THE RADIO REVOLUTION

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FOREWORD

The Center for Information Strategy and Policy is pleased to publish this essay on *The Radio Revolution,* the first of a series of related monographs on the four key revolutions in communications between the invention of the printing press and the current Information Revolution, however imprecisely defined. Subsequent essays in the series will cover the telephone, telegraph, and television. Individually these inventions stemmed from different roots and had diverse, wide-ranging effects. In combination with the computer, however, these four revolutions together laid the foundation for the present revolution in information and communications technologies that are, in turn, reshaping how human societies function..

The series was frankly motivated by my speculation that there is an intriguing symmetry to these four revolutions. Two of these innovations in communications capabilities—the telegraph and the radio—had truly revolutionary impacts in the military domain as direct two-way communications mediums; but the radio's principal impact on civilian society came through broadcasting, an application not intended by Marconi.* The two other innovations—the telephone and television—seem to have had relatively less dramatic effects on the military but were fundamental in reshaping civilian life as we know it. However, in both cases for the military, the instrument itself became an important component and enabler of larger integrated systems and processes that would not have been possible without the ability to transmit voice and pictures in real time. Recognizing the causes of these differences in impact and implication could provide a significant source of understanding as we attempt to forecast how the new revolution will reshape our societies and our lives. In particular, the degree of impact on and acceptance in the respective military and civilian domains of each of these innovations appears to be a strong function not of technology but of culture; in each case, the course of adoption was greatly affected by cultural norms and predispositions that, in turn, created demands on how the technology needed to be packaged and adapted.

* Indeed, one of the ironies is that the telephone was intended as a broadcasting vehicle, rather than as a point-to-point communications tool, while the radio was developed primarily as a means to communicate with mobile ships.

This series has a number of objectives. First, the individual papers will explore these revolutions in order to illuminate and understand the specific sources and particular impacts of each innovation in the civilian domain, as well as on the military. These four cases point towards the difficulties of forecasting how technologies will develop and what impacts they may have, whatever their inventors' intentions. *The Radio Revolution* recounts how broadcasting became the dominant application for radio in spite of its inventor's intentions. Second, the series will try to discern whether there are more general lessons in these earlier revolutions that may enable us to better understand the course that revolutionary technologies may take. As this essay on the radio highlights, the course of innovation and its ultimate exploitation and adoption by society is affected by far more than the kernel of technological invention; regulation, commercial equities, culture, and human emotions such as pride all may have as much to do with the ultimate form of an innovation's application as the intention of its inventor. Third, as a whole, the series will try to understand how and why each community—civilian and military—exploited and applied these technologies in the way it did, and from this understanding, to explore the nature of these differences and implications for the revolution now at hand.

If lessons from these previous communications revolutions are relevant to the one that is ongoing, we may better be able to understand and appreciate the intimate linkages between culture and technology, between the ways that people use things and how technical innovations develop, and between technical progress and societal adaptation.

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EXECUTIVE SUMMARY

"The Radio Revolution" examines the story of the invention and progressive adoption of the radio, studying it as a proxy for the momentous advances in information technology of the present day. If we accept that successive advances in information technology can be part of the same process of technological change and thus share important characteristics, then the value of studying this earlier revolution becomes obvious: we can examine the radio revolution with a hindsight, a perspective, and an objectivity that are impossible to attain in the case of the present information revolution. We can examine a revolution that appears to have run its course, instead of one whose course we can barely yet even predict. The process of identifying and understanding the important determinants of the radio's particular course will aid us in recognizing the directions that the latest revolution in information technology might take.

The paper's first section examines the radio from a historical perspective, studying the first fifty years of the invention's development and highlighting the succession of different incarnations and applications through which it progressed. The radio's eventual uses, such as broadcasting and close coordination of military action, were not at all apparent at its invention. Studying the story of their gradual discovery and implementation raises a number of important points, including the surprising impact of individual personalities and accidents of history on the course that an invention follows; the advantages and disadvantages of different responses to new technology, notably rapid adoption versus "wait and see"; the catastrophic potential consequences of the ineffective use of a new technology; and finally, the unique economics of broadcasting. The historical section of the paper also draws attention to a number of instances of remarkable similarity between the radio revolution and the information revolution of the present day.

The second section of the paper looks more closely at the effects of the radio. It distinguishes between the civilian and military spheres, and erects a framework to categorize radio's consequences, dividing them into first-order (substitution), second-order (intensification), and third-order (transformation) effects. This framework shows a gradual progression in the use of the new technology, from superficial substitutions, through more effective and widespread use, to profound

changes in the structure of society. By cataloguing effects in areas as diverse and basic as language, group membership, economic structure, and political debate, this section illustrates the fundamental level at which technological change takes effect, and how it can reverberate through a society. This section's use of a broader analytical framework to classify the effects of radio has a second important implication as well. By suggesting that the effects of different technological changes can be classified using the same analytical structure, this section implies that the effects of an innovation can at some level be predicted. It is important to realize, however, that prediction is possible only at the level of process, and not at the level of specifics. We can dependably expect the current information revolution to have first-order, second-order, and third-order effects, but we cannot predict what those effects will be. Nevertheless, an improved understanding of the process of technological change is valuable in its own right.

The paper closes with a review of its conclusions and a number of suggested directions for future enquiry. A paper of this length can only scratch the surface of so expansive and multifaceted a subject, so that ample opportunities for further research exist. These include studying the process through which national militaries adopted the radio, the uses to which they put it, and the appropriate role for government in information technology. Contributions in these subject areas could all provide valuable context for better appreciating how the current technological revolution might unfold.

INTRODUCTION

The radio is the communications technology that defined the first half of our century. Indeed, in concert with its daughter the television and granddaughter the computer,[1] it has defined our age. No invention since the printing press has had a comparable effect on the perceptions of ordinary people: about their community, about their country, about their world. During the course of the century, almost every facet of life has changed because of the radio—who today can imagine commerce without ubiquitous, hard-sell advertising? Or the military without mobile communications? Or politics without any means other than the written word for a politician to communicate directly with a large constituency? These concrete changes in the ways we behave and organize our society are of profound importance individually, and together constitute a revolution. As we stand today at the brink of another information revolution, we would do well to examine a previous one in order to understand better how such phenomena unfold and to prepare ourselves more effectively for the changes we are likely to face in our own lifetimes.

To encourage such understanding and preparation, this paper analyzes the radio revolution from two perspectives, examining both the process of revolution and its impact after the fact. Accordingly, the body of the paper is divided into two parts. The first is organized historically, examining four major stages in the radio's development between its invention in 1894 and 1945, when television began to displace the radio as the cutting edge of communication. The reader can draw two important lessons from Part One. The first is that the radio went through a long

[1]By way of the transistor; see Irwin Lebow, *Information Highways and Byways: From the Telegraph to the 21st Century* (New York: IEEE Press, 1995), p. 65.

process of evolution after its invention so that its eventual applications were not only different from those predicted at its debut, but beyond the wildest dreams of its early proponents. The second lesson is that the impact of the radio was by no means felt all at once—it occurred in stages, the timing of which depended on other technological developments, and on the political and social environment as well.

Part Two is organized thematically, looking back at the first fifty years of radio and assessing the invention's consequences for different spheres of human activity. It examines in turn the military and civilian worlds and plots radio's impact, distinguishing its first-order, second-order, and third-order effects.[2] This classification scheme captures well the incremental nature of the radio revolution.

The paper concludes with a final discussion of the themes that recur throughout the story of the radio: the relationship between the radio's technical strengths and weaknesses and its eventual uses; the discontinuous nature of technological change; the difficulty of predicting the path a new technology will take; and finally, the parallels between the revolution at the beginning of this century and the revolution at the end of it. A paper of this length, however, cannot hope to exhaust a subject as vast as the development and impact of the radio, and accordingly it closes with suggestions for further research.

[2]This system is based on Thomas Malone's tripartite taxonomy of the effects of technological change, described in Thomas W. Malone and John F. Rockart, "Computers, Networks and the Corporation," *Scientific American* 265, no. 3 (September 1991): pp. 128–136, and discussed in detail in the "Impact" section below.

PART ONE – HISTORY

A. 1894 TO 1914 — INVENTION AND EARLY APPLICATIONS

We date the invention of the radio from the experiments of a young Italian named Guglielmo Marconi in 1894. However, it is important to note that Marconi was by no means the sole contributor to the new science.[3] His experiments were based on James Clerk Maxwell's prediction in 1873 that an electric current sent back and forth through a wire very quickly would produce electromagnetic waves radiating at the speed of light; Heinrich Hertz's discovery of these waves in 1885; and Sir William Crookes' realization that these waves could be used for communication.[4] Marconi's immense contribution was to make the device work. A talented entrepreneur as well as an inventor, Marconi ceaselessly promoted his invention; and when the Italian Ministry of Posts and Telegraphs showed no interest in it, he took it to the British Post Office instead, reasoning that the greatest maritime power in the world would surely see the value of a device to communicate with ships.

His first major sponsor was William Preece, the Post Office's chief engineer, who supported Marconi's early experiments to increase the range of the device but became angry when the young Italian formed a private company to promote his invention instead of simply giving it to the Post Office.[5] The resulting feud lasted for years, preventing the Post Office from buying Marconi's equipment, and pushing Marconi into the arms of the British Admiralty for support instead. Marconi's trials continued with the Admiralty's sponsorship; and he began to push his invention

[3]Daniel R. Headrick, *The Invisible Weapon: Telecommunications and International Politics, 1851–1945* (Oxford: Oxford University Press, 1991), p.117.
[4]Lebow, op. cit., pp. 70–71.
[5]Headrick, op. cit., p. 117.

into the public eye with publicity stunts such as installing a wireless in the Royal Yacht, and reporting the results of the America's Cup race of 1899 for the New York Herald.[6]

The Royal Navy first tested Marconi's radio sets on maneuver in 1899, and the results were so impressive that the British War Office ordered a few sets for the Boer War. While these sets did not function well on land because of South Africa's severe storms and their own bulk, they proved invaluable after the army gave them to a naval squadron in the area.[7] Based on that success, the Royal Navy ordered 32 sets in July 1900, a further 50 in 1901, and many more for years after that, equipping all of its ships and making Marconi its sole supplier for wireless equipment despite the many competing firms that sprang up.[8] The Italian navy also purchased Marconi's sets, and the German navy supported the development of its own version of the wireless. The French, on the other hand, did little to adopt the new invention; and the United States reacted ambivalently. While the U.S. Navy did begin buying sets in 1902, it did not use them to coordinate operations until 1907, and did not adopt them comprehensively until 1912.[9] The U.S. Navy's mixed feelings about the radio stemmed from a conflict between the need for central coordination of the fleet and the individual captain's desire for freedom of action.[10] The U.S. took much longer to resolve this contest of values than did the Royal Navy or others, and suffered for it by only developing radio doctrine ten years later. Conversely, however, it also benefited by being able to equip its shore stations with newer and more reliable continuous wave transmitters instead of the older spark sets that were initially the only kind of radio available.[11]

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[6]Lebow, op. cit., p. 68.
[7]Richard Norman Vyvyan, *Wireless Over Thirty Years* (London: G. Routledge & Sons, 1992), p. 109; Headrick, op. cit., p. 118.
[8]Headrick, op. cit., p. 118.
[9]Ibid., pp. 124–127.
[10]Lebow, op. cit., pp. 81–82.
[11]Headrick, op. cit., p. 127.

Besides pursuing naval contracts for his wireless sets, Marconi also wooed commercial shipping and passenger lines with great success. In 1900 he founded Marconi's International Marine Communication Company (its name a clear indication of Marconi's thoughts about his invention's most useful application[12]), which entered contracts with many of the largest shipping lines and Lloyd's of London, the marine insurance giant. Marconi's sold wireless service to its shipping customers, rather than wireless sets. This kept the customers' start-up costs low and ensured the proficiency of the operators, who were trained and employed by Marconi's; but it also meant that Marconi's controlled the network.[13] Marconi's took advantage of this market power by instituting a policy of non-interconnection, putting great pressure on shipping lines to deal only with it since it had the largest network of ship and shore stations, and it carried Lloyd's worldwide marine intelligence network as well.[14] Marconi in effect created a self-contained network where none need have existed (since without a non-interconnection policy the radio sets of different manufacturers could communicate very easily with one another) and used the resulting increasing returns to scale to gain monopolistic power.[15]

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[12]Lebow, op. cit., p. 73.
[13]Ibid., p. 79.
[14]Headrick, op. cit., p. 119.
[15]The modern idea of increasing returns to scale comes from the work of W. Brian Arthur, and its applicability to network-based industries is described in "Increasing Returns and the New World of Business," *Harvard Business Review*, July–August 1996, p. 103. Arthur argues that the high-technology industries that are beginning to dominate the modern economy exhibit increasing returns to scale (where increasing production generates higher profits per unit, so that initial growth facilitates more growth and market domination), in contrast to the traditional idea in economics of decreasing returns to scale (where increasing production earns lower profits per unit, and growth becomes increasingly difficult at larger sizes). Marconi's business strategy aimed, a hundred years ago, to take advantage of this precise effect by restricting the benefits of being able to communicate with those on Marconi's network—ships, shore stations, information resources (Lloyd's)—to those who were also on Marconi's network. As a result, the installed base of Marconi transmitters grew tremendously. Comparisons with large software companies and the computer operating system market would not be inappropriate, except that network effects are intrinsic to operating systems unless effort is made to avoid them, whereas in the case of marine communication network effects had to be consciously created—this was possible because of the absence of regulatory regimes and anti-trust controls. See also "The More You Sell, the More You Sell" (an interview with Brian Arthur), *Wired*, October 1995, pp. 132–133, 188.

Marconi's monopoly of wireless service was successful enough that it began to antagonize foreign governments and even some groups in Britain, including his old nemesis the Post Office. International conferences ensued in 1903 and 1906 to discuss interconnection, and also to agree on allocation of the spectrum to avoid interference since the growing number of stations in many countries was starting to cause problems. Radio waves cannot be programmed to die out when they reach international boundaries, and multiple transmissions over the same frequency disrupt one another. Therefore, for any country to use radio profitably and dependably, some sort of international cooperation is necessary to minimize overlapping use of the same frequencies.[16] On the interconnection issue, the British government successfully defended Marconi at the first conference, but at the second one relented in return for international acceptance of commercial service at low (long-wave) frequencies. It thus accepted a weakening of Marconi's position in order to ensure that his right to operate at all was protected from the many nations (the United States included) who advocated reserving the long-wave portion of the spectrum for government monopolies.[17] Despite this blow, Marconi's remained by far the most powerful force in marine communication.

Such dominance was not, however, the limit of Marconi's dreams. He had continued his efforts to extend the range of his equipment, and in 1901 he surmounted a hurdle larger than most by successfully signaling across the Atlantic. His stated ambition was to challenge the monopoly of the cable companies on trans-Atlantic communication; and, after a few more years of experimenting, this he was able to do. Commercial service started between Glace Bay, Nova Scotia and Clifden, Ireland in 1907. Although service was at first weak and undependable, Marconi built ever-more-powerful stations, using ever-lower frequencies, and was able to

[16]Lebow, op. cit., pp. 82–83. The omnidirectional spread of radio waves also creates a potential for problems within countries, forcing governments to devise domestic frequency allocation schemes.
[17]Headrick, op. cit., pp. 120–121.

offer around-the-clock trans-Atlantic service by 1912.[18] Germany, France, and the United States followed Marconi and began work on their own worldwide wireless networks to link up their colonies and commercial partners as well as to develop an international communication option that, unlike cables, was neither owned by Britain nor hostage to the cable-cutting ability of the Royal Navy.[19] Each country built its own global network of long-wave stations, happily accepting the immense antenna size, power requirements, and costs that long-wave transmission required. Britain also worked on a global Imperial Wireless Network, but without the same sense of urgency as the other powers, partly because of political pettiness on the part of those making communications policy, and partly because Britain already controlled the cables. Therefore, British policy-makers looked upon wireless as a supplement to the telegraph rather than as a replacement.[20]

By the beginning of the First World War, the radio had been in existence for twenty years and had thoroughly penetrated a number of fields, especially shipping, where all ships of any consequence carried sets, and international communication, where many nations relied on radio for dependable links with the rest of the world. However, the truly revolutionary use of the new technology, through broadcasting, had not yet arisen. The early applications of radio were all point-to-point—the technology was used only for communication between limited numbers of participants (usually two) to exchange information in both directions. At that point the radio could only be used with Morse code, and served as an extension of, or replacement for, the telegraph. Furthermore, the first important applications of

[18]Ibid., p. 130. Note that early radio transmission was dependent on the time of day because of the differing characteristics of different layers of the ionosphere. The D layer, closest to earth, appears during the day because of the ionizing effects of the sun's energy on atmospheric gases. When present, it absorbs radio waves, preventing them from reaching the E and F layers, which reflect radio signals and are useful for long-distance transmission by serving as a kind of mirror over the horizon. Furthermore, radio signals can also be affected by the water contained in the atmosphere, making transmission dependent on weather as well. See *Encyclopaedia Britannica*, 15th ed., s.v. "broadcasting."
[19]Headrick, op. cit., pp. 128–130.
[20]Ibid., pp. 131–133.

radio were military and strategic as much as commercial—a very different situation from that of the telephone or even the telegraph. The wide variety of reasons behind the course of the radio's development over these first few years are instructive, for they indicate the diversity of influences dictating the course of a technological revolution.

First of all, it should come as no surprise that a new invention was used to meet an existing need before it began creating new needs. When radio made communication with ships possible, it bridged the gap between two of the most important technologies then existent: the steamship and the telegraph.[21] It therefore made up for an obvious inadequacy of technology up to that point: it extended telegraphy to places that wires could not reach,[22] thereby meeting needs already created by the second- and third-order effects of the telegraph, which caused people to communicate more, and eventually to construct a society more dependent on communication.[23] Marconi himself saw wireless exclusively as an extension of the telegraph, failing to make the leap of imagination necessary to see it in any other light.[24] In his Nobel lecture of 1909, he discussed current and future uses for his invention. He listed communication with warships and ocean liners, outlying islands, towns and villages in colonial and developing countries, and even, "leaving the regions of fact, and entering the regions of speculation," contact between distant lands at opposite ends of the globe. He never, however, departed from the point-to-point paradigm that had governed radio up to that point.[25]

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[21]Susan J. Douglas, *Inventing American Broadcasting: 1899–1922* (Baltimore: Johns Hopkins University Press, 1987), p. 9; Lebow, op. cit., p. 79. The first successful trans-Atlantic telegraph cable was completed in 1866.
[22]Wilbur Schramm, *The Story of Human Communication: Cave Painting to Microchip* (New York: Harper & Row, 1988), p. 207.
[23]Please see the "Impact" section below for a much fuller explication of Malone's taxonomy, to which this statement refers.
[24]Douglas, op. cit., p. 40; Lebow, op. cit., p. 68. Indeed, "wireless" was short for "wireless telegraph."
[25]Marconi, Guglielmo, "Wireless Telegraphic Communication," in George Shiers, ed., *The Development of Wireless to 1920* (New York: Arno Press, 1977).

Second, early radio was constrained by its own comparatively primitive state of technological development. Although voice transmission was demonstrated experimentally in 1906 by Reginald Fessenden, it did not become practical until 1915 when AT&T transmitted voice from Arlington, Virginia to the Eiffel Tower in Paris.[26] It is difficult to judge the importance of the lack of voice communication in restricting radio to telegraph-like applications, however. On the one hand, it is clearly easiest to use a new invention within its existing capabilities; in fact one of radio's most important customers, the military, may have been quite comfortable with a telegraph-like radio because of such a device's by-product of written messages, and the military's experience with tools requiring specialist operators. On the other hand, though, wireless voice communication was far from inconceivable, given the existence of the telephone and the efforts of Fessenden and Lee DeForest to transmit voice; and yet we do not even see predictions of uses of a non-point-to-point character.

Also in need of explanation is the military character of the radio's first years. A number of elements explain this, the first and most curious of which must be termed an accident of history: the clash of personalities between Marconi and William Preece of the British Post Office. This disagreement and the feud that ensued caused Marconi to work more closely with the Admiralty on naval applications for his invention; the feud also provoked such long-standing antipathy in the Post Office toward the wireless and its creator that it refused to deal with him for years afterwards. The second, related, element encouraging military development of the radio was a legal constraint: the Post Office had a monopoly on internal communications, forcing Marconi to look farther afield for applications for his invention. This constraint not only led to naval use, but also to commercial ship-to-shore service and international radiotelegraphy. Finally, the rapid military

[26]Schramm, op. cit., pp. 207, 219.

use of the radio was encouraged by an environmental factor: the turbulent politics of the world into which the radio was born. The 1890s were an era of increasing tension as the long-standing European political order began to fray. In the words of one author, where the telegraph was invented in a peaceful time and thus thought to be peaceful by nature, the radio "was born into an age of jittery jingoism and started life as a weapon in the commercial and military rivalries of the great powers. Thus do humans unfairly project their own virtues and vices upon the machines they create."[27]

Radio's use for international communication soon after its discovery is a third occurrence that bears explanation. First, as discussed above, the Post Office's monopoly on internal communication encouraged Marconi to look towards international communication. Second, although international communication was easily accomplished by cable and thus not an unmet need in the same sense as maritime communication, cables were still far from satisfactory from the point of view of many countries. This was because international telegraph cables were for the most part owned by Britain: only Britain had the surplus capital, the industrial sophistication, and the naval and maritime might to undertake an enterprise as expensive, difficult, and risky as laying intercontinental cables. Even those few cables not laid or controlled by Britain were nonetheless vulnerable to the cable-cutting ability of the Royal Navy. In the atmosphere of international competition and suspicion of the first part of this century, other nations leapt at the chance to build their own communication networks, so as to tie together their own empires without external influence and to ensure communication in the event of war.[28] Political circumstances therefore once again dictated the course and timing of the new invention's development.

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[27]Headrick, op. cit., p. 116.
[28]Ibid., pp. 128–130.

B. 1914 TO 1918 — THE GREAT WAR AND USE IN BATTLE

Radio was still in its adolescence when the First World War began, and while it played a significant role, it was far from pivotal. In fact, as will be seen below, many of the most important examples of radio use in the war were negative, characterized by a failure to use the device effectively and an ignorance of its full range of consequences.

The radio's first obvious application in World War I was to permit continued international communication by the Central Powers after the Royal Navy cut their telegraph cables. This was a mixed blessing for the countries concerned, however, because when carried by radio, their communications were vulnerable to detection and decryption. In any case, radio turned out to be much less dependable than had been hoped because, just as foreign cables were vulnerable to cable-cutting by the Royal Navy, foreign radio stations were vulnerable to British landing parties. Most of Germany's global radio network lasted only weeks after the outbreak of hostilities (admittedly an improvement over its cable network, which lasted four hours) so that by 1915 its overseas communications were limited to two radio links with the United States, both subject to American restrictions on encryption.[29] To send coded messages it had to route them through a cooperative neutral country (frequently Sweden) to disguise their origins and then send them over British lines, where they were vulnerable to decryption.[30]

The most significant military use of the radio in the First World War was in naval warfare. It allowed naval headquarters to directly control fleets at sea, and it allowed individual ships to communicate with one another to share information and coordinate action locally. Furthermore, through radio direction-finding—a process of triangulation to determine the source of a radio transmission—it allowed

[29]Ibid., pp. 140–143.
[30]Ibid., p. 168.

combatants to learn a substantial amount about the location of their enemies. The use of radio in these capacities during the war had a number of successes and failures, the latter generally resulting from an unfamiliarity with the new device.

Radio was necessary for the German U-boat campaign against allied shipping, in which German naval headquarters used it to communicate the expected routes of targets. It also, through decryption and direction-finding, allowed the British fleet to find the German fleet in mid-1916, and engage them at the Battle of Jutland.[31] On the other hand, perhaps because of naval conservatism, radio was used very poorly after Jutland began, for the British Admiralty, despite decrypting most of the German messages almost immediately, often did not send them out to Admirals Jellicoe and Beatty at Jutland, who in turn often did not act on the messages they did receive.[32] The limits to radio's effectiveness at sea in the First World War were highlighted by the Battle of Coronel in November 1914. Cape Horn was well beyond the range of the British Admiralty's radio transmitters, so communications traveled from London by cable to a friendly local station, where they were then sent on by radio. The entire process often took several days to complete a two-way exchange of messages, but nevertheless the Admiralty tried to control events from London. In combination with lax radio security, which allowed a superior German force to find the British South Atlantic fleet, this mistake resulted in the worst naval defeat Britain had suffered in over a century.[33]

Radio was also used in land warfare in the First World War, but with even more dubious results. In theory radio should have been very useful because it allowed lateral communication, was more robust than cables (which were frequently severed by shelling), and was mobile, and thus useful during attacks. In practice, however, the radio sets of the time presented many technical problems. They were too bulky

[31]Vyvyan, op. cit., p. 127.
[32]Headrick, op. cit., pp. 163–165.
[33]Ibid., pp. 161–162.

to be truly portable; they had to be carried between two soldiers who became obvious targets.[34] Furthermore, spark transmitter sets caused interference, drastically limiting the number of sets that could be used along a single front. Finally, First World War sets could only be used with Morse code, requiring operators with specialized knowledge. The portability and interference problems were largely solved by 1918 when smaller sets using thermionic valves were introduced, but voice-transmitting sets that could be used by ordinary soldiers were not deployed on land before the end of the war.[35]

In addition to these technical problems, radios on land were as vulnerable to the techniques of communications intelligence—direction-finding, interception and decryption—as their seaborne equivalents; and on the German side, they faced the additional problem of jamming from the Eiffel Tower. Communications intelligence was especially useful in trench warfare because the battlefield changed so slowly—information remained valuable long enough after it was collected for it to be sent through the decryption and dissemination process.[36] Even without decryption, much intelligence about force dispositions and planned maneuvers could be gained from careful observation of levels of radio traffic, call-signals, and location of transmitters.[37] As was the case at sea, one of radio's most important effects on land was its contribution to the loss of a battle. The Russian army before the Battle of Tannenberg decided to broadcast its attack orders in plain language to save time. The result, after German interception, was a disaster for Russia that set it on the path to military collapse and, arguably, eventual revolution.[38]

Because of all of radio's drawbacks, the telegraph was used whenever possible in the First World War. However, radio was still very valuable for use near the front

[34]Vyvyan, op. cit., p. 116.
[35]Ibid., pp. 112–117.
[36]Ibid., p. 113.
[37]Headrick, op. cit., p. 156.
[38]Ibid., pp. 155-6; Vyvyan, op. cit., p. 118.

line, where cables had a limited lifespan because of shelling. The Germans actually relied more on radio than did the Allies for the simple reason that at the beginning of the war they had pushed the Allies back into territory with undamaged telegraph networks, while they themselves had to occupy land where the cables had been destroyed by earlier fighting.[39]

One application for which the radio was critical in the First World War was air warfare. Besides radio, no other means existed to communicate effectively between air and ground so that, once the potential utility of planes was recognized, great efforts were made to solve the technical communications problems that presented themselves. These problems were similar to those affecting ground warfare: the sets were too large and heavy for use in planes; the primitive transmission technology caused interference; and the lack of voice-transmission capability (radio-telephony) forced pilots to learn Morse code to use their wireless sets. In contrast to ground warfare, however, efforts to solve these problems met with fair success in the case of planes, partly because the greater carrying capacity of planes did not require as radical miniaturization. Also, it was perhaps easier to synthesize two new technologies than to integrate a new one with an old one. In any case, sets were made small enough for airborne use quite rapidly, continuous wave transmission (reducing interference and increasing range) was introduced in 1916, and radio-telephones were introduced in 1918.[40] Radio-equipped planes were most useful for reconnaissance and especially artillery-spotting, in which an artillery officer observed the battlefield and called in targets and corrections from the air, allowing more accurate and rapid artillery strikes.[41]

It appears, then, that radio's use in the First World War, while important, did not represent the revolution that some had expected—or that was to come twenty

[39]Headrick, op. cit., p. 155.
[40]Vyvyan, op. cit., pp. 134–139.
[41]Headrick, op. cit., p. 156; Vyvyan, op. cit., pp. 132–134.

years later. Early radio was prevented from playing a more useful role in the war by its own technical deficiencies such as interference, lack of radio-telephony, and bulky size,[42] and also by a lack of understanding of its strategic implications.[43] It was this lack of understanding that caused some of radio's most prominent appearances in the Great War to be negative in character. However, the First World War was nevertheless very important in the history of radio because it provided an opportunity for radio's technical flaws and strategic consequences to be examined in the light of battle, and either protected against or taken advantage of in time for the Second World War.

The First World War greatly accelerated the pace of technological development in the radio field for two reasons. First, the pressure of wartime necessity created added incentives for innovation. Second, one of the principal factors delaying the introduction of new products before the war—scattered patent ownership—was obviated for the course of the war by the drastic action of the United States Navy. The Navy assumed the right to order radio equipment using any existent technology from any manufacturer capable of making it, and took on liability for all patents infringed in the process.[44] For the first time, all of the many refinements of the radio that had built on Marconi's work, and whose patents had been held separately by squabbling inventors and corporations, could be built into the same equipment. The most important combination of technologies was as follows: (1) the Audion or triode (which soon became the vacuum tube), invented in 1912 by Lee De

[42]Lebow, op. cit., p. 88.
[43]Headrick, op. cit., p. 163.
[44]Lebow, op. cit., p. 85. Traditionally, the dissemination of a new invention is delayed for several years to provide a financial incentive for technological development in the form of a temporary monopoly. In the case of the radio, however, the U.S. Navy decided that during wartime the costs to society of preventing such dissemination were too high to justify abiding by the patent restrictions. It bears noting that governments face similar dilemmas in the case of many other developments, for instance new life-saving drugs developed by the pharmaceutical industry. In any individual instance the balance of arguments may seem in favor of disseminating an invention. However, when the issue is considered on a broader scale, it becomes apparent that such magnanimity would have the eventual effect of stifling inventiveness by removing the economic incentives driving it.

Forest and used for signal amplification, the rights to which were owned by AT&T;[45] and (2) the diode, on which the triode depended, invented by James Fleming and owned by American Marconi.[46] The combination of these two inventions, along with the voice transmission that they made practical, and the progressive miniaturization of the war years, was an earthshaking outcome of the war, for together these technologies laid the technical groundwork for one of the most important developments of our age: broadcasting.

C. 1918 TO 1939 — RADIO CHANGES EVERYTHING

The period between the world wars saw two significant developments in radio: refinement of point-to-point transmission technology and the entirely new application of broadcasting. The technical innovations that led to these developments continued in part because active efforts to combine dispersed patents continued as well. Concerned about scattered patent ownership and the risks of leaving the rights to strategic technologies in foreign hands, the U.S. Navy, though giving up its own control, persuaded General Electric to purchase the Marconi Company's American subsidiary.[47] It convinced GE of the wisdom of such an arrangement by offering to surrender its own patents to the new entity free of charge; and it convinced American Marconi by otherwise refusing to return the Marconi shore stations that it had taken over during the war, making Marconi's ship-to-shore service close to useless. Out of this arranged marriage which "played fast and loose with the nation's antitrust laws"[48] came the Radio Corporation of America, a subsidiary of GE. RCA and GE then entered an agreement with AT&T in 1919 to share the vacuum tube-related patents so that each could act as a

[45]Douglas, op. cit., p. 243.
[46]Lebow, op. cit., pp. 86–87.
[47]Ibid., p. 97.
[48]Ibid., p. 98.

monopolistic supplier in its chosen business: RCA in transoceanic telegraphy and ship-to-shore communication; AT&T in radio telephony and the manufacture of wireless telephones; and GE in the manufacture of radio receivers. It bears noting that none of these companies considered the possibility of radio broadcasting, even on the very eve of its invention.[49]

The conclusive resolution of the patent problems which had dogged radio for years set the scene for continued progress. This progress could be seen not only in broadcasting, which will be discussed below, and in innovative uses of point-to-point radio such as a crude navigation system (a precursor to the global positioning system) in which direction-finding by many ground stations was used to inform pilots of their location,[50] but also in one last but important technological development: short-wave radio. Once the potential of short waves was exploited commercially after 1924, radio rivaled or surpassed cables by all measures except security. Indeed, radio was the sole carrier for intercontinental telephony until 1956, when the first trans-Atlantic voice cable was laid.[51]

Among the critical ingredients in the increasing hegemony of radio, short-wave transmission deserves further attention. Ever since Marconi's first trial-and-error attempts at increasing the range of his radio sets, radio experimenters had noticed that, while low-power short waves could be received at very short distances, longer waves and greater power were required to transmit over longer distances.

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[49]Ibid., p. 99. It is even more astounding that the radio was not perceived as a potential broadcast medium when it is considered that even the telephone was seen by some as such. A few cities saw the development of complete telephone broadcasting systems in the 1890s, most notably Budapest, Hungary. However, aside from these limited examples, the telephone remained a point-to-point medium. See Sivowitch, Elliot N., "A Technological Survey of Broadcasting's 'Pre-History,' 1876–1920," in Shiers, op. cit.

[50]Vyvyan, op. cit., p. 161.

[51]Bryan Bunch and Alexander Hellemans, *The Timetables of Technology* (New York: Simon and Schuster, 1993), p. 386. Voice radio was particularly vulnerable to intercept, however. Despite the existence of real-time voice scramblers, in the opinion of Winston Churchill the only certain way to ensure security during a radiotelephone call was "first to telegraph in cypher [*sic*] a memorandum in short numbered paragraphs, and then to conduct the conversation by reference to those paragraphs." (Quoted in Headrick, op. cit., p. 228.)

According to this logic, to transmit across truly vast distances such as from one side of the Atlantic to the other, very long wavelengths were required, necessitating exceptionally large, powerful stations. These stations were correspondingly expensive, costing as much as £500,000 to build,[52] and they kept the cost of transmitting by radio roughly equal to that of transmitting by cable, despite the immense costs of cable-laying. What these early scientists did not realize was that, while long waves traveled long distances by following the contours of the earth as a ground-wave, short waves could also travel long distances, but by reflecting off the upper layers of the ionosphere as a sky-wave. However, sky-waves are only detectable within sight of the transmitter or over sufficient distance to allow the waves to reach the ionosphere and then return to earth by reflection.[53] Over medium distances they are useless, so that as progressively more distant transmissions were attempted, short-wave was abandoned before its long-distance properties could be observed.

The usefulness of short waves was only discovered when amateur radio enthusiasts, who had been confined to the short-wave part of the radio spectrum in order to keep the valuable long-wave portion clear for military and commercial traffic, discovered that they could send and receive intercontinental messages with their tiny, low-power, home-built sets, even though they could not contact neighboring towns.[54] Only then did the radio companies realize the mistake they had made by constantly striving for greater and greater power with long waves, which not only required immense antennas, but gave very narrow bandwidth, meaning they transmitted comparatively little information per unit of time. Marconi himself greatly regretted this error and the expense it caused, reflecting, "I

[52]Headrick, op. cit., p. 204.
[53]*McGraw-Hill Encyclopedia of Science and Technology*, 7th ed., s. v. "radio broadcasting," and "radio wave propagation."
[54]James Wood, *History of International Broadcasting* (London: Peter Peregrinus, Ltd., 1992), p. 22.

admit that I am responsible for the adopting of long waves for long-distance communication. Everyone followed me in building stations hundreds of times more powerful than would have been necessary had short waves been used. Now I have realized my mistake. . . ."[55] It was as if, after pulling at the door of long-distance transmission for years with all their strength, the radio companies discovered that if they pushed, they could walk right through. Long-wave remained superior for some naval uses since it was more omnidirectional than short-wave and could be received by submarines at shallow depths; but in other applications it was swiftly eclipsed.[56] Short-wave was conclusively superior: it used smaller and cheaper antennas, it required less power, and yet it provided greater bandwidth.

Despite the remarkable utility of short-wave, by far the most important development in radio during the inter-war period was broadcasting. This took America and the world by storm in the spring of 1922, causing then Secretary of Commerce Herbert Hoover to describe it as "one of the most astounding things that [has] come under my observation of American life."[57] In actual fact, however, its roots lie farther in the past. Broadcasting grew out of amateur radio use in a process strongly reminiscent of the development of the Internet more recently. Hundreds and then thousands of ordinary citizens bought kits to build their own radios and then used them to contact one another and listen to marine broadcasts. The primitive technology of the time made constant tinkering necessary to ensure optimal reception, but part of the hobby's appeal was the scope it gave for the development and exercise of technical ability in an increasingly technical world.[58] Radio amateurs came under harsh criticism after the *Titanic* incident for allegedly interfering with rescue efforts; and, as the airwaves became more crowded, they

[55]Quoted in Headrick, op. cit., p. 122.
[56]Lebow, op. cit., pp. 92–94.
[57]Quoted in Douglas, op. cit., p. 303.
[58]Ibid., pp. 190 ff.

were increasingly constrained by government regulation and licensing. Their activities were banned altogether during the war; but ironically, during the same period their talents proved to be a critical resource for the military, which faced a desperate shortage of skilled wireless specialists.[59] After the armistice the wireless operators of wartime once again became the amateur enthusiasts of peacetime, their ranks now swollen by the many operators introduced to the wireless by the military. The number of sets sold and number of licensees continued to climb; and once continuous wave transmitters and vacuum tube receivers became widespread, amateurs began to transmit voice and music as well as the Morse code to which they had previously been restricted. Gradually some amateurs became very popular for the music selection and commentary of their increasingly regular transmissions, and many other amateurs began to listen to them.[60] What had begun life as a point-to-point medium had evolved into something else: broadcasting was born.

The birth of broadcasting is traditionally dated as 27 October 1920, when Westinghouse in Pittsburgh obtained a license for station KDKA for the explicit purpose of broadcasting. KDKA grew out of the amateur efforts of Dr. Frank Conrad, a Westinghouse employee of some fame in the Pittsburgh area for his music transmissions on Thursday and Sunday evenings. A local department store began to promote its radio equipment as a means for purchasers to listen to Conrad's transmissions; and when a Westinghouse vice-president noticed the store's advertisement, he realized what radio's true calling really was. He persuaded Westinghouse to immediately pursue the new market, and established KDKA just in time to broadcast the Harding-Cox presidential election.[61] It is worth noting that the idea of broadcasting had been raised before, in a prescient memorandum in 1916

[59]Critics of computer hackers, take note!
[60]Schramm, op. cit., p. 220.
[61]Lebow, op. cit., p. 101.

by David Sarnoff, president of American Marconi and eventually RCA,[62] and in the ongoing efforts of Lee De Forest during the 1900s and 1910s.[63] However, these early prophets were ignored—broadcasting's time had not yet come.

Although broadcasting technically began in late 1920, it exploded into the public consciousness in 1922. People scrambled to buy receivers and companies rushed to set up stations. In a process again reminiscent of the Internet, the fact that no obvious means had been found for anyone but equipment manufacturers to benefit financially from radio—since advertising was not yet common—did not dissuade all kinds of other companies, from newspapers to department stores, from starting their own radio stations; the important thing was to have a radio presence.[64] The industry grew exponentially: sales of radio sets and parts rocketed from $60 million in 1922 to $358 million in 1924,[65] and the number of receivers went from 400,000 in 1922, to 13 million in 1930, and 51 million by 1940.[66] Independent stations opened all over the country, but gradually these stations were consolidated into networks owned for the most part by the large radio companies, especially RCA. Advertising was introduced by AT&T under the name "toll broadcasting" during that company's brief flirtation with radio broadcasting in the early 1920s, and radio began to exhibit most of the characteristics we are familiar with today.[67]

The last piece to fall into place before radio truly became the medium that we now know was news coverage. It was not until the mid-1930s that newspapers and radio stations reached an agreement over access to news agency copy, allowing radio stations to offer regular newscasts rather than just news bulletins and commentary shows.[68] In addition to news, entertainment, and advertising, radio was also used

[62]Schramm, op. cit., pp. 207–208.
[63]Ibid., p. 219; Lebow, op. cit., p. 100.
[64]Wood, op. cit., p. 27.
[65]Douglas, op. cit., p. 303.
[66]Schramm, op. cit., p. 249.
[67]Lebow, op. cit., p. 105.
[68]Schramm, op. cit., p. 226.

for political purposes, to provide a direct means of contact between leaders and their constituencies. The most famous examples of such use of the new technology are without a doubt Franklin Roosevelt's "fireside chats" with the American people, and Winston Churchill's patriotic speeches to an embattled Britain. By 1938, according to an FCC survey, airtime was filled in the following proportions: 53% music, 11% talks and dialogues, 9% drama, 9% variety shows, 9% news, 5% religious broadcasting, 2% special events, and 2% miscellaneous broadcasting. Additionally, 64% percent of programming was live, split in equal proportions between local and national network content, 21% was from electrical transcriptions, and 12% was from phonograph records.[69]

The tremendous popularity of radio broadcasting can be ascribed to its many advantages compared to the media which predate it:

- It can communicate instantaneously and update stories whenever new information is received, whereas publishing is restricted to a limited frequency of print runs.
- By communicating the human voice it adds an emotional content and visceral credibility to information transmission that is much more difficult to achieve with the narrower emotional bandwidth of the printed word—for instance, a writer must be skilled indeed to achieve an equivalent emotional effect to that created by the sound of someone crying on the radio. One of the most famous examples of the power of emotion communicated by radio was the report of the *Hindenburg* disaster of 1937—the reporter who had been sent to record the airship's arrival for archival purposes managed to

[69]Christopher Sterling and John M. Kittross, "The Golden Age of Programming," in David Crowley and Paul Heyer, eds., *Communication in History: Technology, Culture, Society*, 2nd ed. (White Plains, N.Y.: Longman Publishers, 1995), p. 250.

communicate the horror of what he was seeing with enough force to shock a nation.[70]

- It can give a listener a "public" experience—contact with strangers and new ideas—in the comfort of the home, making it more convenient for the consumer, and more effective for the advertiser because of its greater invasiveness. It is a visitor that people are willing to invite into their homes every night; it easily crosses the doorstep barrier erected against traveling salesmen and the like.
- The radio is also appealing from a consumer's perspective because after the initial capital investment in the receiver, the variable costs of consuming more programming are zero in financial terms (although greater in opportunity terms) because advertisers pay for programming. The only way for a privately-owned radio industry to coax more money out of a broadcasting consumer is to convince him or her to buy another radio—fortunately for the industry, technological innovation has frequently simplified this task. In a system of publicly-owned broadcasting, such as in the United Kingdom, a mandatory annual licensing fee for receiving equipment can be another means of forcing continued expenditure; but even such a fee can be seen as a recurring capital investment (arising after the previous year's license has depreciated), after the payment of which variable costs are again zero. Unlike print or live performance, radio is an "all you can eat" medium.
- Finally, the economics of information transmission are changed from the producer's perspective as well, since the (admittedly decreasing) variable costs associated with larger audiences that hamper other media do not apply in the case of radio. A broadcast over a given area will cost exactly the same,

[70]Schramm, op. cit., p. 226.

regardless of what portion of the potential audience actually listens to it. In contrast, a publisher must print another copy of a newspaper or book for each additional reader, and a live performer must seek a larger venue to accommodate a larger audience.

Broadcasting has been almost exclusively privately owned and operated in the United States, but many other governments have treated it differently. In Britain radio was seen not merely as a business opportunity, but as an instrument of social control. Broadcasting remained a government monopoly under the British Broadcasting Corporation until 1954, and carried programming calculated to improve listeners, such as classical music, patriotic speeches and military marches.[71] As the Second World War approached and international tensions mounted, European governments began to use radio not only to influence the opinions of their own people, but to influence other nations as well: radio propaganda was born. Radio propaganda was first practiced by Italy and Britain in North Africa and the Middle East, but eventually spread back to Europe where Germany and the Soviet Union used it to vilify opposing political systems.[72]

The advent of broadcast radio at the beginning of the 1920s was one of the most important developments of our century. As we shall see below when we examine the radio's impact, its effects were felt throughout society, in every field of endeavor and at every social level. We must, therefore, try to understand why it happened when it did. Obviously, certain technological developments were necessary before broadcasting could become practical; these developments alone were not enough, however, for by one estimate the invention was technically possible by 1915, and yet did not appear for a further five years.[73] Fortunately, some further explanations are suggested by the historical narrative above. Between 1915 and 1917 the chaotic

[71]Wood, op. cit., pp. 31–35.
[72]Ibid., pp. 39–42.
[73]Sivowitch, op. cit.

patent situation prevented technological innovations from being turned into marketable products, and from 1917 to 1918 the war took precedence over civilian applications. Also, the number of skilled and interested wireless owners grew steadily throughout the period, perhaps reaching a critical mass at which a new means of linking them together became possible and even likely. Even after 1918, however, the prospect of broadcasting was almost universally ignored. It arose when it did because someone in a position of power had the flash of insight and imagination to see the invention in new terms, rather than according to the point-to-point paradigm that had been universally accepted until then.

Finally, it is also tempting to draw conclusions from the coincidence of the transition from ham radio to broadcasting and the movement of the radio equipment from the garage to the living room in most houses. This move only became appealing for the average family when a variety of innovations made the radio a more convenient and acceptable piece of equipment rather than just a more capable one: it had to run on dry cells, or, better yet, house current, to avoid the risk of acid from wet cells staining carpets; it had to be packaged in an attractive case that would not look out of place surrounded by other furniture; it had to have a tuning knob so that stations could be found dependably; finally, it had to have a loudspeaker so that the whole family could listen at once, rather than taking turns with headphones.[74] These innovations changed the radio from a tool into an appliance. They did not make the radio a more powerful invention; but they did make it a more practical one, and thus more appealing to the average reception-oriented consumer.

[74]Lebow, op. cit., p. 103.

D. 1939 TO 1945 — THE SECOND WORLD WAR AND A MILITARY REVOLUTION

The radio was of decisive importance in the Second World War, profoundly affecting almost every aspect of the conflict. It was used in both point-to-point and broadcasting applications, and was not restricted to use on the battlefield. To a degree never before possible, radio brought the war home. Radio's heightened importance in the war also led inevitably to the heightened importance of its nemesis, communications intelligence. Although the basic tools and techniques of this discipline were very similar to those available in the previous conflict (with the notable exception of radar), the net effect was far greater because of more effective use. Close, structured connections between intelligence-gatherers, analysts, decision-makers, and war-fighters meant that information could be collected, processed, passed on and acted upon quickly enough for it to be of consistent value. Even as the pace of combat increased, the pace of information processing and dissemination increased even more. Intelligence therefore became a far more significant force multiplier than it had ever been in the past.

In the military, similar developments occurred in each realm of warfare to take advantage of the radio more effectively than had been done in World War I. In each case, strategies were devised with the radio in mind. Systems of warfighting were built around constant communication and, for the first time, took full advantage of the radio's capabilities. Most of the truly important strategic advances of the Second World War were revolutionary for this reason.

Two of the most important types of naval warfare in World War II exemplified this trend.[75] German wolf-pack tactics in the Battle of the Atlantic depended on the radio to transmit target information and to coordinate attacks. German naval headquarters collected information about convoy routes and location through aerial surveillance and spies, but it needed the radio to pass the information on to the U-

[75]Headrick, op. cit., pp. 246–250.

boats for action. The U-boats in turn used the radio to communicate target location to one another, to coordinate their attack so as to take advantage of their superior numbers, and then to inform headquarters of the results of their efforts. Ironically, Allied anti-submarine warfare also relied upon German use of the radio, for it was through the interception and direction-finding of German transmissions that U-boat actions could be anticipated and countered, and the U-boats destroyed. The Allies further depended upon the radio to coordinate their own anti-submarine attacks and to redirect convoys to safe areas.

Land warfare saw even greater changes in strategy due to the radio than did naval warfare, for the simple reason that it had benefited so little from the radio in the First World War. The radio was used most effectively by the German army, whose operational doctrine of *Blitzkrieg* depended on it. *Blitzkrieg* used the radio both to support mobility and to maintain control, two desirable capabilities which up until then had been mutually exclusive.[76] Heinz Guderian, the commander of the German panzers, had the insight to put a radio set in every tank and then lead the attack from the front, as a "modern Alexander" (his expression).[77] These innovations allowed him to maintain first-hand knowledge of conditions along one part of the front without sacrificing second-hand knowledge of, or lateral control over, other parts. Furthermore, a decentralized command structure allowed fleeting opportunities to be exploited locally by individual units without losing touch with the rest of the force. Finally, *Blitzkrieg* used the radio to direct air support.[78] By directly coordinating air power with actions on the ground, the air power could much more effectively be translated into results measurable in captured territory. The results of *Blitzkrieg* are well known, and its devastating effectiveness and

[76]Martin van Creveld, *Command in War* (Cambridge, Mass.: Harvard University Press, 1985), pp. 191–193.
[77]Kenneth Macksey, *Guderian: Panzer General* (London: MacDonald and Jane's, 1975), pp. 61, 66.
[78]Christopher Bellamy, *The Evolution of Modern Land Warfare* (New York: Routledge, 1990), pp. 84–85.

consequences for European history must be counted among radio's most important effects. *Blitzkrieg* and its imitations were not the only example of an army using the radio to improve communication and develop new war-fighting techniques, however. The U.S. Army used it for concentration of artillery fire, allowing the firepower of an entire battalion or more to be rapidly concentrated on a single target, based on the directions of a single observer.[79]

Radio was used in air warfare, as in other applications, in a coordinating capacity. Headquarters and many independent units were linked with one another and able to act in concert and share information. The most revolutionary example of such a system in the air was undoubtedly British air defense during the Battle of Britain.[80] In a situation where it possessed inferior numbers, the Royal Air Force used radio and radar, an outgrowth of radio, to achieve victory against the odds. Information about incoming German bombers was collected from a number of sources, including early warning radar and the Royal Observer Corps, and sent to a central control room. From the control room, an individual controller using radio directed fighter planes to intercept the bombers, keeping them apprised of the evolving situation as perceived by radar, and directing them to new targets if necessary. With radar and radio, therefore, Britain did not need to maintain a continuous defensive cover over all of its territory. It could instead conserve its resources—aircraft, fuel, and pilots—by sending fighters only where they were needed and for as long as they were needed.[81]

Finally, beyond the military sphere, the radio carried the Second World War off the battlefield and into homes to a far greater extent than had ever occurred before. Through wartime broadcasting and propaganda, the radio made the war more

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[79]Ibid., p. 83.
[80]Shelford Bidwell, *Modern Warfare: A Study of Men, Weapons and Theories* (London: Allen Lane, 1973), pp. 84–85.
[81]R.V. Jones, *The Wizard War: British Scientific Intelligence 1939–1945* (New York: Coward, McCann & Geoghegan, Inc., 1978), p. 199.

immediate and unavoidable for civilians, especially in North America where people were less directly affected by war violence. The Second World War was a war of ideology; and using the radio as a weapon, the heart and mind of every citizen became an ideological battlefield. In the United States, CBS's coverage of the war with correspondent Edward Murrow was nothing short of legendary. Murrow, with the help of the particular qualities of radio, made extremely emotional broadcasts from London during the Blitz. His opening signature, "This is London," entered the mainstream of our language, and symbolized the extent to which he transported the listener to his own location and shared the experiences that he himself was undergoing. He consciously strove to generate sympathy among the American public for the British cause, by transmitting subjective coverage of the wartime experiences and tribulations of ordinary Londoners, rather than dry, objective updates on political developments.[82] Murrow was successful in this enterprise not only because of his own talent, but because of the inherent characteristics of radio. Because of its ability to broadcast instantaneously and its reliance on the human voice, the radio offered an immediacy and intimacy of coverage impossible in the press, but still forced the listener to take much of what the announcer said on faith, unlike television.[83]

Governments were not slow to recognize the wartime value of a medium that so effectively aroused emotion. Hence, the Second World War was characterized by propaganda broadcasts by all the major powers, intended to bolster the morale of their own citizens, erode the morale of their opponents, or give hope to occupied peoples. Goebbels saw propaganda directed towards German citizens as crucial for the war effort, for in his predictably phrased opinion, "The future of the entire German race hung on convincing the nation that it was the greatest on earth."[84] It

[82]William Stott, "Documenting Media," in Crowley and Heyer, op. cit., p. 245.
[83]Ibid., p. 248.
[84]Wood, op. cit., p. 71.

must also be noted that during Britain's darkest hour during the war, the broadcasts of Winston Churchill were of inestimable value in maintaining British morale and convincing the British people of their own future. In an offensive capacity, broadcasting even made its way onto the battlefield, although its effectiveness there has been an object of controversy. The Japanese "Tokyo Rose" broadcasts were explicitly designed to make American soldiers homesick and tired of war;[85] and Allied broadcasts after D-Day were calculated to instill terror and despair in German soldiers and thereby make reconquest easier.[86]

The examples described above give a fair impression of radio's importance in the Second World War. *Blitzkrieg*, wolf packs, the British air defense system, and live reporting were all revolutionary aspects of the war that produced them, and all depended to a greater or lesser degree on the radio. We must once again ask why these developments occurred when they did, however. More specifically, why did they occur in the Second World War instead of the First World War? Many of the reasons should be clear by now. The radio's own technological development, the patent ownership issue, and the decline of cables have all been described above. Beyond those reasons, however, the science of strategy took time to evolve to take optimal advantage of radio technology, and to combine it profitably with other technologies, such as the tank and the plane. Guderian is hailed as a genius for having used the radio to decentralize command and lead from the front, and so he should be. He was the first to see the potential of the new technology for waging war completely differently. His insight, and the insights that led to the other inventive radio applications of the Second World War, including political broadcasting, took time coming; without them the eventual utility of the radio was impossible to predict.

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[85]Ibid., pp. 85–87.
[86]Ibid., pp. 51–52.

PART TWO – IMPACT

The preceding brief history of the radio's development and applications describes a process of slow innovation, not an invention that changed the world overnight. The radio penetrated different spheres of society only gradually—forty-five years after its invention, even as the Second World War began, people were still coming to terms with its implications. This gradual character and discontinuous development are of great interest in their own right, however, and can be mapped out in specific stages using Thomas Malone's hierarchy of first-order, second-order, and third-order effects of technological change.[87] Malone's scheme is as follows: first-order effects are uses of a new technology as a direct substitute for the old technologies it replaces; second-order effects are the more frequent or intensive execution of tasks using the new technology because of the improvements in efficiency that it provides; third-order effects are new forms of behavior dependent upon the new technology, and which did not exist before its invention. As we examine both the military and civilian spheres below, we will see clear progressions between first-, second-, and third-order effects, and gain a better understanding of the nature of technological change.

A. THE MILITARY SPHERE

The first-order effects of the radio on the military are obvious. The new invention provided vastly more efficient, reliable and versatile communication under many circumstances: army units did not have to lay telegraph wires or send couriers or carrier pigeons to keep in touch with one another; warships did not have to go into port in order to get instructions from headquarters; planes did not have to

[87]See Malone and Rockart, op. cit., p. 128.

return to base to communicate their observations of enemy movements and dispositions to those who could use them; commanders did not have to know the location of their units to communicate with them; governments did not have to rely on vulnerable cables for their strategic communications. A clear process of substitution took place in each of these cases, with the radio replacing either cables, or some other technology more primitive than cables where cables could not reach. Most of the applications of the radio in the First World War had only first-order effects—they made combat more efficient, but did not fundamentally change the activities of the military, or the character of war. Even the reliance of early radio upon Morse code and a cadre of specialist operators did nothing to alter military traditions of reliance upon written orders and communications specialists.

The radio's second-order effects on the military are harder to distinguish because they are incremental changes in usage, rather than qualitative changes in equipment. However, even if they do not change the fundamental structure of an operation, they can drastically increase its effectiveness. Second-order effects are instances where volume of radio communication increases not only because traffic switches over to radio from other, inferior media (a substitution effect in economic terms), but because the availability of cheaper communication prompts new communication that would not otherwise have occurred at all (an income effect in economic terms). When the world's militaries switched over to radio, they did indeed find themselves gradually using the new technology more than they had used the old, especially as progressive refinements made it more practical. Commanders obtained more regular reports on the progress of their forces once such reports could more easily be sent, and they could dare to change tactics in the middle of an engagement with a reasonable hope that the result would be something better than chaos. Compared to the naval engagements of the Nelsonian era, when any change in the signal flags often led to confusion and disaster, this was

an immense improvement.[88] Individual units, in turn, coordinated their own actions with one another more frequently once such coordination could be maintained directly and efficiently, rather than running along traditional lines of communication through the entire command hierarchy.

When we look for historical examples, the most significant second-order radio effects evident in the First World War were in naval warfare. Navies shared much more information than they ever had in the past, communicating the location of targets, the current activities of ships, and other relevant pieces of information. However, this increased information flow did not change the character of naval combat. Battles still looked largely the same as they had for years previously, almost despite the radio—German U-boats used the invention only to learn the location of targets, not to coordinate attacks; and the British at Jutland used it to detect the German fleet, but not to coordinate the battle afterwards. During the Second World War, in contrast, second-order effects can be seen not only at sea, but on land and in the air as well. The huge increase in the number of radio sets in use points plainly to second-order effects—where at the beginning of the First World War Britain had only ten radio sets for the entire Royal Army, and by 1918 only 600 radio equipped planes,[89] by 1943, in the Second World War, the U.S. Army had a radio for every 39 soldiers,[90] and every Allied plane was radio-equipped. Clearly more communication was going on, and at lower levels, than ever before. Furthermore, where in the First World War a particularly well-equipped artillery spotter might have used a radio to direct the shots of a small number of guns, by the Second

[88]James J. Tritten and Vice Admiral Luigi Donolo, *A Doctrine Reader* (Newport, R.I.: Naval War College, 1995), pp. 6, 8.
[89]Headrick, op. cit., p. 155–156.
[90]van Creveld, op. cit., p. 238. The upward curve continued after WWII: by 1971, in Vietnam, the U.S. Army had a radio for every 4.5 soldiers.

World War, spotters were linked by radio to entire artillery battalions, or even multiple battalions, and able to control the fire of all of them.[91]

The third-order effects of the radio on the military are not visible until the Second World War, for only then did new forms of warfare explicitly dependent on the radio appear. These new systems of war-fighting, though very different, all used the radio to increase situational awareness, to coordinate attacks, and to increase operational coherence.[92] Wolf-pack tactics, anti-U-boat warfare, and British air defense all used it (and its radar offshoot) to collect information about enemy location and intentions, and then to rapidly and dependably transmit that information from intelligence-gatherers to decision-makers to war-fighters. *Blitzkrieg* used it both to link air and ground contingents and to link a mobile commander with his equally mobile forces. Propaganda broadcasting used it to transmit facts, ideas and emotions far behind enemy lines, and eventually into the homes and the minds of civilians as well as soldiers. All of these examples are similar, however, in that they represent new ways of going about warfare—information-based warfare, mobility warfare, ideological warfare—that would have been impossible without the radio. It was at this level that the radio revolutionized war.

B. THE CIVILIAN SPHERE

For simplicity's sake, and since they have followed largely distinct courses, we will consider the radio's point-to-point and broadcasting applications separately. Both show a clear progression between the three kinds of effects that Malone describes.

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[91]Bellamy, op. cit., p. 83.
[92]For more on "coherence," see Jeffrey R. Cooper, "Towards a Theory of Coherent Operations," 1994.

1. Point-to-Point

(a) First-Order Effects. The first-order effects of radio's point-to-point applications were a series of substitutions for technologies that had existed previously:

- As a device for long-distance communication, the radio encroached upon the telegraph. In 1923, when a telegram from the U.K. to the U.S. cost 12 pence per word by cable and 9 pence per word by wireless, cable companies reported that wireless accounted for 20% of trans-Atlantic traffic, and that their revenues had been adversely affected by wireless competition.[93] However, the substitution process between cables and radio was complicated by the fact that radio was not a notably superior technology for a number of years, until short wave and wireless telephony made it cheaper and easier to use—after those developments, radio supplanted cable very rapidly.
- A related process of substitution occurred between foreign-controlled radio and British-controlled cable. Countries other than Britain leapt at the chance to develop communications links independent of Britain's near-monopoly on cables.
- In the case of communication with ships, the radio substituted for a variety of extremely unsatisfactory technologies, including carrier pigeons, semaphores, and launches into port. The change occurred fairly rapidly; most ships changed over within twenty years. After the *Titanic* disaster in 1912, in particular, when the radio proved its value in dramatic terms by saving over 700 lives, adoption of the radio became almost universal by ships of consequence, due in part to American legislation requiring it.
- In the case of planes, very little attempt was ever made to communicate between air and ground in any way besides the radio, but the radio can still be

[93]F. J. Brown, *The Cable and Wireless Communications of the World* (London: Sir Isaac Pitman and Sons, Ltd., 1927), p. 97.

seen as a substitute for the methods that would otherwise have been necessary.

- Finally, through radio direction-finding, the radio substituted for dead reckoning as a means of navigating ships or planes in poor conditions.

(b) Second-Order Effects. As radio became cheaper and more widespread, second-order effects began to manifest themselves:

- More communication overseas took place, helping to develop international business, strengthening personal ties, and giving greater access to non-local information. When, in 1923, the cable companies responded to the wireless challenge by lowering their rates to match those of wireless, they recovered all of their lost revenue. However, this occurred without devastating radio revenues, meaning that overall traffic had increased significantly over the same period.[94]
- Countries other than Britain used their independent communications networks to transmit more sensitive information and to encourage closer bonds within their empires.
- With navigation and communication aids, travel and shipping became more convenient, safer, and cheaper. It is fair to assume that travel and trade therefore increased, but the effects of radio on such a trend would be dwarfed by other factors and therefore close to invisible in practice.
- Finally, as radio sets became cheaper and more common, amateur radio appeared, for the first time allowing individuals to communicate unaided over long distances. The spread of privately-owned radio sets is evident from the increasing number of amateur transmitting licenses awarded by the Department of Commerce: while only 322 licenses were given out in 1913,

[94]Ibid., p. 97.

the first year of licensing, 13,581 were awarded in 1917. Estimates of the number of unlicensed receivers by that time range up to 150,000.[95]

(c) *Third-Order Effects.* As point-to-point radio became integrated into society, it began to have third-order effects:

- Trade not only increased in volume owing to safer sea travel and better international communication; it also changed in character, for with a radio on board, a ship could change its destination during the voyage based on news of fluctuating demand for its cargo. Similarly, land vehicles could be redirected while in transit, and it became possible to dispatch trucks and taxis by radio. Sea travel also changed in character because passengers were no longer out of touch for the duration of their trips.
- Third-order effects could furthermore be seen in the political sphere, where the large number of separate radio networks led to a more egalitarian distribution of communications capability between nations, and so changed the strategic balance in a manner unfavorable to Britain. This change can be easily appreciated if one considers the distribution of communications resources among countries before and after the invention of the radio. In 1892, shortly before the radio was invented, British interests owned 66% of the world's international cables, including almost all of the intercontinental trunk lines—an awesome predominance.[96] By 1923, not only had Britain's share of cables dropped to a still impressive 50%, mainly because of an aggressive American construction campaign; but its radio network, with a total of 700 kilowatts of high-powered stations, was dwarfed by those of the United States (3,400 kW), and France (3,150 kW), and rivaled even by that of the defeated Germany (600 kW).[97]

[95]Douglas, op. cit., p. 293.
[96]Headrick, op. cit., p. 199.
[97]Ibid., p. 184.

- Finally, the amateur radio craze had particularly profound effects for society for it permitted long-distance, anonymous relationships between operators who could never otherwise have contacted one another. Also, according to one author, by encouraging technological tinkering by ordinary people, amateur radio contributed to a new, technology-centered definition of manhood more in keeping with an industrial society, eroding the nineteenth century ideal of man as a rugged frontiersman.[98] The author highlights this change by tracing the shift in emphasis in juvenile male literature from the wilderness heroes of books such as Jack London's *Call of the Wild*, to the technologically-minded heroes found in the Tom Swift books. Finally, the availability of international voice communication, despite its expense ($21 for a three-minute call from New York to London in 1936),[99] must have done much to change perceptions, and make the world seem a smaller place.

2. Broadcasting

(a) First-Order Effects. Broadcasting became popular so quickly after its invention because it was able to substitute for a variety of different media for different applications, offering enhanced capabilities compared to each of them. It thus had tremendous first-order effects:

- First, it displaced newspapers and especially newspaper extra editions—which virtually disappeared after regular newscasts began[100]—in news dissemination, because it could communicate information more quickly and update stories more frequently, because it was more emotive than the printed word, and because, owing perhaps to its dependence on the human voice, it was more likely to be believed. The most impressive evidence of this last point was the *War of the Worlds* phenomenon of 1938, in which thousands

[98]Douglas, op. cit., pp. 190–193.
[99]George P. Oslin, *The Story of Telecommunications* (Macon, Ga.: Mercer University Press, 1992), p. 281.
[100]Schramm, op. cit., p. 227.

of people fled their homes in terror after tuning in late to a radio-drama describing an invasion of the New York area by Martians. Despite the inherent improbability of the storyline, not to mention the fact that it was broadcast the night before Halloween, people took it as fact because it was on the radio.[101] Additionally, in a 1939 survey by *Fortune* magazine, 49.7% of Americans believed that radio gave them news freer of prejudice, compared to only 17.1% who chose newspapers.[102]

- Second, radio replaced live concerts and performances as the dominant means of communicating music and drama because music and drama broadcast into the home were cheaper and more convenient for consumers—the radio listener did not have to fight crowds, the elements, and high ticket prices to be entertained. Radio was even able to provide better sound quality than was available in the distant cheap seats at a live performance, making the switch almost irresistible.[103]
- Third, radio served as an appealing substitute for the phonograph, because it was again cheaper, in that it had no variable costs, and it allowed the listener to listen to a greater variety of music. New artists, styles, and recordings could be sampled without the financial commitment or bother of buying a record.
- Fourth, radio advertising took some of the marketing and advertising business away from print advertisements and traveling salesmen, because it was a more effective and insistent way to reach a large number of people.
- Fifth and finally, radio partially replaced live appearances and political pamphlets as a means of public political debate. It was a more engaging and

[101]Ibid., p. 228.
[102]Quoted in Stott, in Crowley and Heyer, op. cit., p. 241. 18.3% rated the two media equally, and 14.9% didn't know.
[103]Douglas, op. cit., p. 308.

emotional medium than print, and yet reached a larger audience than a live speech.

(b) Second-Order Effects. Broadcasting's tremendous first-order effects were followed, not surprisingly, by tremendous second-order effects, for the same characteristics that made it such an effective substitute for the many other media existent also made it tremendously appealing in its own right.. As its use continued to increase because of the new possibilities its efficiency offered, all sorts of further changes occurred. As people spent more time listening to the radio, they listened to more news, and became more aware of national and international events. They also listened to more music and drama than previously, making the music and entertainment industries larger than ever before, and more democratic in product, in the sense that entertainment was now directed towards the mass market rather than only the elite who could afford tickets. Finally, greater exposure to radio advertisements made the radio a better marketing opportunity, and propelled the advertising industry to new heights.

(c) Third-Order Effects. The third-order effects of broadcasting dwarfed those of point-to-point applications in the civilian world, proving conclusively that in this application, radio had found its destiny:

- First, radio changed how and where people spent their time. Many kinds of entertainment and stimulus previously accessible only in certain public places were suddenly available in the comfort of the private living room. People therefore left their houses less, and spent less time in the company of strangers.[104] Radio furthermore offered spoken news and drama so that, inevitably, people read less.

[104]Ibid., p. 308.

- Second, radio changed the commercial world, not only by promoting the industries directly associated with it at the expense of those its technology displaced, but also by changing the way products were marketed. The growth of national networks provided advertising opportunities most appropriate for national brands, and thus provoked a wave of mergers and consolidation to take advantage of economies of scale in marketing.[105] Examples of this trend include the creation of the National Biscuit Company by the merger of hundreds of local cracker factories wanting to benefit from a national trademark, and the reduction of the American Tobacco Company's advertised product line from fifty brands to one in order to concentrate all efforts on promoting Lucky Strike cigarettes.
- Radio also changed the entertainment industry by altering traditional forms of entertainment—the radio orchestra and especially the radio drama were significantly different from their pre-broadcasting namesakes. The entertainment industry further changed because of radio's ability to give an unlimited number of listeners access to the same performers. The very best performers therefore became even more popular and sought after because technology allowed them to meet much higher levels of demand for their services. Slightly less talented performers, in turn, suffered, because their services were no longer required as substitutes for the prima donnas. Income within the industry was redistributed accordingly—broadcasting became a "winner-take-all" industry.[106]
- Additionally, radio changed politics by making "radio personality" a criterion for leadership (and as a result greatly helping Franklin Roosevelt). Through

[105]Erik Barnouw, *A Tower In Babel*, vol. 1 of *A History of Broadcasting in the United States* (New York: Oxford University Press, 1966), p. 202.
[106]See "When Winners Take All," *The Economist*, 25 November, 1995, p. 82, which in turn cites Robert Frank and Philip Cook, "The Winner-Take-All Society," (New York: The Free Press, 1995).

its unique impact on the emotions, radio made people more vulnerable to the demagogic side of politics. In Marshall McLuhan's terms, radio is a "hot" medium that therefore takes "hot" personalities such as Hitler and Joseph McCarthy seriously.[107]

- Finally, and perhaps most importantly, radio changed people's perceptions of group membership. Greater national consciousness followed from listening to national networks and learning enough about people elsewhere in one's country to realize their resemblance to oneself. Reflecting this trend, radio also contributed to a homogenization of regional accents into national standards, for instance "BBC English."[108] Ironically, however, even as it raised awareness of national identities, radio also gave a voice to regional differences. Minorities such as the Scots and the Welsh in Britain effectively used radio to rejuvenate disappearing national languages and cultures and promote consciousness of diversity.[109] In a related vein, radio also created a new, previously unknown kind of grouping: the listening community. As programming diversified it became possible for a listener to define preferred types of music and entertainment from the wide variety of choices available. While perhaps not equal to ethnicity in importance, these preferences provided a new way for people to think of themselves, and to identify others with whom they might share interests and values.

[107]Marshall McLuhan, "Understanding Radio," in Crowley and Heyer, op. cit., p. 257.
[108]David Crystal, *The Cambridge Encyclopedia of Language* (Cambridge: Cambridge University Press, 1987), p. 392.
[109]McLuhan, in Crowley and Heyer, op. cit., p. 261.

CONCLUSIONS

In recounting the story of the radio this paper has exposed numerous striking parallels between past events and the technological developments of the present day. Echoes of each of the radio's incarnations can be heard in the discussions surrounding current developments. In the civilian sphere, the radio provided people with a new means of communicating, a new source of information about their world, and a new set of options in defining themselves—foreshadowing the claims made about the information revolution and its associated technologies years later. After an extended existence as a useful but not revolutionary technology, with the advent of broadcasting the radio metamorphosed into something new and greater. Similarly, the Internet, after spending significant time as merely a useful tool for academics and government, suddenly caught the public imagination, and came into its own as a new communications paradigm. In the military sphere, in turn, the radio made possible a new level of awareness of battle conditions, and a less punishing trade-off between mobility and control. The new communications tools of the present day, by providing real-time reconnaissance information and video and data links with field units, are expected to do the same thing. Together, these parallels are excellent news, for not only do they offer reassurance that current upheavals are not the first of their kind, nor any less endurable than previous changes; but they also allow us to be confident about the relevance of the foregoing analysis to events today. The story of the radio does indeed offer valuable lessons applicable to our current situation.

The preceding essay is, by necessity, only a general treatment of a vast and complex subject. Human history is such that the story of any one invention includes windows into the stories of every other facet of contemporary society; but

in this paper we could only gaze through those windows briefly, instead of fully investigating the fascinating subjects seen through them. This paper aimed merely to survey the issues associated with the development of the radio rather than prove a single argument, but consistent themes nevertheless recur throughout the narrative and lead to three valuable insights applicable to other technological revolutions. These insights concern: the relationship between a technology's technical characteristics and its eventual uses; the speed of technological change; and finally, the predictability of technological change.

First, it is evident that the radio's particular uses and effects were consequences of its relative strengths and weaknesses as a technology, as well as of the political, economic and social conditions that prevailed during its development. Different qualities in a technology are valuable in different applications. If we can determine which qualities of radio contributed to each successful and failed application, then we can shed light on the potential uses of future technologies with similar characteristics. An examination of the interaction of the radio with its technological contemporaries, to see why it flourished in some applications but was ignored in others, makes this linkage and the radio's critical qualities clear.

Unlike most other communications technologies (although somewhat like the Internet), radio has a dual identity: it has important uses both as a point-to-point medium and as a broadcast medium. As a point-to-point medium, it competed from the outset with the telegraph and the telephone, which both predated it. In comparison with these technologies it had several notable advantages, making it very popular from its invention onward. Many of these advantages derived in some way from its wireless character. First, because a radio transmitter and receiver were not wirebound, they could be mobile, and furthermore could each be used without knowing the other's location. Second, because no wires were needed, a radio communication network was less expensive to build than a cable or telephone

network, which reduced the level of commitment to fixed patterns of service required of radio companies, and furthermore made transmissions cheaper. Third, the fact that, in contrast to cable networks, radio networks did not require huge capital investments strung out across the ocean floor made them less vulnerable to destruction by potential enemies (although more vulnerable to interference). A final advantage derived from another of radio's technical qualities, and from the contemporary limitations of the telephone and telegraph: with the advent of short waves, intercontinental voice transmission became possible by radio; it was thirty years before wire telephones achieved the same feat.

The radio was certainly not without disadvantages: it was vulnerable to interference and dependent upon weather and distance; it offered limited privacy; it had a finite number of channels, the rights to which had to be distributed carefully. Still, its advantages made it very appealing for certain uses, as we saw above. The military profited greatly from the mobility it allowed, as did maritime interests. Governments profited from its low fixed costs and more defensible infrastructure. Consumers benefited from its intercontinental telephonic capabilities. Accordingly, for a number of point-to-point applications, it became the preferred technology. Equally notably, however, in the case of local and national long-distance civilian point-to-point communication it did not have an appreciable impact. For such applications the radio offered very few meaningful advantages over the telephone, since mobility and defense were not important for the average consumer; and it furthermore threatened significant disadvantages, such as lack of privacy, cluttered airwaves, and large long-wave antennas (since short-wave is only useful over long distances). There was also a further barrier to the use of the radio for civilian point-to-point communication: different transmission distances require different frequencies, which in turn require different antennas and propagation paths. In the days before digital technology, the user of a radio-telephone would have had to have

a number of antennas and know which one to use for each call, or would have had to relay the call through a central retransmitter with many antennas, thus degrading the signal substantially. National broadcasting networks did not face this problem because they only used the radio for local retransmission. The content traveled between the studios and the local broadcasters by telephone lines.

As a broadcast medium, radio had no direct competition until the television arose in the late 1940s. Before that time it had only indirect substitutes, such as the phonograph, newspapers, books, and live events. In comparison to these technologies radio had a number of immense advantages. First and foremost, it instantaneously communicated the human voice, with all of its subtleties of emotion and meaning; using the same techniques, it also communicated music. Second, it had very low costs attached to it from a consumer's perspective, for not only was there no charge for listening after the initial equipment purchase, but it wasn't even necessary to leave the home to partake. Despite the radio's disadvantages in the form of decreased human contact, reliance on second-hand description of events, and advertisements, the combination of emotional content, affordable price, and convenience proved spellbinding—the result was the radio explosion of the 1920s. On the other hand, however, radio did not, in general, completely replace other media (an exception was the newspaper extra). Instead, use of the other technologies simply became more precisely restricted to the particular applications where they truly were most appropriate. Some even profited from the radio through a process of symbiosis; examples of this include schedules of radio broadcasts published in newspapers, and new phonograph record titles promoted by radio.

Although it is beyond the chronological span of this paper, it is worth noting a further example of this process of accommodation in the interaction between the radio and the television. Television could not hope to entirely replace the radio,

because it was not an exact substitute. Television merely forced the radio to concentrate on what it did best, and the qualities that it alone could offer. First, radio demanded the attention of only one of the five senses, leaving the others free to perform other tasks. It was thus much easier, for instance, to work or drive with a radio than with a television. For all of the situations where people were not in their homes and in a position to devote solid blocks of time to leisure pursuits, the radio remained the broadcasting medium of choice. Second, radio receivers were easily portable, allowing them to be wedded to the automobile more effectively than the television ever could be, and to be brought along on picnics, fishing trips, and the like.

The second broad insight that this paper offers is that, contrary to perceptions of technological progress as rapid, or even, at the level of individual inventions, instantaneous, the process of the adoption of new technologies is surprisingly slow and even stealthy. The two perspectives upon the radio revolution that this paper offers both make this point clearly. In Part One, we observed the slow sequence of new applications of the invention as technical refinement made it more versatile and human ingenuity applied it to more areas. In many cases, the eventual uses were completely different from anything the original inventors of the radio had envisioned, and certainly the later refinement of the technology went far beyond the expectations of those who first worked on it. In Part Two, we examined the effects of the radio in succession, dividing them into distinct stages. In most instances, the immediate, first-order effects seemed superficial in comparison to the eventual earth-shaking changes that followed. The difference between the radio's immediate applications and effects and those that followed years later was so immense that any appreciation for the initial effects seems almost ironic. For example, in 1899 Marconi's wireless was considered so revolutionary, and such an advance in comparison to any other method of communication, that the First Lord of the

British Admiralty, George Goschen, was driven to congratulate Marconi "on having brought his invention to its present state of perfection."[110] One can only imagine what Goschen would have thought of the invention's later progress—hand-held voice communication, radar, broadcasting, and other miracles. As impressive as the invention seemed at its debut, time molded it into something far more extraordinary.

Finally, the third major insight of the preceding paper is that the effects of technological change form a curious mixture of predictable and unpredictable elements. On the one hand, the *process* of change is predictable. In applying Malone's taxonomy, Part Two dissected the consequences of the radio into different groups with definable characteristics, and demonstrated the links between them. By referring to a general model of the stages that a new technology moves through, it showed that different revolutions follow similar, and therefore foreseeable, courses. Any new technology will first have superficial effects as a direct substitute for pre-existing technologies, then more significant effects, as its increased efficiency leads to greater dependence upon it, and finally profound effects, as the fundamental structures of society change to take full advantage of the new invention's capabilities. On the other hand, however, the *particulars* of technological change are unpredictable. Although we can assume that a remarkable new invention will have third-order effects, we do not know what they will be, or when they will occur. The effects may not even occur in order—the second-order effects of point-to-point radio predated the first-order effects of broadcasting (although for the purposes of the taxonomy, broadcasting could claim to be an invention in its own right). Technological change depends on too many factors—including not only economic, social and political influences, but the serendipity of human inventiveness as well—for the eventual uses of a new technology to be obvious at its invention.

[110]Headrick, op. cit., p. 117.

This paper broaches many subjects without pursuing them fully and thus provides ample material for further thought. A number of these topics are of particular interest because of their relevance to the present information revolution.

In the military sphere, more attention deserves to be given to the process through which the military adopts, slowly comes to terms with, and devises strategies taking account of, new communications technologies. The military must strike a careful balance between the development of technology and of doctrine. If either one gets too far ahead of the other or if they are poorly matched, disaster can ensue, as we saw in numerous examples above. Because of this tension, technological development poses a dilemma for the military: whether to adopt a new technology early, so that doctrine can evolve to take advantage of it, or late, so that the technology can evolve and its eventual shape become clearer. Study of various militaries' diverse responses to, and successes and failures with, the radio may prove helpful for those struggling with issues related to the adoption of today's new information technologies.

On a second military note, the most interesting Second World War applications of the radio—submarine warfare, *Blitzkrieg*, and British air defense—can be seen as early instances of knowledge-based warfare, in that their strengths lay in their ability to rapidly disseminate information about the battlefield and to permit action based on that information. This allowed U-boats to consistently find merchant ship targets and to attack them in sufficient strength; it allowed panzer units to exploit any temporary weakness in the enemy's resistance; and, it allowed Fighter Command to mount a defense only when and where one was necessary, instead of wasting resources protecting empty air. As the role of information in warfare gains increasing attention in today's strategic debates, these earlier innovations deserve further inspection through the information warfare lens—the processes through

which they were developed and the difficulties that were experienced in adopting them may prove informative.

A third subject worthy of further investigation is the role of government in technological innovation. Governments played an important part in the development of the radio, starting with the early support of Marconi by the British Post Office and Admiralty, continuing through the U.S. Navy's efforts to untangle the patent knot during and after the First World War, and visible still later in antitrust action against RCA (ironically, a monopolist created by government action).[111] Many instances of governmental involvement in the radio industry were positive, but some were decidedly not. Perhaps with further study of the successes and failures of involvement in radio, lessons about appropriate governmental involvement in other communications technologies can be discerned.

Time and again this paper makes evident the remarkable correspondence between the process and consequences of the radio's development in the first half of this century, and those of the latest information technology developments of today. The relevance of the suggestions for further research to current discussions only serves to demonstrate this connection between the past and the present yet again. The fundamental purpose of this paper is to highlight this connection. Such links constitute a strong argument for historical study as a means of comprehending current issues—the stories of past communications inventions and their varied effects upon society offer a valuable resource for understanding the present and preparing for the future. To neglect this resource would be a missed opportunity, for despite, or indeed perhaps even because of, their distance in time, an understanding of past inventions provides a valuable sense of perspective sometimes lacking in study of the momentous developments and debates of today.

[111]Lebow, op. cit., p. 106.

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