of Storytelling: New Models for Movies*, 10 VA. SPORTS & ENT. L.J. 106, 109 (2010) (analyzing the effect of Internet distribution of video entertainment).

111. *What is Windows NT*?, THENETWORKENCYCLOPEDIA, http://www.thenetworkencyclopedia.com/entry/windows-nt/ (load balancing was a feature of Microsoft Windows NT, introduced in 1993); *Local Director*, CISCO SYS., https://www.cisco.com/web/offer/localdirector/docs/lodir_rg.htm (Cisco introduced a more sophisticated load-balancing product in 1996, promoted as a replacement for the Domain Name Service (DNS) round robin strategy).

112. KJ (KEN) SALCHOW, JR., LOAD BALANCING 101: THE EVOLUTION TO APPLICATION DELIVERY CONTROLLERS 1 (2007), https://www.f5.com/pdf/white-papers/evolution-adc-wp.pdf.

113. *Id.*

114. *Id.* Early efforts involved having a DNS serving the URL of the service provide different IP addresses in rotation, as queries were received. *Id.* at 1-2. Later developments involved having a cluster of servers listen to one IP address through a border router, which then redirected queries to various servers behind the firewall with locally assigned IP addresses. *Id.* at 3. Later, "application delivery controllers" were developed, which resided outside application servers. They presented virtual server addresses to the outside world and then forwarded connections to the most appropriate real server. *Id.* at 4.

Wireless data communications at speeds similar to those employed in wired computer networks have permitted the Internet to expand beyond the infrastructure defined by physical wires.[115] One can now access the Internet, at least in areas of fairly dense population, from nearly anywhere.

Development and deployment of wireless data systems that could handle data at speeds useful to computer networks awaited assignment of higher-frequency radio spectrum and hardware that could operate at those higher frequencies.[116] In 1985, the FCC first authorized the use of unlicensed[117] spread spectrum[118] transmitters in the 902-928 MHZ, 2400-2483.5 MHZ, and 5725-5850 MHZ bands.[119] The result was an explosion of wireless local area networks (LANs) under protocols popularly known as Wi-Fi.[120]

Third (3G) and fourth generation (4G) wireless technologies, generally associated with smart phones, enabled high-bandwidth wireless connections for a variety of portable devices, including smartphones, tablets such as the iPad, and netbook and laptop computers.[121] These technologies became

115. *See*, YOUNG, *supra* note 89, at 15.

116. Theoretical principles of radio engineering dictate that the bandwidth of a signal increases as the data rate being transmitted increases. The higher bandwidth necessary for higher data rates could not be accommodated at lower frequencies which were already crowded with broadcast radio and television, military and public safety, and other commercial communications.

117. Before that, every transmitter required a station license.

118. FCC, REPORT OF THE UNLICENSED DEVICES AND EXPERIMENTAL LICENSES WORKING GROUP 8, n.13 (2002), https://transition.fcc.gov/sptf/files/E&UWGFinalReport.pdf [hereinafter FCC Unlicensed Devices Report] (explaining spread spectrum modulation: "Spread spectrum communication systems use special modulation techniques that spread the energy of the signal being transmitted over a very wide bandwidth. The information to be conveyed is modulated onto a carrier by some conventional techniques, usually a digital modulation technique, and the bandwidth of the signal is deliberately widened by means of a spreading function. The spreading technique used in the transmitter is duplicated in the receiver to enable detection and decoding of the signal. Spread spectrum systems offer two important technological advantages over conventional transmission schemes. First, the spreading reduces the power density of the signal at any given frequency within the transmitted bandwidth, thereby reducing the probability of causing interference to other signals occupying the same spectrum. Second, the signal processing in spread spectrum systems tends to suppress undesired signals, thereby enabling such systems to tolerate strong interfering signals").

119. *Id.* at 8.

120. *Id.* at 6.

121. *3G and 4G Wireless*, FCC, http://www.fcc.gov/topic/3g-4g-wireless (last visited Mar. 25, 2019).

commercially available in 2001[122] and 2010, respectively.[123] Expanding broadband wireless access was an important goal of the congressionally mandated National Broadband Plan,[124] published by the FCC in 2010.[125]

The ubiquity of high-bandwidth wireless data connections means that one can be connected to the Internet all the time. Constant connectivity has two major implications. First, it dramatically increases demand for Internet-accessible products and services. Audiences can listen to music almost constantly, watch movies or other video entertainment at odd moments of leisure while they wait for appointments or ride the bus or train, and order books or other consumer products impulsively, as soon as they hear favorable reports from a friend or on the radio or television. This phenomenon means that industry structures built around segmentation of delivery channels-such as movie theaters, television, and DVDs in the video entertainment industry must now recalibrate their business models to accommodate a marketplace where the old product categories are irrelevant.

Second, ease of use becomes even more important when one is browsing the Internet, checking out friends on Facebook, playing a song, watching a movie, or ordering merchandise on a small handheld device instead of a desktop or laptop computer. This means that consumers will gravitate to one-stop integrated services such as Amazon and Facebook, instead of going to the trouble of checking out different websites. This is likely to intensify the preference for cyberspace "empires," considered in II.A.

Opposing these phenomena is the desire of potential advertising sites to capture a user for as long as possible; Facebook does not want someone browsing her friends posts to leave Facebook to go to YouTube.

The barriers to further absorption of music and video entertainment by the Internet are not technological; they arise from the reluctance of present market occupants to modify intellectual property restrictions to allow

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122. *See* Danielle Dunne, *What is '3G' Technology?*, CNN, Oct. 22, 2001, http://europe.cnn.com/2001/TECH/industry/10/22/3g.defined.id g/index.html.

123. Kristena Hansen, *4G Wireless Technology: A Look at What's Ahead*, L.A. TIMES (June 13, 2010), http:// articles.latimes.com/2010/jun/13/business/la-fi-4g-20100614.

124. 47 U.S.C. § 1305 (2005) (authorizing the establishment of a national broadband service development and expansion program).

125. FED. COMM. COM'N., CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN (2010), http://download.broadband.gov/plan/national-broadband-plan.pdf.

distribution of content outside of walled gardens.[126] The aggressiveness of new entrants to the video production industry opens up the opportunity to cast aside some of the most restrictive licensing practices. As Amazon and Netflix produce their own TV series and movies, they are free to innovate in intellectual property arrangements as well as using as fully embracing the Internet as a distribution mechanism.

E. Internet Adopts Telephony

AT&T,[127] Verizon, and Sprint all have announced plans to replace their PSTN with voice over IP by 2020.[128] This involves replacing Signaling System 7 ("SS7")[129] with Internet protocols, particularly with SIP for call setup.[130] The FCC generally accepts the need to make the transition.[131] The transition faces some challenges, however. The FCC identifies three essential technology transitions: migration from TDM (time division multiplexing) and SS7 to SIP/IP networks,[132] replacement of traditional voice protocols with VoIP,[133] and transition of the last mile from twisted pairs of copper wire to fiber optic, coax, and wireless.[134] The increasing availability of handsets is allowing for VoIP over WiFi, freeing a wireless voice customer from a tie to the PSTN.[135] After the transition, service providers must figure out how to assure service quality over a network whose

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126. *See* Henry H. Perritt, Jr., *Uber Television: Internet-Only Television Stations*, 23 UCLA ENT. L. REV. 75-76 (2016) (discussing walled-garden restrictions on television and movie content available on the Internet).

127. Jon Brodkin, *AT&T plan to shut off Public Switched Telephone Network move ahead at FCC, Jan. 30,* 2014, Ars Technica (Jan. 30, 2014, 1:00 AM), http://arstechnica.com/tech-policy/2014/01/att-plan-to-shut-off-public-switched-telephone-network-moves-ahead-at-fcc/.

128. *See generally* Larry Hettick, *Replacing the PSTN with VoIP: Not If, But When*, http://www.networkworld.com/article/2226769/uc-voip/replacing-the-pstn-with-voip—not-if—but-when.html.

129. *SS7 Protocol Suite*, Radcom Academy, http://www.protocols.com/pbook/appletalk/ss7/.

130. Session Initiation Protocol ("SIP") is an application-lawyer protocol defined in RFC 3261. IETF (Date) https://tools.ietf.org/html/rfc3261.

131. *See In the Matter of Tech. Transitions*, 29 FCC Rcd. 1433 (2014).

132. *Id.* ¶ 16.

133. *Id.* ¶ 17.

134. *Id.* ¶ 18.

135. *See How Does Mobile VoIP Work?*, VOIP-INFO.ORG, https://www.voip-info.org/mobile-voip (last visited Mar. 24, 2019).

management is distributed,[136] and to preserve other "core values" of the public telephone system.[137] Not least of the challenges is what to do with the telephone numbering system.[138]

Replacing the PSTN with the Internet does not imply a wholesale physical substitution of equipment and wires. While a few legacy SS7 switches may be retired and replaced with IP routers, most telephone voice calls and data will move over the same optical fibers, wires, and microwave links as before the transition. The information will be packaged differently: chopped up into Internet Protocol packets and multiplexed with other IP packets as opposed to traveling as continuous streams through a dedicated circuit.

F. Consistent Themes

Each of these adoption stories involves repeating themes. In each case, the Internet's open architecture allowed users of pre-Internet proprietary systems to continue to use their existing hardware and application software as they connected them to the Internet at its edges.

The Internet's embrace of the OSI model lowered the barriers to entry for innovators. Innovators needed only enough capital to innovate at one layer, without having to develop and deliver a complete end-to-end system. The proven efficacy of the Internet's self-regulatory regime allowed the Internet to evolve without having to get permission from the government at every step or to deal with regulator and legislator prescriptions, based on guesswork, about what course technology should take.

As its popularity has expanded, however, and as mobile access has become more important, the Internet's evolution has exhibited a huge appetite for additional radio spectrum and for more efficient ways to use the spectrum already allocated to Internet connected uses. Each of these themes

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136. *See* Larry Hettick, *Why Replacing the PSTN with VoIP Won't Be Easy*, Webtorials (Feb. 5, 2015), https://www.webtorials.com/content/2015/02/why-replacing-the-pstn-with-voip-wont-be-easy.html.

137. *2014 Technology Transition*, *supra* note 131, ¶ 1 (articulating goal as to "speed market-driven technological transitions and innovations by preserving the core statutory values as codified by Congress—public safety, ubiquitous and affordable access, competition, and consumer protection.").

138. *See generally* Henning Schulzrinne, *Transitioning the PSTN to IP*, https://www.ietf.org/proceedings/86/slides/slides-86-iab-techplenary-4.pdf (comprehensive slide presentation transitioning from PSTN to IP; emphasizing limitation of conventional telephone numbers).

makes the Internet an attractive new parent for PMR.

III. Trends in Radio Communication

A. Spark Gaps, Vacuum Tubes, and Mobility

Radio is a little over 100 years old. Its history can be summarized efficiently with reference to about a half dozen key milestones in its development. The first milestone was Guglielmo Marconi's December 12, 1901 demonstration of trans-Atlantic radio telegraphy.[139] Marconi had aggressively publicized the ability of radio signals to transmit information in the form of Morse code characters. These signals were initially transmitted by dozens, then hundreds, then thousands of miles by setting up demonstrations which culminated in the *transatlantic demonstration*. Marconi did everything he could to publicize them. Marconi's U.S. Patent No. 763,772, issued in 1904 was declared invalid 40 years later in *Marconi Wireless Telegraph Co. v. United States*.[140] The Supreme Court observed, however, that while Marconi used the inventions of others, he was the first one to achieve commercial success[141] and earned the reputation as the inventor of radio.[142] He emphasized that long distance radio communication could provide an alternative to telegraph communication, which involved high rates, and difficulties in maintaining the transatlantic and long distance telegraph cables. After he overcame accusations that the whole thing was a fraud because long-distance radio communication was impossible, he obtained a few paying customers, but was constantly on the brink of bankruptcy. The British Admiralty was interested in using radio communication to reduce its dependence on telegraph cables, which could be sabotaged, and were during World War I. The Titanic disaster 1912 fueled the market for shipborne radios and the shore-based apparatus to communicate with them. The two main problems with the early spark gap transmission was, first, the apparatus for transmitting a radio signal was cumbersome and dangerous because it exposed the operator to very high

139. *See Guglielmo Marconi: Biographical*, THE NOBEL PRIZE, http://www.nobelprize.org/nobel_prizes/physics/laureates/1909/marconi-bio.html (last visited Mar. 24, 2019).

140. 320 U.S. 1 (1943).

141. *Id.* at 35.

142. *Id*. at 38.

voltage, and second, each communication used the entire radio spectrum. Marconi himself solved the second problem by adding tuned circuits to both transmitters and receivers[143] but it was only the development of oscillators employing vacuum tubes that eliminated the need for a spark in the open air stimulated by voltages in the range of 10,000 volts.[144]

Vacuum tube technology developed between 1910 and 1920, beginning with Fleming's popularization[145] of the vacuum tube as a rectifier to improve radio receiver design. Later, Lee De Forest's use in triode tubes, allowed amplification.[146] Edwin Armstrong explained how the tubes could drive oscillators, mainly in receivers. His oscillator concepts also replaced the spark gap in transmitters.[147] Richard Sarnoff organized the Radio Corporation of America as a public-private partnership to control radio communication in the United States, thus demand intensified.

The widespread commercialization of the telephone created an incentive to develop radio technology that could transmit voice, and that happened early experiments with radiotelephony, in 1906.[148]

Voice and music broadcasts were commonplace by the 20s, and their popularity drove demand for home radio set, supplied by RCA and others. This occurred even as RCA and Westinghouse developed the earliest radio station networks. The automobile was also coming of age in the 1920s, and automobile enthusiasts wanted to enjoy radio while they were driving. The technical challenges of providing frequency stability despite the vibration and suppressing noise from automobile ignition systems frustrated many engineers, but Motorola gradually overcame them and pioneered the development of commodity car radios supported by its own distribution and support network. Before Motorola's innovation in marketing, every radio

143. *Id*. at 6 (summarizing principal claim of Marconi patent).

144. Hal Kennedy, *How Spark Transmitters Work*, http://www.arrl.org/files/file/History/History%20of%20QST%20Volume%201%20-%20Technology/Kennedy%20N4GG.pdf (last visited Feb. 8, 2019).

145. *Marconi Wireless Telegraph Co.*, 320 U.S. at 54-55 (holding that he did not invent it).

146. *See* U. S. Patent No. 879,532 (filed Feb. 18, 1908).

147. U.S. Patent No. 1,113,149 (filed Oct. 6, 1914).

148. Mitchell Stephens, *How the Earlier Media Achieved Critical Mass*, N.Y. TIMES (Nov. 20, 1995), https://www.nytimes.com/1995/11/20/business/earlier-media-achieved-critical-mass-television-lucy-sure-didn-t-start-it-but.html (providing brief history of radiotelephony).

had to be custom designed and installed in a particular model of car.[149] From there, it was only a small step forward to organize broadcast stations for police departments, sending one-way broadcasts to patrol cars that had Motorola radios installed. By the end of the 1930s, Motorola had also figured out how to add a transmitter to the mobile unit and had persuaded the FCC to allow public safety communications to be moved to higher frequencies where they would be a bit harder for criminals to monitor.

As the United States' involvement in World War II increased, the army's need for a portable radio led Motorola to adapt its mobile police radio technology to a radio transceiver. Motorola called the device a "walkie-talkie," which was a mainstay of infantry unit communication throughout the war, and later in the Korean War.[150] But the vacuum tubes necessary for portable radio transceivers burned out periodically and used a lot of electrical power. The necessary batteries impaired portability. The invention of the transistor in 1948 by Bell Labs[151] and its rapid commercialization significantly reduced power, weight, and size of radio technology. Everything could be smaller now, and not require such large and heavy batteries. Transistors also revolutionized digital computer hardware. Digital computers were just beginning to enter the public consciousness, but since at least 1962 they all used memories in the form of magnetic cores; it was not until the mid-60s that transistor flip-flops replaced magnetic cores. As growing computational intensity demanded larger memories, pressure built to miniaturize flip-flops. Integrated circuit chips were the result of innovations in material science and manufacturing than in electronics, radio engineering, or computer science.

B. Higher Frequencies

The technologies discussed in other subsections of this section all made it possible to conduct radio communications on higher and higher

149. KATHI ANN BROWN, CRITICAL CONNECTION: THE MSS STORY 32-37 (1992) (describing history of Motorola "service stations" for mobile radios).

150. HARRY MARK PETRAKIS, THE FOUNDER'S TOUCH: THE LIFE OF PAUL GALVIN OF MOTOROLA 139-153 (1965) (providing account of Motorola's development of walkie talkie and handi talkie).

151. U.S. Patent No. 2,569,347 (filed Sept. 25, 1951) ("circuit element utilizing semiconductor material"). The Shockley patent related to a point-contact transition. A much earlier patent, issued to Julius Edgar Lilienfeld, U.S. Patent No. 1,745,175, related to a field effect transistor, but Lilienfeld was unable to commercialize his invention.

frequencies, which made greater bandwidth available, enabling greater density of communication.

C. Miniaturization

As computing power grew and became cheaper and smaller, radio designers realized they could substitute digital computers for many analog devices—inductors, resistors, and capacitors—in radio circuits. The result was software defined radios ("SDRs"), which took advantage of digital signal processing ability to generate signals at specific frequencies and to convert those signals, especially for signals already in a digital form. Hardware could now be generic and programmed on any frequency or range of frequencies, as desired by users.

Miniaturization radio technology and the elaboration of cell phones into more broadly capable devices that can provide access to the Internet exploded the need for additional radio spectrum for the cell phone service providers. Earlier, at the time the 1996 Telecommunications Act was put together, policymakers realized that "personal data assistants" would enter the market and require a lot more spectrum. That led to the idea of spectrum auctions.

D. Networking

As Section II.A explains, point-to-point communication between two users is of limited utility for many PMR activities. Broadcasting is not the only activity in which radio communications need to reach multiple users at the same time. In broadcasting, the recipients of the information are passive. The activities considered in Section II.A require that the recipients must be able to participate—to transmit their own information. This networking capability has been a feature of radio communication since the earliest days. The fact that early spark gap transmitters transmitted signals that occupied the full radio spectrum meant that every radiotelegrapher was on one big party line. As technology advanced, two party communication was the norm for most communications on particular frequencies, but it was easy for a HF "nets" to be organized in which more than two people came together on the same frequency at the same time.

PMR systems on VHF and UHF frequencies typically involve multiple users on the same frequency, enabling them to hear and talk to each other. The Internet allows the geographic scope of such communications to expand, while its routing technologies and multicast capabilities maintain the one-to-many and many-to-many features that define many PMR networks.

Network management is inherently more challenging when digital communications are involved than when analog voice communications are involved. Users of analog voice systems coordinate their activities on a network simply by listening for each other's transmissions and not transmitting at the same time as someone else. In networks with large numbers of participants, a dispatcher or net control station allows requesting stations to talk, and participants wait for permission from the dispatcher or net control station.

Ironically, the earliest precursor of the Internet was AlohaNet, developed in the early 1970s. It was built in Hawaii as a way of mediating contention among multiple radio transmitters for the same communications channel. AlohaNet became the basis for Ethernet and much cellphone signaling subsystems. It successfully allowed and coordinated access to the same radio and frequency by using multiple digital transmitters. It also allowed routing packets in a decentralized system with no single point of failure.

By the mid-1900s, the Internet was ready to tie over the air resources. The multicasting protocol[152] had been finalized in 1989 and voice over IP 1997. RFC 2198 had progressed to the point that Skype was possible. Skype launched in 2003.

E. Digitization

As Section II.C.2 explains, the earliest radio signals were digital, such as Morse Code. Radio teletype, which became widespread during the Second World War is also digital. But digital radio did not expand much beyond these modes until the computer revolution made it easy to manipulate bits rather than struggling to manage, sample, and compress analog waveforms. Computer networking, implemented initially over wires, created a demand for wireless digital networking. It also led to the desire to mix text and voice communications. The purpose was to reduce the susceptibility of communications to noise, and to squeeze bandwidth demands during the digitization of voice communication.

152. Steve Deering, *Host Extensions for IP Multicasting*, IETF TOOLS, https://tools.ietf.org/pdf/rfc1112.pdf (last visited Feb. 8, 2019).

F. Interoperability

September 11, and subsequent mass casualty events, generated pressure for interoperable public safety communications systems. When analog voice communication was the norm, interoperability required only the availability of shared frequencies. With the rise of digital radio, different proprietary digital systems could not communicate with each other. The desire for interoperability spawned the P 25 initiative, considered in section II, and continues to influence development of PMR.

G. One Infrastructure: Firstnet

The integration of mobile two-way radio system into the public telephone system is only the beginning.[153] The architecture of the public telephone system resembles the architecture of private mobile radio systems linked through the Internet. Both have an air link, connecting hand held or vehicle-mounted transceivers—cell phones and walkie-talkies—to higher powered transceivers—cell towers or radio repeaters. These are then connected to each other through a fixed, mostly terrestrial, infrastructure. As public telephone system technologies become indistinguishable from the Internet as they merge, more and more users of traditional two way radio systems are supplementing their communications assets with cellphone calls.[154]

Various mandates for interoperability and the growing use by public safety personnel of cellular telephone devices on the job have led to Firstnet, a federal government initiative to blend together two-way radio, the Internet, and the public telephone system. Some industry publications also use the acronym PoC, standing for "push to talk over cellular."[155] It is a generic term

153. The term PSTN, or Public *switched* telephone system, is no longer appropriate because most telephone traffic now moves in packet networks which are not switched like legacy telephone networks.

154. Many PMR applications involve many-to-many communications. The telephone network was designed for one-to-one communications. Conference call setups borrowed from the telephone technology and multicasting, borrowed from the Internet standards suite, are necessary to allow these PMR systems to function as intended.

155. *See* SAROKHANIAN & NEWBURN, *supra* note 10, at 4 (describing Fairfax County, VA's conversion from P25 to AT&T's PoC offering; using the term "PoC"); VDC Research, PTT over Cellular Solutions: Why PoC Solutions Make Sense for Critical Communications, https://www.business.att.com/content/whitepaper/vdc-poc-solutions-white-paper.pdf.

for subsuming PMR into the cellular network infrastructure. The demand for PoC is driven to some extent by the growing desire to be able to exchange data and video images. Now, PMR users often carry cell phones as well as their PMR handsets to take photographs or shoot video of crime scenes, accident scenes, and infrastructure items that have been inspected and might need repair. PoC will permit its users to integrate their voice communications with their data collection and imagery.[156]

Police departments already have a technologically sophisticated interface between their two-way radio systems and the PSTN in the form of 911 centers. The telephone company provides call setup software that permits any telephone subscriber to dial 911 and have the call be routed to the 911 center for the agency with proper jurisdiction. Third-party contractors typically provide the equipment used by 911 center personnel, giving them simultaneous radio communication with responding officers and telephone communication with the person requesting assistance.[157]

When two-way radio moves into the cellular telephone system, the media access and control function will be managed by traditional cell phone logic between the handset, and the cell tower at the edges of the system. That does not, however, resolve the question of how the traffic will move within the network or how the transport layers in the core of the system will be managed. That well may be according to Internet protocols. That conclusion is more likely if voice telephone traffic increasingly is using Internet protocols at the network and transport layers inside the regular cell system.

To do that, the Congress established a new agency within the Department of Commerce to design a "First Net," and has authorized some $5 billion dollars for that purpose.[158] The statute requires that the FCC grant a 10-year

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156. *See generally* DAVID KREBS, PTT OVER CELLULAR SOLUTIONS: WHY POC MAKE SENSE FOR CRITICAL COMMUNICATIONS (2016), https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwivzZDnwbrRAhVH5GMKHcNgD_oQFggcMAA&url=https%3A%2F%2Fwww.business.att.com%2Fcontent%2Fwhitepaper%2Fvdc-poc-solutions-white-paper.pdf&usg=AFQjCNEikN7zrJgOG5H56ZqeO8M_Hq8ikQ&sig2=iIJBhpA_An9VqdPutmbk7w.

157. *See generally* 911, CENTRALSQUARE, http://www.tritech.com/solutions/inform/inform-911 (last visited Mar. 25, 2019); *see also Public Safety Radio Dispatch Systems*, AVTEC, http://www.avtecinc.com/industries/public-safety?_vsrefdom=ppcgoogle&ex=kpaaeq-eep549-hmlsi&keyword_session_id=vt~adwords%7Ckt~911%20dispatch%20system%7Cmt~b%7Cta~155747627237&_vsrefdom=wordstream&gclid=Cj0KEQiA4o3DBRCJsZqh8vWqt_8BEiQA2Fw0eWl9n7fslV48-g7S8hrpfgKJDXZQ2BCYXo5Qd2-yYeQaAos48P8HAQ (advertising IP dispatch systems for 911, railroads, utilities) (last visited Mar. 25, 2019).

158. *See generally Public Safety First*, FIRSTNET, https://www.firstnet.gov/sites/default/files/LTE%20Overview-.pdf (last visited Feb. 8, 2019).

renewable license, to FirstNet, which then must establish a network meeting through contractors with the following requirements:

"NETWORK COMPONENTS—The nationwide public safety broadband network shall be based on a single, national network architecture that evolves with technological advancements and initially consists of—

(1) a core network that—

(A) consists of national and regional data centers, and other elements and functions that may be distributed geographically, all of which shall be based on commercial standards; and

(B) provides the connectivity between—(i) the radio access network; and (ii) the public Internet or the public switched network, or both; and

(2) a radio access network that—

(A) consists of all cell site equipment, antennas, and backhaul equipment, based on commercial standards, that are required to enable wireless communications with devices using the public safety broadband spectrum; and

(B) shall be developed, constructed, managed, maintained, and operated taking into account the plans developed in the State, local, and tribal planning and implementation grant program under Section 6302(a)."[159]

Section 6202(b)(2)(A) mandates CMRS as the radio access network; there is no room for using more traditional non-cellular radio technologies to perform this function. In contrast, Section 6202(b)(1)(B)(ii) allows the vendor to choose between the Internet and the public telephone system as the routing and connection infrastructure.

Technical requirements include public safety requirements that overlap commercial LTE networks; LTE products from OEM vendors, such as priority and QOS features; and multimedia broadcast techniques, as well as other, undefined capabilities.[160]

The FirstNet RFP requires that the network:

- Include APNs for interoperability;[161]

159. 47 U.S.C. § 1422 (2012).

160. Technical Advisory Board for First Responder Interoperability, *Recommended Minimum Technical Requirements to Ensure Nationwide Interoperability for the Nationwide Public Safety Broadband Network*, FIRSTNET, 25 (May 22, 2012), https://ecfsapi.fcc.gov/file/7021919873.pdf (Venn diagram depicted as Figure 1).

161. *Id.* § 1.3.1 ¶¶ 4, 5.

- Provide for access to the global Internet, including IPv4 and IPv6;[162]
- Support roaming onto FirstNet partner networks, when the hardware permits any type of roaming onto commercial networks;[163]
- Hardware conform to 3GPP TS 36.306 for radio access capabilities[164] and to 3GPP Release 9 UU for minimum interoperable interfaces;[165]
- Meet quality of service criteria 3GPP "Rx" interface;[166]
- Must support user mobility across the entire FirstNet, including networks of op-out states;[167]
- Priority and preemption capability;[168] and
- Provide for network security using state-of-the-art public-key encryption.[169]

The FirstNet statute does not require that any entity actually *use* the network that it mandates, although it is possible that the Congress will appropriate money to fund grants to state and local government entities that connect to it. FirstNet is closely associated with homeland security. The Department of Homeland Security has been a generous benefactor of state and local first responders, and the popularity of anti-terrorist programs is likely to continue and assure full funding to homeland security related programs, including FirstNet.

Firstnet is scheduled to be available in 2018, in an initial subset of states or regions of states. Major cellphone providers are already selling PoC to larger public service units, anticipating eventual absorption into FirstNet.[170] Harris Corporation promotes its BeOn product as a way of integrating P25 systems into the public telephone network. BeOn is an app that runs on a

162. *Id*. ¶¶ 7, 8, 11.
163. *Id*. § 1.3.2 ¶ 15.
164. *Id*. § 1.3.2 ¶ 13.
165. *Id*. § 1.3.2 ¶ 12.
166. *Id*. § 1.3.1 ¶ 6.
167. *Id*. § 1.3.5 ¶ 24.
168. *Id*. § 1.3.6.
169. *Id*. § 1.3.7.
170. *See* SAROKHANIAN & NEWBURN, *supra* note 10, at 4 (describing Fairfax County, VA's conversion from P25 to AT&T's PoC offering).

smart phone but looks like a PMR transceiver to a PMR system.[171] Harris also offers the LMC1000, a specially designed smart phone for first responders.[172]

H. Communications Security

Communication security has been a concern since the earliest days of the telegraph. Commercial users of Western Union published code books for employees so that they could send their commercial messages in code. Seventy-five years later, concern over monitoring of police-radio broadcasts led Motorola to move police radio frequencies out of the broadcast band to higher frequencies. Now, encryption is a common but usually optional feature of most communication systems.

Security is a greater concern for radio communication than for communication that moves through wires or optical fibers. Anyone can snatch a radio signal out of the air and read it, if the message has been transmitted in the clear. Intercepting messages traveling on wires are optical fibers requires more effort. The eavesdropper must tap, the wire or optical fiber or arrange for interception of traffic at a switch or router.

Moving PMR communications to the Internet and to the public telephone system makes no difference to information security. The air interface—the point of greatest vulnerability to interception—can either be encrypted or not, depending on the assessment of the users costs and benefits. If the air link is encrypted, its content will remain encrypted as it moves through the Internet or the public telephone system.

Encryption imposes costs, however. First, it degrades performance. Processing encrypted communications is going to be slower than processing its plain text equivalent on any system. If one wants to ensure the same performance for encrypted as for unencrypted communication, one must pay for higher levels of processing power. In addition, encryption makes interoperability much harder to achieve. State of the art encryption depends on distributing and managing encryption keys, and the complexity of that process opens up many possibilities for failure when one integrated system tries to exchange information with another independent system.

An eavesdropper would not be able to tap the proprietary lines of a

171. *See Harris*, BEON MOBILE APPLICATION, https://www.harris.com/solution/beon-secure-group-communications-application (last visited Feb. 15, 2019).

172. *Id.*

communications contractor, but he won't be able to tap the circuits of a public telephone operator or the Internet, either. Indeed, it might be easier to corrupt an employee of one contractor than to figure out whom to corrupt among the tens of thousands that run parts of the public telephone system on the Internet.

Beyond that, the move to digital radio communication makes eavesdropping much more difficult. It is commonplace for hobbyists and news organizations to program simple radio scanners to listen to analog communications on local public safety frequencies. A scanner capable of doing that is available for less than $100. Listening to digital traffic on digital radio communications requires more sophisticated receiving equipment. An eavesdropper can, of course, buy a transceiver marketed to PMR users, but before the transceiver would be useful to intercept communications, the listener must know what frequencies, node numbers, and talk group names to program into it. Eavesdropping remains a possibility, but it is much more challenging and costlier.

Any security assessment must begin with a realistic evaluation of the risk. Risk depends on the motivation of the adversary and the cost to the adversary of compromising security. For the vast majority of PMR communications, the motivation to intercept is low and the cost of interceptions is high, higher after the transitions discussed in this article than before. Why would anyone intending to do harm want to monitor all the taxicab dispatch transmissions, or the transmissions of hotel maids to the housekeeping departments?

V. Radio Regulation

Radio communication has some of the most detailed regulation of any human enterprise. Engineering standards for transmitter power, frequency deviation, and antenna location proliferate. From its inception until the regulatory reform movement of the Ford Administration, the FCC followed the public utility regulation model that had developed around railroads and electric utilities. It was not much of a reach to adapt regulatory ideas for these industries to the telegraph and telephone industries which grew up technologically alongside railroads, and then, later, to the radio and television broadcast industries that developed a generation or two later.

Twenty-five years ago, students of the then just emerging Internet realized that communication regulation, which had developed separately for telegraphy and telephone, two-way radio, radio and television broadcasting, and cable television would have to be reconsidered as the theretofore distinct means of communication merged.[173]

The FCC has, since the regulatory reform movement first took root in the Ford Administration, made its regulation significantly more flexible. Frequencies now are allocated to pools, replacing much more detailed frequency assignment for specific radio services. Specific frequencies are assigned by private sector frequency coordination entities designated for geographic regions of the country, sometimes supplemented by coordination entities designated for particular industries. Regulation of the amateur radio service is almost completely privatized, with accredited operators designing and administering licensing tests and a volunteer organization developing frequency plans for the different bands of spectrum. Performance standards abound, however, addressing things such as maximum effective power and modulation categories on different frequency bands.

A. Traditional Regulation: Preventing Interference

The core activity of radio regulation is licensing transmitters. The federal Communications Act of 1934 prohibits transmitting radio signals except through a licensed station, under the control of a licensed operator.[174] This licensing, Congress believed, would mitigate the risk of interference, because it would limit the number of stations capable of interfering with each other, and it would ensure that they were operated by people who understood how to keep their signals within allowable limits. Licensing, however, limited the supply of radio users, and the FCC also is charged with promoting competition as much as it can.[175] Also, it must allocate access to the radio spectrum—a scarce public resource—so as to ensure and promote the public

173. *See* ITHIEL DESOLA POOL , TECHNOLOGIES OF FREEDOM (1984); Henry H. Perritt, Jr., *Market Structures for Electronic Publishing and Electronic Contracting* in BUILDING INFORMATION INFRASTRUCTURE: ISSUES IN THE DEVELOPMENT OF THE NATIONAL RESEARCH AND EDUCATION NETWORK (Harvard University and McGraw-Hill 1992) (explaining how the Internet would cause the collapse of regulatory categories); Henry H. Perritt, Jr., *Tort Liability, the First Amendment, and Equal Access to Electronic Networks*, 5 HARV. J. LAW & TECH. 65 (1992).

174. 47 U.S.C. § 301.

175. *See generally* 47 U.S.C. §§ 151-261 (imposing pro-competitive obligations in conjunction with AT&T breakup).

interest.[176] Later, it also became obligated to promote universal service and to assure the public safety as it engages in its regulatory activities.[177] Some of these goals are directed more narrowly at certain communications modes more than others, The universal service obligation focuses on telephone communication by common carrier,[178] for example, but the goals nevertheless sit in the general background and influence the FAA's broad philosophy.

From the outset, radio regulation has been concerned with preventing interference, and that remains its core concern. Radio regulation matured through the 1920s, taking a form in the 1934 Communications Act that lasted for 75 years. This traditional form of regulation comprised a triad of command-and-control regulatory restrictions. First, radio transmitting equipment had to meet certain standards of power levels, frequency stability and suppression of spurious signals, and be licensed to operate on specific frequencies. Second, transmitting stations and radio operators had to be licensed. Third, operators and station licensees had to follow certain operating rules.

The FCC itself prescribed the content of rules on each of these subjects. FCC examiners rode circuit to administer operator examinations, and FCC inspectors checked up on compliance by operators and station licensees. Notice and comment rulemaking permitted regulatees to submit detailed suggestions for regulatory content, but rarely did a comment from a regulatee simply get translated by the Commission into a final rule; usually the Commission staff worked out detailed compromises among different proposals.

The private mobile radio service is regulated by Part 90 of the FCC regulations. The public cellular system is regulated by Parts 20 and 22 as commercial mobile radio systems ("CMRS") and public mobile radio systems. Classification as a commercial mobile radio means the imposition of Title II common-carrier obligations. Part 22 imposes technical and licensing obligations on public mobile radio systems whether or not they are common carriers under Part 20. Cellphone systems are called "CMRS" by the FCC.

176. *See* Turner Broadcasting System v. FCC, 512 U.S. 622, 637-640 (1994) (summarizing scarcity rationale for broadcast TV regulation).

177. *See*, *e.g.,* 47 U.S.C. § 615a-1 (imposing obligation to provide 911 service).

178. *See* 47 U.S.C. § 254(b).

B. Reform and Privatization

Advances in technology have expanded the possible means of preventing interference, beyond simply limiting the number of transmitters allowed on the same frequency. Technology now permits multiple stations to operate on the same or nearby frequencies without interfering with each other. One such technology is the placement of radio repeaters and base stations into cells with caps on transmitter power so as to reduce the likelihood of an overlapping signals.[179] Another is directional antenna design which can allow signals to be sent in only one direction without interfering with signals sent on the same frequency in other directions.[180] A third is code division multiplexing, combined with carrier detection multiple access ("CDMA"), in which bursts of transmissions can be sent on the same frequency by multiple transmitters and be sorted out at the receiving end based on coded preambles. CDMA transmitters are polite, in that they listen to the channel and try to avoid transmitting on top of someone else. Some of these techniques are more suitable for wired circuits than for wireless circuits and others, like the antenna technologies, are more suitable for wireless; wires and optical fibers are inherently directional.

Many of these techniques for reducing interference have been developed and refined in the context of computer networking rather than radio communication, but as radio and computers become more integrated, they significantly enlarge the toolbox available to private actors and the FCC to mitigate interference. As a result, the FCC has become more flexible in allowing transmissions on the same frequency.

Beginning with the deregulation movement in the Ford Administration in the mid-1970s,[181] accelerating through actual deregulation of railroads and airlines in the Carter Administration and then building further steam in the Reagan and Bush Administrations of 1980s, the regulatory reform movement had reached full momentum in the Clinton Administration, with

179. *See* Section I.B (describing architecture of cell telephone system).

180. *See* ARRL, THE ARRL 2015 HANDBOOK FOR RADIO COMMUNICATIONS § 21.1.1 (ARRL et al. eds, 92nd ed. 2014) (explaining antenna directivity and gain); *How Cell Towers Work*, UNISON, at p.7, http://www.unisonsite.com/pdf/resource-center/How%20Towers%20Work.pdf (explaining and illustrating how directional antennas permit frequency reuse on the same or nearby cell towers).

181. The author was Deputy Undersecretary of Labor during this period, responsible for intensifying the Labor Department's regulatory reform initiative.

the struggle to figure out how to regulate the Internet, and the effort to rationalize regulation of the newly broken up telephone enterprises, in the 1996 Telecommunications Act.[182] The shift toward privatizing communications regulation emerged soon thereafter as a distinct initiative.

The following milestones mark the reform of communication. regulation

- The shift toward privatizing licensing
- The shift toward eliminating regulation of certain services altogether and the shift toward granting group licenses for other services
- Rationalization of the number of different radio services[183]
- Delegation of frequency coordination to private organizations[184]
- Regulation of the Internet

During the same period, the FCC lightened the hand of regulation further by designating major portions of the 902-928 MHZ, 2.4 GHZ, and 5.7 GHZ bands as unlicensed,[185] requiring spread spectrum modulation[186] to prevent interference and designating much of the mobile aviation and marine services as eligible for class licenses, relieving users of the requirement to obtain individual operator and station licenses. The precursor to the

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182. Telecommunications Act of 1996, Pub. L. 104-104, 110 Stat. 56 (Feb. 8, 1996).

183. FCC, Second Report and Order, Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them and Examination of Exclusivity and Frequency Assignments Policies of the Private Land Mobile Services, PR Docket No. 92-235, Report No. WT 97-5 (Feb. 20, 1997), https://transition.fcc.gov/Bureaus/Wireless/Orders/1997/fcc97061.txt [hereinafter 1997 Consolidation Order].

184. *See generally* FCC, *Industrial/Business: About*, http://wireless.fcc.gov/services/index.htm?job=service_home&id=industrial_business (last visited Feb. 19, 2018) (overview of industrial/business radio service, including description of frequency coordination, FCC frequency licensing, and frequency pools); *see also* 1997 Consolidation Order, *supra* note 183, ¶¶ 32-34 (explaining origin and role of frequency coordinators).

185. Before that, every transmitter required a station license.

186. FCC Unlicensed Devices Report, *supra* note 118. The FCC explained spread spectrum modulation: "Spread spectrum communication systems use special modulation techniques that spread the energy of the signal being transmitted over a very wide bandwidth. The information to be conveyed is modulated onto a carrier by some conventional techniques, usually a digital modulation technique, and the bandwidth of the signal is deliberately widened by means of a spreading function. The spreading technique used in the transmitter is duplicated in the receiver to enable detection and decoding of the signal. Spread spectrum systems offer two important technological advantages over conventional transmission schemes. First, the spreading reduces the power density of the signal at any given frequency within the transmitted bandwidth, thereby reducing the probability of causing interference to other signals occupying the same spectrum. Second, the signal processing in spread spectrum systems tends to suppress undesired signals, thereby enabling such systems to tolerate strong interfering signals." *Id*.

unlicensed spectrum step had been citizens band radio, which was popular in the 1980s, and for which users did not need operator or station licenses. During its peak popularity, the citizens band itself was cacophonous and the home of much bad behavior, but it did not have an adverse effect on other services, one of the ongoing fears that had motivated broad licensing requirements.

In the new unlicensed spectrum segments, the FCC protected against interference by setting tight standards for equipment, limiting transmitter power and requiring manufacturers to use sophisticated techniques like spread spectrum to improve spectrum-use efficiency. Privatization received a nudge by the auction requirements of the 1976 Act, assigning spectrum to the highest bidder, a statutory mandate conceptually inconsistent with the premise that the FCC should dole out spectrum and control its use to serve the public interest as the Commission defined it. In many cases, third parties have bought blocks of frequencies at auction and sell or lease them to individual entities. The FCC is involved only at the margins of the market. In 1997, the Commission consolidated twenty distinct private mobile radio services[187] into two frequency pools: a public safety pool and an industrial/business pool.[188]

Two procedures have emerged to allocate the frequencies in the two pools. In both cases, the initiative for assignment of a new frequency comes from a user entity or its radio communications vendor. The first system is the traditional one: the application goes to the FCC, and it holds an administrative hearing to determine if new frequencies should be allocated.[189] The second system is growing in popularity. The user or its contractor develop a plan for a communication system, which necessarily involves radio frequencies for repeaters and mobile transceivers. That entity

187. 1997 Consolidation Order, *supra* note 183, ¶ 6 (identifying Public Safety Radio Services: Local Government, Police, Fire, Highway Maintenance, Forestry-Conservation, and Emergency Medical Radio Services; Special Emergency Radio Service; Industrial Radio Services: Power, Petroleum, Forest Products, Film & Video Production, Relay Press, Special Industrial, Business, Manufacturers, and Telephone Maintenance Radio Services; and Land Transportation Radio Services: Motor Carrier, Railroad, Taxicab, and Automobile Emergency Radio Services).

188. *Id.* ¶ 3 (summarizing Commission action).

189. The FCC's involvement with the railroad industry's massive Positive Train Control ("PTC") project provides a good example of how reformed PMR regulation works. *In the Matter of FCC, PTC-220, LLC Request for Modification of Station KIVD0007 and Waivers to Implement Positive Train Control*, DA 16-1406 (Dec. 19, 2016) (accepting modification of station license for New York and Philadelphia-area commuter railroads to allow an additional block of frequencies).

then applies to the frequency coordinator, which may be a spectrum leasing manager,[190] and presents justification for granting the request, demonstrating by engineering studies the improbability of interference with existing users.[191] Much of the ultimate interaction with the FCC on licensing is conducted by frequency coordinators.[192]

The FCC approved leasing of spectrum and encouraged development of an efficient secondary market for spectrum in 2004.[193] It specifically authorized "spectrum manager leasing," in which the licensee retains de jure control of the licensed frequencies, while transferring de facto control to the lessee.[194] It determined that leasing is not necessary on shared frequencies.[195]

In 2015, the FCC proposed further changes in its rules to facilitate deployment of SDRs and cognitive radios.[196] The FCC's regulations for cellphone providers similarly have evolved toward greater flexibility and reliance on private accommodation rather than agency litigation. "Telecommunications carriers" must interconnect with other "telecommunications carriers" and must not install network features or functions that do not conform to standards developed under Section 255 or

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190. *See id.* ¶¶ 23-25 (describing PTC-220, LLC as a joint venture of the seven U.S. Class I railroads, which has acquired 220-222 MHz band spectrum to support its members' interoperable PTC deployment).

191. *See* FCC, *supra* note 184 (explaining that frequency coordination usually files license application with FCC on behalf of the primary applicant).

192. FCC, Amendment of Sections 90.20 and 90.175 of the Commission's Rules for Frequency Coordination) of Public Safety Frequencies in the Private Land) Mobile Radio Below-470 MHz Band, WT Docket No. 02-285, FCC 02-255 at ¶ 12 (Sept. 16, 2002), https://apps.fcc.gov/edocs_public/attachmatch/FCC-02-255A1.pdf (describing Universal Licensing System and observing that frequency coordinators submits large percentage of license applications in batch electronic form).

193. *See* FCC, FCC Expands Spectrum Leasing Rules and Speeds Processing to Create Additional Opportunities For Access to Spectrum Through Secondary Markets, https://www.fcc.gov/spectrum-leasing-releases (July 8, 2004) (press release announcing Second Report and Order, WT Docket No. 00-230 (July 8, 2004), https://apps.fcc.gov/edocs_public/attachmatch/FCC-04-167A1.pdf).

194. *Id.* ¶. 7.

195. *Id.* ¶ 62.

196. Amendment of Parts 0, 1, 2, 15, and 18 of the Commission's Rules regarding Authorization of Radiofrequency Equipment Request for the Allowance of Optional Electronic Labeling for Wireless Devices, 80 Fed. Reg. 46900, https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-92A1.pdf, FCC 15-92 Para 13 (proposed on July 21, 2015) (to be codified at 47 C.F.R. 0, 2, 15, 18) (explaining cognitive radios).

256.[197] But cell providers may use "any technology that meets all applicable technical requirements" in the FCC rules.[198] The rules limit transmitter power and antenna height, unless all affected cell systems concur with exceeding the limits.[199] In 2014, the Commission relaxed its emission limit rules for cellphone fixed sites.[200] Cell providers must work out channel use with each other.[201] The Commission does require cellphone manufacturers to offer hardware that handles 911 calls, but that also is a performance rather than an engineering standard.[202] The Commission is authorized to encourage and participate in the development of standards by private standard-setting organizations, but not to mandate standards on its own.[203]

C. Regulation of the Internet

The rough Internet analogy to a station license for a radio transmitter is the assignment of an IP address in the domain name to an Internet node, but no one in the United States needs a license to establish or operate an Internet node. No governmental entity has ever prescribed a standard for the design of Internet hardware or software such as routers or packet structures. Instead, from the beginning of the Internet's release from its tethers to Defense Department laboratories and university computer science departments, regulation of the Internet has been a private responsibility. In August 2016, the United States Government took the final step in privatizing regulation of the Internet, by handing over full control of the domain naming system to ICANN.[204]

The Internet Engineering Task Force,[205] a relatively loose association of

197. 47 U.S.C. § 251(a). CMRS is a telecommunications service, and CMRS providers are common carriers. Part 22, which regulates CMRS, is a part of 47 C.F.R. Chapter I, Subchapter B "Common Carrier Services."

198. 47 C.F.R. § 22.901.

199. 47 C.F.R. § 22.913.

200. 79 Fed. Reg. 72143, 72145 (Dec. 5, 2014) (explaining new rule's flexibility).

201. 47 C.F.R. § 22.907.

202. *See* 47 C.F.R. § 22.921 (requiring hardware to handle 911 calls on a specific basis).

203. 47 U.S.C. § 256.

204. *See* NTIA, Q and A on IANA Stewardship Transition, https://www.ntia.doc.gov/other-publication/2016/q-and-iana-stewardship-transition-0; *see generally* https://www.icann.org/resources/pages/welcome-2012-02-25-en.inter.

205. *See* IETF, https://www.ietf.org (last visited March 3, 2019).

computer science academics and industry representatives[206] had already organized a process for the development of "Requests for Comments" ("RFC" that articulate standards for matters as diverse as the basic specification for the structure of an IP packet to methods for speeding up and slowing down bit streams millisecond-by-millisecond to variations in congestion in routes between a video entertainment producers and a consumer of a streamed movie.)

Although some critics, especially outside the United States, urge that regulatory responsibility should be shifted to official bodies such as the intergovernmental ITU and lament US dominance of the Internet, there is a little user—as contrasted with political—support for changing the current system of private regulation. The IETF has done a more than satisfactory job through the RFC process, and it is perceived to be legitimate and relatively unbiased, in terms of giving advantage to proprietary technologies. It is much more responsive and quicker to accommodate innovation in the form of new technologies than the ITU or national governments, where stakeholders can effectively defend the status quo against disruptive technologies. From its beginning, it has been committed to open architectures and transparent development.[207] All RFC's are public, and free, unlike many other communication standards, some of which may be open but cost several hundred dollars.[208]

Also, the IETF process has managed to avoid the committee paralysis that encumbers most other communication standards organizations, encouraged by a large paid staff that engage in various rent seeking behaviors.[209]

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206. IETF is an activity of the Internet Society. *See About Internet Society*, INTERNETSOCIETY.COM, http://www.internetsociety.org/about-internet-society/ (last visited Mar. 3, 2019).

207. "The IETF is completely open to newcomers. There is no formal membership, no membership fee, and nothing to sign. By participating, you do automatically accept the IETF's rules, including the rules about intellectual property (patents, copyrights and trademarks). If you work for a company and the IETF will be part of your job, you must obviously clear this with your manager. However, the IETF will always view you as an individual, and never as a company representative." IETF, https://www.ietf.org/about/participate/ ("Participation" section).

208. *See* IEEE Standards Store, IEEE 802.11ad-2012, https://www.techstreet.com/ieee/standards/ieee-802-11ad-2012?product_id=1820568 (quoting price of $223 for basic WiFi standard). .

209. Christopher R. Leslie, *Cartels, Agency Costs, And Finding Virtue in Faithless Agents*, 49 WM. & MARY L. REV. 1621, 1687-1690 (2008) (explaining agency costs in context of trade association efforts to establish cartels).

Open standards are an important part of pro-competition policy. When the standards for interconnecting adjacent layers of the OSI stack are open for use by anyone, economic efficiency can result from specialization.[210] A new entrant need not deliver functionality throughout the entire OSI stack in a vertically integrated product; rather it can specialize in offering functionality in only one or a few layers. This kind of competition in vertical markets can be stifled, however, if suppliers with market power keep the interfaces at different levels of the technology stack secret, and even worse, if they protect them by patent or copyright infringement litigation.

Even as antitrust law has become more comfortable with a wide variety of vertical market restraints,[211] technology and engineering culture has opened up standard-setting and standards use. The Internet Engineering Task Force a strong example of the cultural trend. Governmental regulation still takes place beyond the edges of the Internet, and these regulatory regimes grow in importance as more Internet traffic ends up as RF traffic. Radio links handle more Internet traffic as RF transmissions bridge the last mile between consumers and the core infrastructure, mostly from cell towers to broadband wireless devices such as tablets and cell phones.

D. Monopoly and Market Structure

Competition long has been a concern in the political economy of communications. Strong network effects operate in most communication systems, so that a supplier who gains significant market share enjoys a competitive advantage that increases in direct proportion to its growing market share.[212] Furthermore, the FCC's station licensing, restricting access to spectrum, artificially limits supply and imposes barriers to entry.

While technology of optical fiber, cable television coaxial cable, the Internet, and higher frequencies on the radio spectrum have opened up many alternatives to over the air radio communications on the parts of the spectrum most heavily used, spectrum scarcity remains a significant constraint on competition. Even someone with the best idea in the world can't offer it in

210. *See* Adam Smith, The Wealth of Nations text at notes 2-4 (1776) (explaining how pin makers become more efficient by specializing).

211. *See*, *e.g.*, Continental T.V., Inc. v. GTE Sylvania, Inc., 433 U.S. 36, 50-54 (1977) (explaining that vertical restraints can promote competition).

212. *See* United States v. Microsoft, Corp., 253 F.3d 34, 49-50, 83-84 (D.C. Cir. 2001) (explaining network effects as a limit on competition).

the marketplace unless he gets access to the necessary radio spectrum. The FCC's spectrum auction policies reflect a competition concern, as the Commission reserves certain blocks of spectrum for small entities and has opened the possibility of secondary markets for spectrum, thereby reducing barriers to entry.[213] Its steps to cause forfeiture of spectrum not actively uses is a further step to promote competition.[214] Even in the wired realm, competition policy is evident in communications regulation. Net neutrality regulation is essentially a legal prohibition on monopolistic refusals to deal that would represent barriers to entry for new entrants.

Competition in PMR has waxed and waned. Motorola invented land mobile radio. From about 1940 until the turn of the 21st century, it was the dominant player, with a 90% market share in civilian and military sectors, setting the pace for user adoption of new technologies as it incorporated them or did not incorporate them into new product models, and enjoying substantial pricing power. Except for the defense establishment, it faced a very fragmented market on the demand-side—thousands of state or local police departments, fire departments, and almost equally fragmented civilian mobile radio users, although railroads and some large utilities had a little more bargaining power.

Through the '70s, '80s, '90s, and into the 21st century, the volume of calls by would-be competitors to open up the market began to increase. Would-be new entrants pointed out that they could deploy technologies that Motorola had been slow to adopt, that they could offer cheaper prices, if only they could get a level playing field

Eventually, their cries resonated with legislators at the state and federal level and with executive branch officials and began to produce results. Increasingly, discussions of modernization of communication systems included the idea that any new system should have an open architecture so the competition could be free. Systems for the future should be interoperable.

Interoperability was the goal of P 25, even before September 11.[215] It was to be an open standard that any vendor could incorporate into its products. But Motorola largely captured the P 25 process through its extensive tentacles reaching into not only state houses and congressional committees,

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213. *See* FCC, Secondary Markets Initiative, https://www.fcc.gov/wireless/bureau-divisions/technologies-systems-and-innovation-division/spectrum-leasing/secondary.

214. *See* NTCH, Inc. v. FCC, 841 F.3d 497, 501 (D.C. Cir. 2016) (referring to FCC steps to prevent Verizon from "warehousing" spectrum).

215. *See Spectrum Management*, APCO INT'L, https://www.apcointl.org/spectrum-management/resources/interoperability/p25.html (describing goal and genesis of P25).

but also standards committees. After September 11, the major potential competitors, Harris and Kenwood, gave up their hope for P 25 as an engine of competitive entry and began to embrace DMR in the United States. DMR was a European standard, developed largely in parallel with P 25, but it had a reputation for being cheaper and just as good in permitting repeaters to be tied together through the Internet and in meeting the 6.25 KHz bandwidth requirement.

Motorola responded to the growing popularity of DMR by marketing proprietary enhancements that did not generally permit other vendors' products to connect to it. For pessimists, it appeared that Motorola had captured DMR as well as the P25. That, then, led to the development of dPMR, another European standard, largely an updated DMR, and Kenwood and ICOM launched a new proprietary NXDM standard mainly based on it.

Assessing competition must start with a definition of the relevant markets.[216] The market for PMR comprises five distinct segments: the market for portable and mobile hardware, the market for base station hardware, including repeaters; the market for software to tie the hardware together, the market for radio access services, and the market for routing and wired access.[217]

Replacement of existing PMR technologies with push-to-talk-over-cellular ("POC") technologies will have varying impact on these market segments. The shift will involve replacement of mobile transceivers with hybrid devices that have some of the features of cell phones and some of the features of current handheld two-way radio devices. Just as cell phone hardware is sold by entities independent of the telephone companies, such as Apple and Samsung, the new devices similarly will be sold in a competitive market. The existing PMR manufacturers have the strongest incentive to do the necessary development work; without it a substantial part of their existing business may disappear. Still, both existing telephone vendors and existing two-way radio vendors have only half of the requisite knowledge to accomplish good hybrid hardware design.

The market for repeater hardware will shrink because the radio access networks will be part of the regular cellular system. PMR does not generate enough traffic, compared to cellular traffic from the general public, to make

216. Brown Shoe Co. v. United States, 370 U.S. 294, 324(1962) ("The 'area of effective competition' must be determined by reference to a product market (the 'line of commerce') and a geographic market (the 'section of the country').").

217. Wired in this context includes optical fiber and fixed point to point wireless.

much difference in the demand for sale of system hardware. Network management hardware will have to function differently, managing cell phone "calls" instead of radio "transmissions," so there should be significant new demand for this type of hardware. The people in the best position to satisfy this demand are the existing vendors of dispatch and PMR network management hardware, because they understand customer needs best. The software to tie PMR users together will have to perform the same functions performed by existing PMR network management software. Which vendors have an edge in designing and marketing it depends on whether the new network is implemented through the public telephone system or IP. Section 6202(b)(1)(B)(ii) of the FirstNet statute permits either or both. The manifested intention by telephone providers and the FCC that the public telephone system merge into the Internet suggests the best design for FirstNet rely on the Internet for routing. If this turns out to be the case, existing PMR vendors will have a competitive edge.

The market for network access is likely to be quite different from the existing cell phone market. PMR users are not likely simply to subscribe to FirstNet's contractor (likely AT&T or Verizon) directly. Rather, a new industry segment of FirstNet access contractors is likely to arise. These contractors will integrate hardware, software, and connectivity, managing the interconnection with cell phone companies and Internet service providers. These vendors will specialize in product features tailored to the needs of PMR users; they are unlikely to hold themselves out as alternative cellphone providers; the PMR market simply is not big enough to support the capital to construct a parallel cell phone infrastructure. Still, Although AT&T and Verizon dominate the cellphone market, smaller providers offer competition in some markets,[218] and incumbent cellphone provider have an obligation to connect with other cellphone providers.[219]

218. *Competitive wireless carriers take on AT&T and Verizon*, CNET (Sept. 10, 2012, 12:01 AM), https://www.cnet.com/news/competitive-wireless-carriers-take-on-at-t-and-verizon/ (last visited March 3, 2019).

219. "Telecommunications carriers" must interconnect with other "telecommunications carriers" and must adhere to industry technical standards. 47 U.S.C. § 251(a). CMRS is a telecommunications service, and CMRS providers are common carriers. Part 22, which regulates CMRS, is a part of 47 C.F.R. Chapter I, Subchapter B "Common Carrier Services."

E. Open Standards

Moving any regulatory regime toward greater reliance on market forces and private institutions to control access implicates the insights of a couple of generations of economists, from Ronald Coase to Mancur Olsen and Oliver Williamson. Coase and Williamson directed attention to transaction costs as the major determinants of whether firms choose to perform activities inside their organizational boundaries or, instead, to buy those activities. Their basic premise was that firms bring the activities inside when the transaction costs of doing them in the market are too high.

Olsen's key insight was that private ordering inside an organization such as a profit-seeking business firm or a non-profit trade association encounter transaction costs of their own. These costs include free riding, rent seeking, and cheating.[220] Competition-law economics long has recognized that cartels aimed at limiting competition tend to break down because of these forces, even though adherents to their standards would benefit by limiting competition.

Centrifugal forces make it difficult for private standard-setting and regulatory organizations to achieve their intended purpose. They tend to fall apart, because the incentive to participate and to adhere to their mandate is thin and unequally distributed. When they do not collapse, they engage in formal activities that do not have much actual effect on behavior in the market. They also can drift toward retarding innovation and limiting competition because their standards block disruptive new technologies.[221] Regulatory agencies may attempt to make them more effective by adopting their mandates as regulatory requirements, but that may simply codify anti-

220. *See* Sidney A. Shapiro, *Outsourcing Government Regulation*, 53 DUKE L.J. 389 (2003) (applying transaction-cost economics to private standards setting organizations and concluding that they may impose higher transaction costs than government prescription of standards); *id*. at 404-411 (identifying rent-seeking, hold-up, and incomplete consideration of public interest in private standard setting organizations).

221. Sean P. Gates, *Standards, Innovation, and Antitrust: Integrating Innovation Concerns into the Analysis of Collaborative Standard Setting*, 47 EMORY L.J. 583, 601-612 (1998) (suggesting framework for balancing pro- and anti-competitive effect of standards and recognizing that standards can impede innovation); *See* Allied Tube & Conduit Corp. v. Indian Head, Inc., 486 U.S. 492, 500-501 (1988) (discussing factors that government antitrust scrutiny of private standards setting activities).

competitive standards.[222] Seeking to achieve the benefits while avoiding the anti- competitive effects of private regulation, the Justice Department, the FCC, and the courts have imposed a number of due process requirements on private standard-setting organizations.[223] These safe harbors recognize that a private regulatory organization, in order to have an effect, must constitute itself as a concerted refusal to deal, a prima facie violation of Section 1 of the Sherman Act.[224] The safe harbors set the outer limits of a privilege that avoids antitrust liability.

VI. New Regulation

Framing a rational regulatory strategy for the post-adoption situation requires reconsidering the perceived risks that justified regulation in the first place. Chief among them was interference, followed closely by monopoly and other market failures, and then by the public interest, especially public security.[225] Any strategy developed to mitigate these risks must also involve measured change and respect the roles of states in the federal system.

The absorption of PMR by the Internet does not directly portend any sort of revolution in regulation of PMR, itself. The FCC will continue to be concerned about frequency assignment and use beyond the edges of the Internet—in the RAN—and about assuring sufficient spectrum for all of the services. The IETF will continue to work out standards for new technologies; ICANN will continue to administer the domain name and IP address

222. *See* Henry H. Perritt, Jr., Digital Communications Law § 8.07 at 8-13 to 8-19 (2010) (reviewing FCC authority to impose standards and require connectivity).

223. Emily S. Bremer, *American and European Perspectives on Private Standards in Public Law*, 91 TUL. L. REV. 325, 341-348 (2016) (providing overview of U.S. standards setting process and the law that constrains it).

224. *See, e.g.*, Research In Motion Ltd. v. Motorola, Inc., 644 F.Supp.2d 788, 790 (N.D. Tex. 2008) (denying motions to dismiss antitrust claim against Motorola for failure to license patents incorporated into standard); Henry H. Perritt, Jr., *Cyberspace Self-Government: Town Hall Democracy or Rediscovered Royalism?*, 12 BERKELEY TECH. L.J. 413 (1997) (analyzing various private structures, including standards setting organizations, for regulating the Internet).

225. Of course, redesigning and reconsidering regulation will be unnecessary if the adoption does not take place. But the advantages of folding PMR into the Internet and the public telephone system are sufficient that the adoption is nearly certain to occur, eventually. Elements of it already are occurring, simply because of market forces. This is not a transition that is taking place only because the Congress mandated it; the 2012 mandate is simply a congressional effort to channel a transition already is occurring.

assignment systems. Public safety service frequency coordinators will not be replaced by ICANN, and the FCC will not start assigning IP addresses. Absorption of PMR into the public cell system and into the Internet, does, however present new economic and technology issues that invite some kind of regulation. Whether particular regulatory proposals have merit should depend on the particular risks they are supposed to mitigate, and their cost effectiveness in doing so.

A. Assuring Reachability

The risk is the stations will transmit signals that interfere with each other so that a receiver cannot detect the information contained in any of them. Direct interference is familiar: two stations transmit at the same time on the same frequency or wired circuit. Another type of interference is equally problematic: two or more stations have the same address; a signal intended for one of them will get directed to another.

Section I.A details the FCC's history as starting with the goal of preventing interference by requiring station and operator licenses. The risk of interference in the radio portion of PMR remains, but the techniques for avoiding it have multiplied, now including low power cellular transmitters, adaptive antennas, and code- and time-division multiplexing. The FCC has recognized that the government does not need to do everything and has delegated a substantial part of its authority to private intermediaries. Its basic approach to radio-frequency allocation is sound for the future, but it must embrace the reality that the frequencies in RANs associated with cellphone networks and the frequencies in the PMR services will often be used interchangeably for the same traffic.

The FCC has figured out that it need not give separate attention to the licensing of each radio transmitter. Rather, it can assign blocks of frequencies, largely through the auction process, and let private intermediaries make secondary markets in frequency reallocation, and private frequency coordinators can keep frequency users from stepping on each other. Absent demonstrated abuses of market power by frequency coordinators or frequency resellers, the reformed approach to frequency assignment is sound.

Within the Internet, interference has not been a problem since the Net's earliest days. IANA does its job well. Attacks on Internet governance, however, could necessitate intervention. If, for example, a nation state should arrogate for itself the responsibility of assigning Internet addresses and assign addresses that overlap with those assigned by the IANA system,[226] chaos could quickly ensue. And, because the Internet's address space is inherently global, some kind of governmental action would be necessary, at the international or the national level, to respond to this threat; an IP address visible in China would be visible in Chicago. Crafting international action would significantly increase the risk of politicizing decision-making, however. That could be avoided by segmenting the Internet so the different parts of it would have different address spaces, but that would end its global character. No immediate action is necessary with respect to interference and station-finding in the Internet, but the Commission must remain vigilant and prepared to act quickly if any signs of fragmentation of the Internet's address space emerge.

B. Promoting Competitive Markets

The risk is that market structures will impair competition, in the form of monopoly power that results in higher than necessary prices and a suppression of technological innovations. Inherent de-facto network effects encourage monopoly; and de-jure monopolies result from spectrum auctions. Protecting competition, post adoption, is considerably more challenging than preventing interference. Open standards are a partial strategy; open standards assure that competitors can connect with monopoly components of the network.

Network effects are even greater when there is only one national emergency communication system. The cost of being an outlier or nonsubscriber lacking access to it is much greater than the cost of simply having an isolated UHF analog radio system for a particular county. In addition, RAN technologies for cellular systems are much more capital intensive than they are for PMR architectures. The cost of capital and imperfections and capital markets favor repeat players and big users of capital represent significant new barriers to entry. Even the most energetic young entrepreneur is unlikely to build, from scratch, a cellular telephone system capable of competing effectively against AT&T and Verizon.

The best regulatory strategies for preserving competition are, first, to protect the character of the Internet and prevent its being corrupted, perhaps on the ground of public security. Citizens and public and private sector entities should remain free to build their own communication systems

226. *See* John Ribeiro, *U.S. Says the Proposed Chinese Regulations May Fragment the Internet*, PCWORLD (May 17, 2016), http://www.pcworld.com/article/3071206/internet/us-says-proposed-chinese-regulations-could-fragment-the-internet.html/.

without connecting them to the Internet, but if they do connect them to the Internet, they must meet certain obligations. Packet rejection and throttling, absent emergency situations, are not consistent with those obligations. In other words, Net Neutrality is useful with respect to Public Safety communications as well as television and movie entertainment.

Second, public policy should continue to embrace open standards, and antitrust regulators should be, if anything, more vigilant in policing against anti-competitive licensing practices by patent owners who have participated in the standard-setting process and made their patents available as part of public standards. This means that Band 14 should be available for use by the public, as long as adequate bandwidth is available for public safety communications.

1. Requiring Open Standards and Interconnection

Technology permits products and services from different suppliers to be tied together in an integrated communication service; that is the premise of the OSI stack, and the reality of the Internet. The competitive opportunities afforded by this architecture can be frustrated in three major ways. First, a dominant supplier wishing to extend its market power over one element to adjacent elements can keep its interfaces secret or protect them with intellectual property–patents in the devices or the protocols, copyrights in the software. Second, it can express the interfaces in open standards, but not allow competing suppliers to connect physically. Third, it can adhere to open standards and allow physical interconnection, but only on onerous economic terms.

Litigation eventually leading to the breakup of AT&T illustrates all of these techniques to block competing access to a communications network. The breakup of AT&T started with efforts by Carterfone, and then MCI, to force their way into the middle of AT&T's communications stack.[227] Carterphone demanded the privilege of connecting its hardware at the edge of the network, in the "last mile." Carterphone offered competing alternatives to the customer hardware manufactured by AT&T's captive

227. *See* Jack Faucett Associates v. American Tel. & Tel. Co., 744 F.2d 118, 120-124 (D.C. Cir. 1984) (reviewing case-law and FCC decisions related to AT&T's refusals to allow interconnection of competing devices at various levels in its network).

western electric.[228] MCI demanded access to the middle of the communication stack—to the trunklines that carried long distance traffic between local exchanges.[229] The antitrust consent decree that resulted from an antitrust action eventually brought by the Justice Department[230] then morphed into the 1996 Telecommunications Act imposed multiple interconnection obligations on the now separate components that formerly were integrated in AT&T.[231]

Open standards are distinct from interconnections. The provider of a network element may adhere to an open standard but be unwilling to let someone else connect to that element. The FCC and the telephone company have substantial experience in arm wrestling over interconnection obligations under the 1996 act. Even if a network element offers an open standard to the outside world, and even if the owner of the element allows interconnection in the physical sense, the economic terms the owner insists on may be such as to frustrate the practical utility of the interconnection.

The policy debate under the 1996 Act was influenced by the argument that incumbent providers would lack the incentive to invest in a new technology if they had to share their investment with competitors who had not invested. This argument is considerably weakened in the FirstNet context because public funds have been used to make the investment.

A tension exists between network security and open networks that enhance competition. Networks can always be made secure when only one entity controls every network element. That architecture, however, is antithetical to the competitive marketplace represented by the Internet. Section IV.C considers how to resolve the tension. The FirstNet statute

228. *See* Hush-A-Phone Corp. v. United States, 238 F.2d 266 (D.C.Cir. 1956) (rejecting FCC order allowing AT&T prohibition of telephone attachments); in *Use of the Carterphone Device in Message Toll Telephone Service,* 13 F.C.C.2d 420 (1968) (applying Hush-A-Phone to hold unreasonable AT&T tariff that prohibited interconnections that did not adversely affect telephone system), *reconsideration denied,* 14 F.C.C.2d 571 (1968).

229. *Compare* MCI v. AT & T, 708 F.2d 1081, 1093-1100 (7th Cir.) (1983) (describing background of dispute over interconnecting competing microwave facilities with AT&T; affirming in part judgment on jury verdict of anti-trust liability) *with* Southern Pacific Communications Co. v. AT & T, 740 F.2d 1980, 1011 (1984) (affirming judgement for AT&T on refusal to allow microwave system to interconnect).

230. United States v. Am. Tel. & Tel. Co.,, 524 F.Supp. 1336, 1368 (D.D.C.1981) (denying motion to dismiss action that eventually led to breakup of AT&T).

231. *See* Henry H. Perritt, Jr., Digital Communications Law § 7.03[F] (2010) (analyzing statutory obligations to interconnect under 1996 Act).

requires adherence to open standards.[232]

2. Establishing Public Goods

The risk is that gaps in the technological or market infrastructure will prevent full realization of technology's potential in private markets. These gaps exist because the services associated with them are public goods.[233] The most important public good for a network is a comprehensive set of open standards. As Section I.C explains, open standards lessen the monopoly power of the dominant suppliers because they reduce barriers to entry. The Internet is the model of a set of open standards that allow of suppliers to participate in the market that it represents. As Section III.D explains, the Internet standards have been developed and adopted with very little governmental involvement, and certainly no regulatory mandate that any particular standard be developed or used. [234]

The level of regulatory intervention has been somewhat greater with respect to standards for the telephone system and radio and television broadcasting. After the AT&T breakup, the FCC aggressively used its power to impose interconnection obligations,[235] but left it up to the providers to figure out what standards to use to effect interconnection. In the broadcast industry, the FCC has always prescribed detailed technical characteristics for modulation, transmitter power, and receiver capability.[236]

Going forward, the default should be the Internet model; the FCC should

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232. § 6206 (b)(2)(B), Publ. L. 112-96, 126 Stat. 211 (requiring FirstNet to "promote competition in the equipment market" by requiring that equipment be built to open, non-proprietary, commercially available standards, be capable of being used by any public safety entity and by multiple vendors across all broadband networks operating in the 700 MHz band, and be backward compatible as much as feasible), codified at 47 U.S.C. § 1426.

233. *See* Chia Hua Chen, Public Goods (2007), MASSACHUSETTS INSTITUTE OF TECHNOLOGY (Feb. 15, 2019, 9:36 PM), https://ocw.mit.edu/courses/economics/14-01-principles-of-microeconomics-fall-2007/lecture-notes/14_01_lec35.pdf (explaining why markets do not produce enough public goods).

234. Governmental contracting requirements are something of an exception, but the mandated adherence to open standards and IP, occurred only after the Internet with a comprehensive set of standards, was solidly in place. *See* ETF, RFC 1169 (Aug. 1990), https://tools.ietf.org/html/rfc1169 (discussing U.S. Government OSI Profile—requirement for government contractors to use OSI stack).

235. 47 C.F.R. § 51.100 (imposing interconnection obligation on each telecommunications carrier).

236. *See* 47 C.F.R. § 73.614 (specifying power and antenna heights for broadcast stations).

refrain from standard-setting activities as long as private sector institutions are doing it well The trigger for FCC involvement should be a demonstrated breakdown in the private standard-setting process manifested either by the inability of market participants to agree on a standard for interconnecting a particular service to the infrastructure or a standard agreed-upon by some of the market participants that has unnecessary anti-competitive effects.[237] An example of the second type of market failure is requiring the use of a patented or copyrighted technology on exorbitant royalty terms.

Part 0 observes that the Internet is not imperial. While it has a democratic government structure, it does not impose this on its new acquisitions . Producers and consumers are free to observe a tight and restrictive regime for protecting intellectual property; they are free to play only in walled gardens. E-commerce remains subject to the usual common-law and statutory legal regimes for consumer protection. The Freedom of Information Act remains operative with respect to governmental information. Only a handful of new legal regimes regulate activities likely to harm Internet connected resources.[238]

3. Providing Breathing Room for Innovation

The most important thing about the regulatory embrace of the Internet's adoption of two-way radio is to avoid mandating compliance with particular engineering standards. When regulatory agencies engage in standard setting, it is extremely difficult to avoid deciding on a standard that has been superseded by new technology by the time the standard is promulgated It is also difficult to avoid the anti-competitive effects of a standard that has too many proprietary elements. The IETF approach is far superior. Compliance with its standard is voluntary, and users vote with their feet when a standard is useful.

The implications of shifting from SS7 to IP have little to do with the change in the protocol itself. The telephone companies may continue to use their own wires, switches, and routers and simply shift to a new protocol defining a packet-switching architecture; nothing changes in terms of

237. *Compare* Rambus Inc. v. FTC, 522 F.3d 456, 460-462 (D.C. Cir. 2008) (overturning FTC decision that participant in standards organization tricked other participants to adopt its patented technology) with *Federal Trade Commission v. Rambus Inc.*, No. 08-694, 2008 WL 5433368 (U.S. Dec. 29, 2008) (Brief Amicus Curia urging grant of certiorari; detailing abuse of standard setting process).

238. *See* CFAA, 18 U.S.C. § 1030.

reliability or regulatory compliance. It is only when the shift in protocols is accompanied by the telephone companies' beginning to use other people's hardware and circuits that the situation becomes more complicated.

An important question about FirstNet is not just whether it envisions that PMR will be subsumed by the cellular telephone system. including its switching, but whether it also assumes that a PMR transmission is a cell phone call from origin to destination or replacing the RF link only with the cell phone infrastructure, thereafter, handling PMR calls through the Internet, as occurs now with most of the modes.

The fact that Voice over IP is handled separately from regular cell phone calls implies a parallel character, part of it circuit-switched or at least multiplexed according to telephone protocols and part of it straightforward IP, UDP and so on.

4. Avoiding Perils of Process Worshipers: Bureaucratization of Standard-setting Organizations

But due process imposes transaction costs of its own. Procedures for participating in the activities of the organization, giving notice and providing an opportunity for input on others' proposals often harden into inflexible rules whose enforcers have lost sight of their purpose. Due process provides opportunities for participants who fear that a good rule will be averse to their economic interests to slow down the adoption of a new standard. As regulatory organizations develop permanent staffs, the people who are drawn to staff them tend to be process worshipers who care less about whether anything ever gets done than maintaining the strict integrity of the rules.

Understanding why these forces tend to undermine private standard setting requires understanding how open standards affect the self-interests of market participants.[239] As a general matter, buyers benefit from broad standards; they ensure buyers of a wide choice of suppliers whose widespread adherence to standards reduces switching costs when a buyer replaces one supplier with a competitor.

Whether suppliers like standards depends on their market share and their judgment about the objective merits of a standard as compared to the latest technology. A firm that dominates the market, as Motorola did for many years in mobile radio, or as Microsoft does for operating systems, has little

239. *See* Henry H. Perritt, Jr., Digital Communications Law § 8.03-8.04 at 8-6 to 8-11 (2010) (reviewing and explaining economics literature on standards setting).

interest in open standards because that will make life easier for market entrants whose business model is premised on taking market share away from the dominant firm.

Conversely, those with little market share favor standards for the same reason the dominant firm opposes them and for the same reason buyers favor them; it makes it easier to convince a buyer that it should switch it's allegiance from the dominant firm to the new entrants without having to incur large switching costs.

Due process is a good thing. It protects those entitled to it from adverse governmental action. The law has extended the constitutional concept of due process to a variety of private sector activities, ensuring that decisions involving adverse employment action are "fair,"[240] and that standard-setting activities that limit market entry be open to participation by all market participants.[241] Administrative agencies write their regulations through the notice and comment process mandated by the Administrative Procedure Act,[242] which allows them to appreciate the impact of the regulations on affected entities and to have the benefit of technical ideas that may not have occurred to their staffs.

Every requirement to be heard, however, opens up pathways for wrecking crews. Every litigator understands that the litigation process can be used for delay, obstructionism and running up costs as well as for seeking to establish the law and facts. The history of adjudicative procedure before the now abolished Interstate Commerce Commission and Civil Aeronautics Board showed that actors often used their opportunities to be heard under the railroad, motor carrier and airline regulatory statutes to block innovations by their competitors.[243]

That reality animates arguments for deregulation and regulatory reform.

240. *See* Henry H. Perritt, Jr., Employee Dismissal Law and Practice § 10.07 at 10-41 to 10-42 (6th ed. 2017) (analyzing sources of law requiring due process by employers).

241. *See* Henry H. Perritt, Jr., Digital Communications Law § 8.08 at 8-33 to 8-35 (2010) (explaining and analyzing statutory guidelines for standards setting organizations).

242. 5 U.S.C. § 553.

243. "Regulators and regulatees are both wary of technological breakthroughs which topple a well-nurtured, highly-valued regulatory system." Mark Green & Ralph Nader, *Economic Regulation vs. Competition: Uncle Sam the Monopoly Man*, 82 YALE L.J. 871, 881 (1973). *See* Richard W. Palmer & Frank P. DeGiulio, *Terminal Operations and Multimodal Carriage: History and Prognosis*, 64 TUL. L. REV. 281, 291 (1989) (reviewing ICC's 1931 *In re* Container Service decision requiring that new intermodal service charge higher rates).

Too many advocates of private ordering instead of government regulation, however, ignore the fact that the same thing might happen in private decision-making institutions.

C. Mandating Societal Benefit

1. Assuring Universal Service

Universal service is a widely accepted feature of the public telephone system, representing a legal obligation because telephone service providers, including cellphone providers, are common carriers.[244] It rarely has been an issue in broadcasting, because broadcasters have an incentive to reach the broadest audience possible. But universal service can be interpreted at two different levels: it may be an obligation simply not to discriminate; or it may be an obligation to extend a service into an area where it is less profitable, maybe even available only at a loss to the provider. This generally is the case for wired telephone service in rural areas and for the provision of high-speed Internet service in the sparsely populated areas. The second interpretation is a much more aggressive intervention into the market; it involves steering private investment resources.

Universal service under either of these interpretations rarely has been at issue in PMR. PMR is not common carriage; that's what the "private"—represented by the "P"—signifies in the FCC lexicon. In addition, public safety agencies have an obvious and legitimate reason for not allowing the population in general to connect to and participate in their communication systems.

But Firstnet presents a new kind of challenge to the universal service concept. The first universal service question is whether FirstNet must allow any of the thousands of public safety agencies in the United States to connect to it. On the face of the question, one would think that such a requirement exists, but it may not be so obvious if a refusal of interconnection is premised on an argument over compatibility of technologies, or on the reachability of FirstNet in a sparsely populated area with very low public governmental budgets. Then the question would be whether FirstNet has an obligation to relax its technical standardization requirements, and whether it has an

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244. *See generally* FCC, *Universal Service*, https://www.fcc.gov/general/universal-service, (reviewing history and requirements for universal service; discussing extension to broadband wireless data services) (last visited Feb. 15 2019).

obligation to obtain more appropriations to build out its network further.

A related universal service question is whether the scope of FirstNet should include private providers of emergency services, such as hospital emergency rooms and ground and air ambulances. FirstNet evolved without such a mandate, and the result will be that private sector emergency services are locked out of public safety communications systems in a way they have never been locked out of analog radio systems.

A second universal service question involves whether the FirstNet contractor, which almost certainly will have a major CMRS at its core, must allow the general public to use some of its resources, such as cellular transceivers deployed on the new Band 14 frequencies where existing cell coverage may be poor for the public, and where the new FirstNet resources have excess capacity.

2. Protecting Public Security

The risk is that public security will be subjected to new dangers from technology, or that improvements in public security made possible by new technologies will be neglected. Security is of paramount importance to FirstNet, even more than for legacy analog radio systems. If the analog radio repeater or base station went down for a particular law-enforcement agency, the personnel still could communicate directly with either other using their radio hardware. When calls go through a centralized system like FirstNet, and the centralized system goes down because of sabotage or defects in design or management, personnel are isolated. One way to assure resiliency in FirstNet is to require talk-around capability, which is a prominent feature of most FirstNet concepts. That, however, does nothing to harden the core of FirstNet against security threats.

In the first that context, the sources of regulation are not only the authority of the FCC, but also the procurement power of the federal government, exercise by the FirstNet agency within the Department of Commerce. As with any system, the designers of FirstNet should pursue the network security goal in a proportional way; seeking to ensure against every threat, no matter how unlikely or modest in impact, would so impair flexibility as to make it useless; people flock to the Internet for a reason, even though it has long been recognized as theoretically insecure.

The most basic threat is the vulnerability of electric power to interruption. Accordingly, the most basic way to enhance security for FirstNet is to assure adequate back up power supplies and robust control software that brings them into action when they are needed. First, Net should better than the

FAA's air traffic control system[245] and United Airlines.[246] Second, most cyberattacks involve penetration and sabotage at the edge of the Internet and other communications infrastructure: on gateway routers, application servers, and user databases, not the core routers, links between routers, and network access points. Often, as in the FAA Chicago Center attack, the point of greatest vulnerability is physical, involving wire vaults. These are easier to secure against intruders than software running on thousands of decentralized routers. Importantly this kind of security can be provided with little or no compromise of the flexible routing principles that define the Internet.

Network security involves two different kinds of threats: threats to the operation and availability of the network, without regard to its content; and threats to compromise the content, either by eavesdropping on it or corrupting it. Encryption is a straightforward way to protect content; it is widely understood and widely deployed. The US intelligence community's constant efforts prevent robust encryption by private acts is testimony to its resiliency. Threats to the operational integrity of communication networks are harder to protect against.

A public security concern separate from concerns about the security of the network itself is the need to ensure critical public safety communications receive priority in shared communication networks. Such a regulatory mandate was not necessary in a world in which public safety communications occurred in communication networks entirely distinct from the public telephone network, unaffected by congestion or inoperability of the public telephone network. PMR communication, including, not only public safety and governmental emergency response communication, but also other critical infrastructure activity such as that relating to energy distribution, and railroad transportation went on his usual, subject only to flaws in the design of those systems for survivability.

Once in the air link for these communications is absorbed into the public cell network and once the links among cortical nodes in the PMR system are effectuated through the Internet, pressure grows to ensure that both cellular

245. Sean Broderick, *Incident Closes FAA Chicago ATC Center*, AVIATION WEEK & SPACE TECHNOLOGY (Sept. 26, 2014), http://aviationweek.com/commercial-aviation/incident-closes-faa-chicago-atc-center.

246. United *Flights Delayed After Computer G*litch *G*rounds U.S. *Planes*, REUTERS (Jan. 22, 2017), https://www.reuters.com/article/us-ual-flights-idUSKBN15705C (reporting computer problem that forced United Airlines to ground all domestic flights).

telephone providers and the many entities that provide Internet connection services give priority to critical communications.

This is entirely different from New Neutrality; indeed, its goal opposes the goal of Net Neutrality. Net neutrality aims at ensuring that every Internet resource processes IP packets without regard to their content or to the participants in the communication to which they are apart. Critical communication priority, on the other hand, requires that Internet resources to be able to identify packets making up critical communications and to set other packets aside to the extent necessary to provide a clear path for the critical packets.

A foreshadowing of these pressures and of regulator response can be seen in the FCC's statement on replacing SS7 with IP and SIP[247] and in the requirements articulated in the FirstNet RFP.[248] In responding to these pressures, regulators will have to sort out a number of issues. Public telephone service is common carriage, subject to price and non-discrimination requirements. Provision of Internet service is not. Connecting PMR services to the public cellular system is un likely be classified as common carriage, but pressure may build to extend the technological possibility of connection to all those presently served by PMR systems, at least the public safety services, and at least if the absorption of PMR and cellular system shrinks the market for PMR to the extent that non-cellular PMR alternatives become practically unavailable. Extension of common carriage to encompass PMR has various alternative implementations that are technologically feasible; telephone service providers know how to give priority to certain calls

Ensuring priority for PMR calls moving through the Internet is far more challenging. Internet engineers have been talking ever since 1990 about ways to afford critical packets priority as they move through and the Internet routing mesh,[249] such features have largely gone unimplemented.[250] Internet

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247. *See* Section III.E, supra.

248. *See Public Safety First, supra* note 160.

249. Usually for communications needing a real time stream, such as voice communications, music, or video entertainment. *See* Matthew Lasar, Did Internet Founders Actually Anticipate Paid, Prioritized Traffic, WIRED (Sept. 11, 2010), https://www.wired.com/2010/09/paid-prioritized-traffic/ (reviewing history of debate over giving priority to certain packets).

250. IP version 4 enables giving priority to certain communications, based on the value of its type-of-service ("TOS") field. But priority depends on routers being designed and programmed to route based on the TOS value, and few do so. VoIP is an exception; it almost always uses UDP

service providers such as Comcast have deployed priority features in routers to discriminate against disfavored communication; implementation that technology is what initially spawned the New Neutrality movement. It is conceivable that the technological details of Net Neutrality could be flipped on their head and turned into a basis for requiring critical packet priority, but that regulatory vision is speculative in the extreme. Content discrimination, the target of Net Neutrality, mainly involves entertainment broadcasts; the critical packet priority goal mainly involves point-to-point communication among handfuls of governmental entities and critical-infrastructure private sector entities. The political organization for shaping regulation is entirely distinct. APCO and the AAR care little about Net Neutrality. Netflix, Amazon, and Disney care little about critical IP packet priority for public safety emergencies.

Other intended features of FirstNet will require modification of FCC rules for CMRS, but no overhaul of the rules is necessary. For example, the FCC will have to relax the prohibition on mobile cellular systems' communicating directly with each other.[251]

D. Adhering to Tradition

Innovation is disruptive, even destructive.[252] As a result, individuals and institutions embedded in the status-quo often energetically resist even the most obviously desirable innovation with only modest disruptive effect. It took years for the fourteen-shot Glock automatic pistol to replace the six-shot 38 revolver as the standard police weapon in the United States.

Disruption amounting to a revolution, however, can substantially impair the functioning of any institution. Obsoleting skills held by many members of an organization and calling into question long-standing are rules and

rather than TCP precisely because TCP's error correction features are likely to interrupt the real-time stream. Sarath Pillai, Understanding Differentiated Services (TOS) Field in Internet Protocol Header, /ROOT.IN~ (Nov. 20, 2017), https://www.slashroot.in/understanding-differentiated-services-tos-field-internet-protocol-header (explaining priority heading in Internet Packet specification).

251. 47 C.F.R. § 22.923 ("mobile stations communicate with and through base transmitters only").

252. "In the words of Joseph Schumpeter, competition is a 'gale of creative destruction.'" (*Fishman v. Estate of Wirtz*, 807 F.2d 520, 577 (7th Cir. 1986) (Easterbrook, J., dissenting from finding of antitrust liability in leasing of sports arena); Hilton Davis Chemical Co. v. Warner Jenkinson Co., 62 F.3d 1512, 1529 n.1 (Fed. Cir. 1995), citing Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy* (3d ed. 1950), rev'd on other grounds, 520 U.S. 17 (1997).

practices in the question usually results in paralysis.

The risk is that precipitous change from long-standing legal structures, such as categories of activities and entities, rules for participation in the marketplace, technological standards, and business models will create confusion and lead to such high transaction costs that everyone subject to the new regulations have difficulty in complying. An associated risk is that too rapid departure from a customary regulatory content will outrun the confidence of regulatory staffs and those seeking to influence the regulatory steps. Regulatory uncertainty will stifle innovation because investors, cautioned by their lawyers are reluctant to risk capital unless they can predict returns, in light of regulatory restrictions.

E. Respecting Federalism

Federalism and federal preemption rarely are at issue in radio regulation. Almost everyone accepts the proposition that radio emissions inherently involve interstate commerce so federal regulation of radio emissions preempts the filed. Likewise, the Internet's ubiquitous character involves interstate commerce,[253] so federal policy that cable television and the Internet should be largely unregulated displace state or local regulation under the dormant Commerce Clause doctrine.

It is unlikely that anyone would seriously challenge the FCC's power to regulate the radio access network, post-adoption as well as pre-adoption. Firstnet inserts the federal government more deeply into state and local policing. While the governmental/proprietary distinction has faded as an instrument for defining the boundaries of the Commerce Clause for federal regulation of state and local employment,[254] it remains useful conceptually; indeed it shapes the scope of federal aviation preemption according to whether the activity being regulated involves matters of traditional state or

253. *See* Granholm v. Heald, 544 U.S. 460, 473-475 (2005) (invalidating Michigan and New York restrictions on out of state wine shipments directly to residents).

254. *See National League of Cities v. Usery*, 426 U.S. 833, 844-845 (1976) (distinguishing between state activities close to the core of sovereignty and commercial state activities, in finding minimum wage regulation of state agencies unconstitutional), overruled, *Garcia v. San Antonio Metro. Transit Auth*, 469 U.S. 528, 541-542 (1985) (noting unworkability of proprietary-governmental distinction).

local concern.[255] Firstnet's clear goal of having every state and municipal police department, fire department, and ambulance service in the country tied into the same communications network sets up a conflict over federalism that has not been present in PMR before.

Presently, the Firstnet statute and the program adopted under it have avoided conflict by making connection to Firstnet voluntary and by providing financial inducements rather than mandates to effect broad connectivity. If that should change, some states and municipalities almost certainly will argue that the federal government lacks the power to force their public safety services to communicate in any particular way. That would be a strong argument.

On the other hand, no doubt exists about a state's power to compel its own municipalities to connect to state resources. The municipalities are creatures of the state and the state may shape state-local relations however it wants, consistent with the state constitution.

States may be pre-conditioned, however, to accept substantially more federal involvement in defining their communications activities that they would have before 2011. The Department of Homeland Security has shoveled enormous amounts of money out to states and municipalities for upgraded systems of all kinds, including radio communications systems, and much of the largesse has been conditioned on detailed specifications. State and local public safety agencies have rushed to get the money and have rarely complained about having to adhere to federal specifications in order to get it.

255. *See* Henry H. Perritt, Jr. and Albert J. Plawinski, *One Centimeter Over My Back Yard: Where Does Federal Preemption of State Drone Regulation Start*, 17 N.C. L.J. & TECH. 307, 353 (2015) (synthesizing criteria for federal preemption of local regulation and identifying matters of traditional state concern as less likely to be preempted).