A QUESTION OF SCARCITY

Spectrum and Canada's Urban Core

Gregory Taylor, Catherine Middleton, and Xavier Fernando

ABSTRACT

This article uses a case study of urban Canada to explore the contentious issue of spectrum scarcity. Drawing upon infrastructure studies, this article argues for more critical approaches to this essential element of contemporary communications. The first part of the article explores positions of various actors in the antagonistic debate regarding spectrum scarcity in the lead up to the Canadian 700 MHz spectrum auction, held in 2014. The second part of the article provides unique empirical data for spectrum traffic on licensed frequencies in a busy urban location. The article reaches an unanticipated conclusion that demonstrates shortcomings in current allocation methods.

Keywords: mobile communications, spectrum, scarcity, infrastructure, communications policy

Introduction

The explosive growth in the mobile communications industry over the last two decades rests upon an increasingly valuable, invisible public resource. Mobile services[1] cannot be provided without making use of radio

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1. The term "mobile services" is used here to describe voice and broadband services made available by mobile providers using licensed spectrum to devices including smartphones, tablets, and mobile broadband hotspots. The terms "mobile data" and "mobile broadband" are used interchangeably (reflecting the common use of both terms by providers and consumers).

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spectrum—the finite frequencies that serve as the conduit for our mobile devices.

Spectrum is a limited yet nondepletable resource that is the site of an intense economic and political battle taking place behind our smartphone and tablet screens. Concerns over interference mean, using currently deployed standards, no two mobile providers can operate on the same frequency simultaneously within a given geographic region, hence the common analogies comparing spectrum to real estate.

As usage of mobile data increases,[2] mobile operators express concern that there is simply not enough spectrum available to accommodate this rising demand.[3] The perceived threat of an imminent spectrum capacity crisis had led the International Telecommunication Union (ITU) to allot prime spectrum previously reserved for broadcasting to mobile operators,[4] demonstrating the ripple effects of contention for spectrum. If we are indeed running out of usable spectrum, this has dramatic impact across a range of contemporary media.

For many regulators, a looming spectrum shortage is accepted as a fact. In 2011, Federal Communications Commission (FCC) Chairman Julius Genachowski viewed a spectrum shortage as a national communications disaster waiting to happen and announced "the clock is ticking."[5] The clock had been ticking for years at that point: Genachowski's point echoed the same scenario his predecessor, Michael Powell, had described seven years earlier.[6]

For mobile providers the financial incentives to encourage more spectrum access are clear, as arguments for spectrum scarcity support locking up exclusive access to these valuable frequencies. The wireless sector is an increasingly powerful industry. Canada's media regulator, the Canadian Radio-Television and Telecommunications Commission (CRTC), reports that in 2015 the wireless market sector was the largest single communications industry in the country, capturing 36 percent of all communications

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Mobile providers, also known as mobile network operators, are companies like AT&T, China Mobile, Orange, Rogers, T-Mobile, Telefonica, and Vodafone. Our discussion of spectrum usage to provide mobile services excludes the use of Wi-Fi or fixed wireless services.

2. According to Cisco, global mobile data traffic grew 63 percent in 2016, with the greatest increase occurring in Africa and the Middle East. Cisco.

3. Weeks.

4. International Telecommunication Union.

5. Genachowski.

6. Jackson.

revenues.[7] Governments worldwide are subject to intense lobbying from a well-financed mobile industry that seeks long-term spectrum access.[8] However, even at the global level of spectrum management, usage remains something of a mystery. A 2014 report for the ITU noted "there are no reliable statistics in ITU on the use of the spectrum already allocated to terrestrial IMT (International Mobile Telecommunications) by a previous WRC (World Radio Communication Conference)."[9]

So, despite the centrality of spectrum to contemporary communications infrastructure, there remain nagging essential questions regarding how much spectrum is required to meet demand for mobile broadband access, and what exactly mobile operators are doing with the spectrum they already have licensed.[10] This article addresses these questions, by reporting on a study (which we believe to be the first of its kind in Canada) that measured spectrum use in a busy urban location in Canada to investigate whether operators had indeed deployed services on their licensed frequencies and whether, if deployed, the services were operating near peak capacity. There is currently no publicly accessible information that sheds light on the usage of Canadian spectrum, the publicly owned conduit for mobile communications. This article provides quantitative data to illustrate Canadian spectrum usage in one of the densest urban areas of the country, offering a unique contribution to information policy studies by exploring the legitimacy of questions of spectrum scarcity using a test case.

At its core, this article tries to establish if spectrum shortage is a political/economic construct or a material fact. The foundational social/economic/scientific question of "is there an impending spectrum capacity crunch?" is a rhetorical swamp filled with contradictory studies and opinions, yet it is absolutely crucial to our society's further mobile growth. According to Sims et al., for the wireless industry "the global effort to overcome the spectrum crunch frames the entire world of spectrum policy."[11] Thus, while this article uses the case study of Canada, its questions and conclusions are of consequence for nations worldwide struggling with issues of spectrum capacity.

7. Canadian Radio-Television and Telecommunications Commission, "Communications Monitoring Report," 70.

8. Snider.

9. International Telecommunication Union—Radiocommunication Sector.

10. Hoffman; Smith.

11. Sims, Youell, and Womersley, 141.

Infrastructure Studies and Radio Waves

> Media and communications researchers have begun to explore the sociocultural and economic relations of mobile telephony, but few have considered the complex materialities of its infrastructure.[12]

Our increasing reliance on mobile devices means spectrum is "how content moves through the world,"[13] making the study of spectrum an area of relevance for all scholars of contemporary communications, not just the electrical engineers and economists who have traditionally tread in this territory. Spectrum research offers a significant contribution to the wider field of communications infrastructure studies,[14] but spectrum is often overlooked in communications scholarship. A search through communications databases shows little research in the field outside of specialized telecommunications publications, and Parks and Starosielski acknowledge that academic work into the wider social implications of materiality such as effective spectrum management is in its relative infancy. There has been some early work done in Canada but nothing that critically assesses the question of scarcity in the era of smart phones, streaming video, and user expectations of constant connectivity.[15] Spectrum seems to uphold Lisa Parks' observation regarding communications infrastructure: "publics are socialized to know very little about their development, operations, and resource requirements."[16]

In the excellent 2015 book *Signal Traffic: Critical Studies of Media Infrastructures*, spectrum does not feature as a prominent area of study.[17] Christian Sandvig speculates, "Discussion of the spectrum is off-putting because it is even more heavily cloaked by jargon than other technology topics."[18] This article attempts to peel away much of the jargon barrier to the study of the radio spectrum and demonstrate its clear relevance to the wider study of information policy. Some amount of jargon is unavoidable

12. Parks and Starosielski, 3.

13. Ibid., 1.

14. Parks and Starosielski; Sandvig, "The Internet as an Infrastructure"; Star.

15. Crow and Sawchuk; Longford; Taylor, "Oil in the Ether."

16. Parks, "Earth Observation," 304.

17. Tawil-Souri offers a chapter in *Signal Traffic* on the colonizing potentials of cellular towers in Israel–Palestine.

18. Sandvig, "Access to the Electromagnetic Spectrum," 51.

but this article strives to place the specificity of spectrum in a larger communications context.

Infrastructure enables the digital network upon which the flow of information to our mobile devices is maintained. The ubiquitous cellular towers that intrude upon our landscapes and hang off the side of buildings are the most obvious physical element of spectrum-dependent mobile networks. Much of the early literature on wireless infrastructure often studied social resistance over the towers' unattractive design and ill-founded health concerns.[19] That discourse has largely subsided and cell towers will quite likely soon be rendered as unremarkable to the public as their telephone pole forebears. While NIMBYism and health concerns may have waned, the central place of spectrum to our wider communications network has only grown in significance.

This article explores the materiality of an immaterial component (it has neither pipes nor wires) of our communications infrastructure. Key features of infrastructure identified in infrastructure studies involve "ubiquity, reliability, invisibility, gateways, and breakdown."[20] The study of spectrum offers a clear bridge across each category. Spectrum is not just "invisible" in the way in which sewers and cell towers may be concealed from public view; spectrum is literally invisible, and does not "become visible when it breaks," as theorized in Star's study of infrastructure.[21] Indeed, spectrum cannot break, only our human-made devices can. We cannot damage or deplete the spectrum; however, its carrying capacity is finite, and therefore the "capacity crunch" theory, on its surface, seems plausible.

Mobile service is now so ubiquitous and reliable, especially in urban centers in the developed world, that we feel a sense of profound isolation in the rare times we are unable to connect. Our mobile devices are a common gateway for a range of digital media and when there is a breakdown on the network of a major carrier, it can be treated as a news story of national importance.[22] The current application of spectrum as a conduit for mobile broadband is a connecting infrastructure, the uses of which now offer a key part of membership in society. The next section examines the question as to whether the spectrum allocated for the provision of mobile broadband

19. Rorer; Hughes.

20. Plantin et al., 2.

21. Star, 382.

22. Sieniuk.

services (MBSs) has sufficient capacity to meet this ubiquitous demand for connectivity.

Spectrum: Crisis! What Crisis?

> Since its inception radio communications has been plagued by a shortage of space for ever-increasing numbers of stations and new services. . . . As new regions of the radio spectrum have been explored and opened to practical operations, commerce and industry have found more than enough new uses to crowd them.[23]

As this quotation from 1952 demonstrates, concerns over spectrum capacity are as old as mobile communications itself. Over the last century the usable radio spectrum has been extended from a few kHz to several hundred GHz, yet perpetual concerns over shortfalls remain.[24] As noted more than half a century ago, industry has always found a way to encourage the perception that the spectrum glass is well more than half full, rendering their prospects for growth perpetually half empty. Despite the long history of alarm for overcrowded airwaves, there is no doubt that contemporary society is asking more from our radio frequencies than ever before. In 2016, more than half of all global mobile traffic was video.[25] An American expert recently sounded the alarm that "by 2020 demand will be more than double available (spectrum) capacity."[26]

Despite the clear growth in data traffic, a fundamental chasm exists between those who insist more spectrum must be freed up for private mobile providers to maintain and improve levels of coverage, and those who see this as a cynical ploy to secure exclusive access to a limited public resource. The message is clear from large mobile providers with resources to compete in expensive auctions: there is not enough spectrum room for everyone and legacy media such as over-the-air (OTA) television should step aside. This demand for more spectrum encapsulates the power struggle between "old" and "new" media. In 2016, the traditionalists are losing.

23. Joint Technical Advisory Committee.
24. Crandall.
25. Cisco.
26. Clarke, 705.

In an unprecedented "incentive auction" run by the FCC in 2016, American OTA television broadcasters were asked to forfeit their spectrum license in exchange for a percentage of the proceeds from the ensuing spectrum auction.[27] This followed the national transitions to digital television broadcasting in 2008 in the United States and 2011 in Canada. The digital television transition was an early view of the disruptive power of the mobile sector and the centrality of spectrum to current media battles: the impetus for the international transition to digital television was not actually about television at all but about reallocating spectrum from use by television broadcasters to exclusive use by mobile services.[28] Public access to television broadcasts via free-to-air signals, a priority since the beginning of the medium in the 1950s, is being superseded by demand for mobile broadband access. The public's growing appetite for mobile data is rewriting what Paul Starr called "The Constitution of the Air."[29]

Given the limited nature of the radio frequencies, there is great pressure on governments to prioritize service access and to allocate this resource to those who most demonstrably covet it by offering the most money. This liberalization of spectrum has gained global acceptance over the past two decades, with the revenues spectrum auctions generate offering governments a relatively painless way to balance budgets. Markets have replaced the traditional administrative model, where government departments had granted spectrum access.[30] Two recent auctions for AWS-3 spectrum in Canada and the United States in 2015 generated over $2 billion (Canadian dollars) and $45 billion (US dollars) for their respective governments, suggesting that the demand for spectrum is not in question. However, the supply side in the classic economic model is not always so clear.

Spectrum scarcity has been common policy orthodoxy for decades but this hegemony has recently faced challenges in pockets around the world. As reported by LS Telcom, some question the methodology used by national regulators and the ITU to assess the key element of spectrum demand.[31] There are also numerous voices in the field that question the dramatic mental image of the FCC's ticking clock with the associated imminent catastrophes of dropped calls and slow streaming services.

27. Federal Communications Commission.

28. Taylor, *Shut Off.*

29. Starr, 327.

30. Cave, Doyle, and Webb; Hazlett, "Assigning Property Rights," "The Wireless Craze."

31. International Telecommunication Union—Radiocommunication Sector; LS Telcom.

The New America Foundation's Michael Calabrese presented a contrary position in 2011:

> Perhaps the most consequential contradiction in telecommunications policy today is the gap between claims of a "looming spectrum crisis" and the reality that only a fraction of the nation's prime spectrum capacity is actually in use even in the most congested urban areas.[32]

Calabrese is hardly alone. This point is echoed in a seminal 2012 report prepared for President Barack Obama by the President's Council of Advisors on Science and Technology:

> The incongruity between concern about a "looming spectrum crisis" and the reality that only a fraction of the Nation's prime spectrum capacity is actually in use suggests the need for a new policy framework. . . .[33]

The significance of this fundamental divergence of opinion cannot be overstated: to challenge the legitimacy of the spectrum scarcity argument is to question the foundation of contemporary global mobile communications policy.

American voices that cautioned against the explosive rhetoric of the capacity crunch adherents received support from across the Atlantic. In 2012, the European Commission established an objective of harmonizing 1200 MHz of spectrum for mobile broadband and then reviewed this objective against an inventory conducted in 2014 to determine if further spectrum would be required. In 2016, the European Commission concluded "Based on the analysis of spectrum supply and demand, the European Commission believes—according to its Report to the European Parliament and the Council on the Radio Spectrum Inventory (COM/2014/0536 final)—that, within the range 400 MHz–6 GHz, there is currently no need for additional spectrum harmonisation beyond the '1200 MHz' for wireless broadband."[34] In short, it was ruled that European mobile ISPs have more than enough spectrum for the European market for the foreseeable future.

32. Calabrese, 1.

33. President's Council of Advisors on Science and Technology, 16.

34. European Commission, 21.

Other contemporary studies note that the seemingly insatiable market demand for spectrum over the past decade may very well be waning,[35] the result of which is that there is much more time before we will face legitimate fears of a capacity crisis.

It is largely beyond the focus of this article, but another enormous challenge to the spectrum crunch argument is the development of new technologies that can detect and use spectrum that is not in use. These "cognitive radios" are part of a wider unlicensed spectrum movement that encourages shared used of spectrum and has the capacity to render current debates over exclusive access obsolete. Alternative models include deploying service on unused television frequencies (known as "white space") or setting aside spectrum for shared unlicensed use.[36] Wi-Fi remains the gold standard as an example of innovation for unlicensed spectrum.

So is the spectrum capacity a ticking clock (a decidedly analog metaphor), as forewarned by the FCC, truly a sign of oncoming communications cataclysm or just a pleasant sounding, antiquated timepiece? The troubling fact is that we do not know. This study is motivated by a desire to acquire tangible evidence of spectrum usage. The context for the study, and the method, are discussed hereafter.

The Canadian Spectrum Scarcity Debate

The Canadian government general revenues receive a substantial boost from successful auctions such as the $5.2 billion raised in the 700 MHz spectrum auction in 2014. While this is a sizable windfall for the government, these licenses in Canada are for twenty years; the initial investment seems less dramatic when amortized over that period. The licensed Canadian spectrum that is the focus of this study is extremely valuable, yet little information can be found in the public domain. Given the uncertainty of most of the publicly accessible data (as explained below), and the results of studies in the United States that showed large reserves of unused spectrum in urban areas, we approached this project thinking that it was very possible that Canadian mobile operators had not deployed service on newly acquired spectrum or, if deployed, were experiencing low traffic density.[37]

35. Wallsten.

36. Noam; Freyens and Loney; Cave and Webb, "The Unfinished History"; Werbach and Mehta.

37. Bacchus, Zdunek, and Roberson; McHenry and Vilimpoc; Werbach and Mehta.

In Canada, the ministry responsible for spectrum policy and management, Innovation, Science and Economic Development Canada (or ISED, formerly known as Industry Canada), operates a publicly accessible Spectrum Management System.[38] This system allows individuals to search for spectrum license holders in certain geographic areas and the accessible data indicates whether the license has not been approved but is pending, or whether the license has been officially approved. There is no available data to determine whether or not the spectrum assigned to license holders is actually in use. The government has introduced policy measures to discourage "warehousing" of spectrum with a 2013 "use it or lose it" clause stipulating specific roll out conditions under clear time frames for spectrum license holders.[39] The auctions held prior to 2013, including the 292 licenses for AWS-1 (2008) and the 52 licenses of personal communication service (PCS) spectrum (2001) had no such conditions attached. Currently, no Canadian spectrum license holder has lost access to the public airwaves because it has failed to deploy service.

So, despite reference by former Canadian Industry Minister Tony Clement that spectrum is the "oil of the 21st century,"[40] there continues to be great uncertainty regarding the fundamental question of need and usage for this key resource. Like oil, the "peak spectrum" theory is strongly contested. Demand is intense but exactly what has happened with spectrum already allocated remains a cloudy issue. The most recent spectrum inventory in Canada was conducted in 2010 and it offered a mixed conclusion: frequencies auctioned in 2008 were 100 percent licensed, but only about a third of this capacity was in use.[41] Despite spectrum since licensed in the 700 MHz (2014), AWS-3 (2015), and 2500 MHz (2015) frequencies, no detailed spectrum data was made public in the ensuing years, so the use of these prime frequencies remains something of a mystery. This fundamental point was essentially conceded by the Canadian government in 2015 when they announced a plan for a Spectrum Analytics Center in Ottawa to allow for the "collection, analysis and visualization of spectrum usage data."[42] This still-unbuilt center is an indirect admission that this key information has been lacking in Canada, despite the immense value of spectrum to contemporary communications.

38. http://sms-sgs.ic.gc.ca/eic/site/sms-sgs-prod.nsf/eng/h_00010.html

39. Industry Canada, "Decisions Concerning the Renewal."

40. Industry Canada, "Speaking Points."

41. Industry Canada, "Radio Spectrum Inventory."

42. Industry Canada, "Digital Canada."

In Canada, recent years have been witness to a very public battle between the three major incumbent mobile operators and the Conservative government of Stephen Harper, which was in power from 2006 to 2015.[43] The government launched a determined campaign to ensure existing mobile operators did not block new market entrants by purchasing all spectrum brought to auction. The Canadian government used a range of policy tools including spectrum caps, set asides, and blocked spectrum purchases in an attempt to bring a coveted fourth national player into the Canadian mobile market. Essentially, the Canadian government's position during this period was that the incumbent mobile operators had more than enough spectrum for the time being and increased competition was the priority.[44]

To understand the demand for spectrum in Canada, we reviewed submissions to Industry Canada's "Consultation on a Policy and Technical Framework for the 700 MHz Band and Aspects Related to Commercial Mobile Spectrum," originally made public in November 2010. This consultation was key in setting the parameters for the auction of the Canadian digital dividend (the 700 MHz band). On the topic of a spectrum shortage in Canada, submissions varied wildly depending upon the market position of the company.

In their 2011 comments submitted in the consultation, the Big Three were unanimous that an impending spectrum crunch was a real and present danger to the Canadian mobile industry.

> It is widely acknowledged that the industry faces a pending spectrum crunch in the very near future.[45]

> Capacity limits are a true threat in the face of continued growth in wireless data.[46]

> There is no merit to the claims that TELUS has no spectrum scarcity and that TELUS is using spectrum inefficiently. Explosive growth in mobile data demand is challenging TELUS' networks and spectrum holdings.[47]

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43. Dobby.

44. The Canadian mobile industry is dominated by the "Big Three" incumbent companies: Rogers, with 33 percent market share; Bell at 28 percent; and Telus at 29 percent. Numerous other regional and smaller players divide the remaining 10 percent of the market. Canadian Radio-Television and Telecommunications Commission, "Communications Monitoring Report."

45. Bell Mobility Inc.

46. Rogers Communications Inc.

47. Telus Inc.

Thus, the spectrum crisis was presented to the Canadian government as an irrefutable truth. However, smaller carriers across Canada (who then collectively controlled less than 10 percent of the market)[48] presented a starkly different position before the regulator and offered arguments that ran contrary to the prevailing orthodoxy of spectrum scarcity put forth by the Big Three.

> It would seem that any spectrum scarcity that may exist is being manufactured, at least in part, by the Big Three. EastLink submits that there is no reason to believe that the Big Three have any legitimate need for additional spectrum in most areas of Canada.[49]

> The incumbent operators have no obligation to acquire spectrum, nor do they clearly have any desperate need, as evidenced by the lack of deployment in the AWS band.[50]

Thus the paramount question, "is there a spectrum shortage in Canada?" depends upon whom you ask. There is no neutral voice. The government itself offered no clear data to support either side of the debate. In the Policy and Technical Framework for the 700 MHz auction Industry Canada simply stated, "most respondents indicated the need for more spectrum to be reallocated to commercial wireless usage going forward."[51] A 2011 study out of the United States listed Canada as the least efficient user of licensed spectrum when measured against the United States, Japan, Germany, the United Kingdom, France, Italy, Spain, South Korea, and Mexico.[52] There is no publicly available Canadian data to support or contest this position.

In the international literature and in the Canadian mobile marketplace, there is no clear consensus regarding the supply of the foundational resource. We know for certain that mobile demand has seen explosive growth and there is a clear economic incentive for companies to seek access to ever more frequencies by convincing regulators that the well is running dry. It was in this environment of uncertainty that we decided to find our own measurements for spectrum usage in urban Canada.

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48. Canadian Radio-Television and Telecommunications Commission, *Communications Monitoring Report*.

49. Bragg Communications Inc. (Bragg is the parent company of Eastlink).

50. Mobilicity Inc.

51. Industry Canada, "Policy and Technical Framework."

52. Carpenter.

Methodology

In the summers of 2013 and 2015, we measured spectrum usage in a public space at one of Canada's busiest urban intersections: Yonge-Dundas Square in downtown Toronto (see Figure 1). We were convinced that if a spectrum shortage exists in Canada, it would be most apparent at a major urban center, where spectrum should be in highest demand. If there was no shortage there, it could likely be concluded there is no spectrum shortage anywhere in the country.

A list of spectrum licenses in the chosen study area was compiled using the Spectrum Direct Geographical Area search on the Industry Canada website.[53] Coordinates for the location were acquired using Google Maps and entered into the search area on the Spectrum Direct site. The study area was chosen because it is a place of great population density and high usage of mobile services in this location was assumed. For each of the two periods of analysis, two electrical and computer engineering students collected data using a spectrum analyzer (see Figure 2). While other activity may be visible on the spectrum visualization, our focus was the licensed mobile frequencies. In 2013, we analyzed three of the licensed spectrum bands in Canada. The station type for the search was set to Spectrum License stations with the radius of the search set to 0.2 km, after a search of one km showed over 450 transmitters in the area—a number too difficult to monitor. Data were collected every 30 minutes for each licensed band in 12-hour shifts on July 2 and September 5, 2013. In June 2015 this procedure was repeated at the same location, using the same equipment, in order to view the deployment of the valuable 700 MHz frequencies, auctioned in February 2014. Two additional bands licensed in 2015 were not analyzed in the study, as it was determined that it was too early to expect full use of the frequencies: the AWS-3 band (auction completed in March 2015) and the Broadband Radio Service 2500 MHz band (auctioned in May 2015). Though there was not a blade of grass in sight, the methodology clearly draws upon what Parks calls "fieldwork" where geophysical positioning is key to research.[54]

We monitored the bands shown in Table 1, licensed by mobile operators in Canada.

53. Industry Canada is now ISED and this database is now called the Spectrum Management System.

54. Parks, "Earth Observation."

TABLE 1 Spectrum Bands Monitored in this Study

	Tx (transmission frequency)	Rx (receiving frequency)	Year Auctioned/ Licensed
Cellular	869–894 MHz	824–849 MHz	1983
Personal Communication Services	1930–1995 MHz	1850–1915 MHz	1995, 2001, 2008
Advanced Wireless Services	2110–2155 MHz	1755–1780 MHz	2008 (auction)
Mobile Broadband Service (2015 readings only)	728–746 MHz 746–756 MHz	698–716 MHz 777–787 MHz	2014 (auction)

FIGURE 1 Study location.

Apparatus: The measurements were taken using a broadband omnidirectional antenna SAS-2300 available from ARA Inc. This antenna had two connectors: one for low band (20–1000 MHz) and the other for high band

FIGURE 2 Tektronix WCA380 spectrum analyzer.

(800–3000 MHz). This is a fairly rugged antenna ideal for spectrum surveillance applications. The antenna is followed by two low noise amplifiers, for both low and high bands. The lower cutoff of the low band low noise amplifier was selected to be about 580 MHz although the antenna could operate all the way down to 20 MHz. This is because we were not interested in frequencies lower than ~600 MHz. Outputs of the low noise amplifiers were connected to a Tektronix WCA 380 Wireless Communications Analyzer that works from DC to 8 GHz. The transmission link from the antenna to the WCA 380 had 50 ohm impedance. The span and video bandwidth settings on the WCA were appropriately selected to get the best spectrum snapshot.

What We Found

Image shots from the spectrum analyzer were taken on the licensed bands of interest every thirty minutes over two separate days in 2013 and two days in 2015. Though there are dozens of images available and on file for this project, the images chosen for presentation in this article were all taken at roughly 17:00. We thought this would demonstrate peak demand since many people in the area are leaving work, as well as students leaving a nearby university at that point of the day. Also, this time coincided with rush hour and there is a busy subway station and public square within the range of the spectrum analyzer.

The following images show output from the spectrum analyzer at approximately 17:00 on two days in each year of the project: July 26 and September 5, 2013, and June 16 and 18, 2015. The images are best viewed in color. Figure 3 offers a guide for interpreting the images. All our measurements

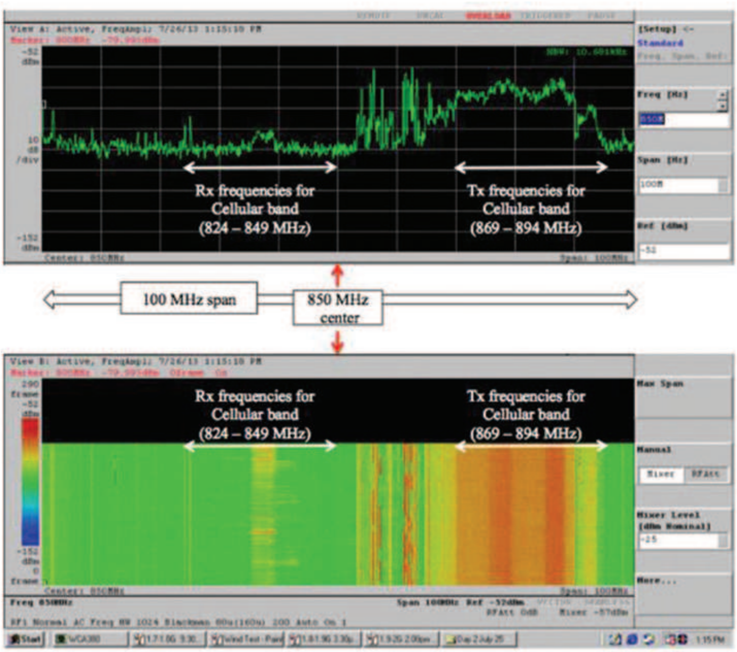

FIGURE 3 An explanation of spectrum analyzer output.

used a span of 100 MHz, meaning that we measured activity in a 100 MHz range. Mobile broadband spectrum is licensed in paired frequencies: Tx frequencies are the spectrum used to transmit from the tower to the mobile device; Rx frequencies are what the tower receives from the device.

In Figure 3, the range is from 800 MHz to 900 MHz, which is the cellular band. Each image has two views. View A on the top shows the spectrum usage at a single point in time, with the bandwidth setting determining the scale for the vertical axis. Each vertical line in View A measures 10 MHz, with the center at 850 MHz (the center for each image is noted on the lower left of Views A and B). The frequencies licensed to mobile operators in this band are shown with white arrows superimposed on Views A and B. View B, at the bottom of the image, is a waterfall history or heat map view, and shows spectrum usage over time. Red shading on the heat map indicates higher usage than areas shaded in orange, yellow, or green. (When viewing the figures in black and white, the heaviest usage is shown as a darker grey color.) The heat map is drawn with horizontal data from each point in time transformed into colored dots and plotted on a line by line basis. Each heat map shows a summary of the spectrum usage for the previous few minutes and provides a more easily understood overview of the usage patterns. In View B of Figure 3, the portions of the spectrum most heavily used are shown with the dark red vertical bands, one below 880 MHz and one below 890 MHz, corresponding to the Tx spectrum licensed to mobile operators Rogers and Bell respectively.

The Bands

Cellular: 824–849 MHz Rx/869–894 MHz Tx (Figures 4–7)

This band is the oldest of the licensed frequencies in Canada. The call for licenses was issued by the Department of Communications in 1982. In 1983 the then Minister of the Department of Communications, Francis Fox, announced that CANTEL (now Rogers Wireless Inc.) was the successful applicant and also invited telephone providers to offer service, which is how Bell got access.[55] This spectrum was awarded via administrative process, not auction.

In the study location, there are two licensed operators on this band, Rogers at 869–877 MHz and Bell at 882–886 MHz (Tx). To view spectrum

55. Industry Canada, "A Brief History."

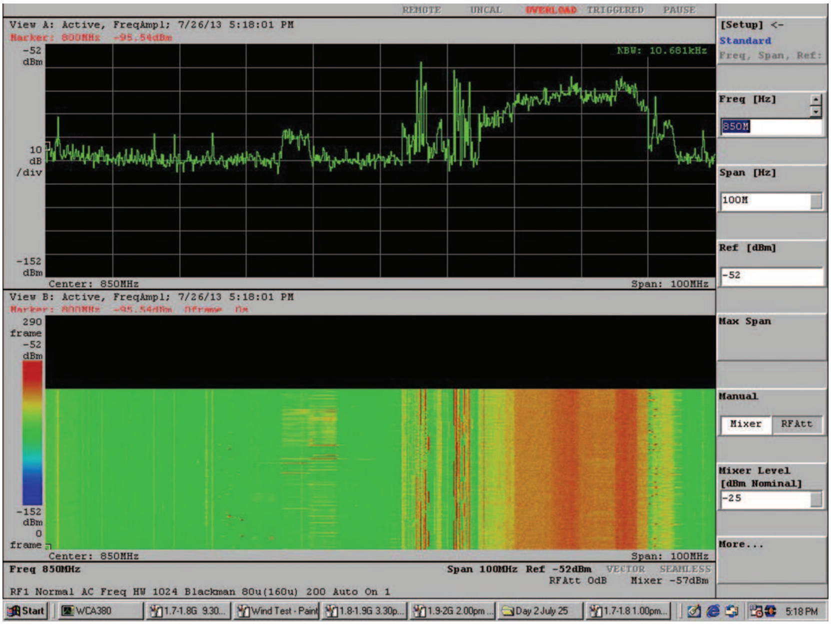

FIGURE 4 Cellular—July 26, 2013, 17:18 (center 850 MHz).

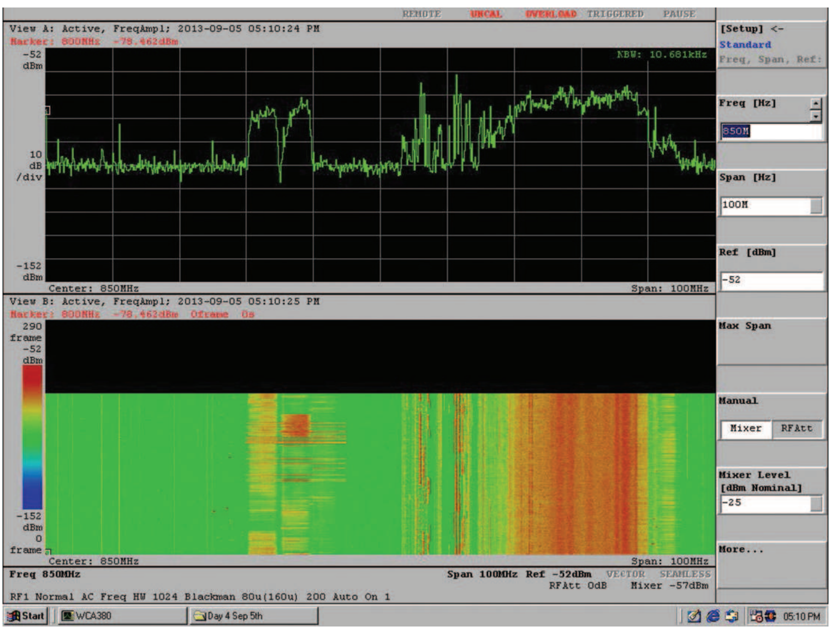

FIGURE 5 Cellular—September 5, 2013, 17:10 (center 850 MHz).

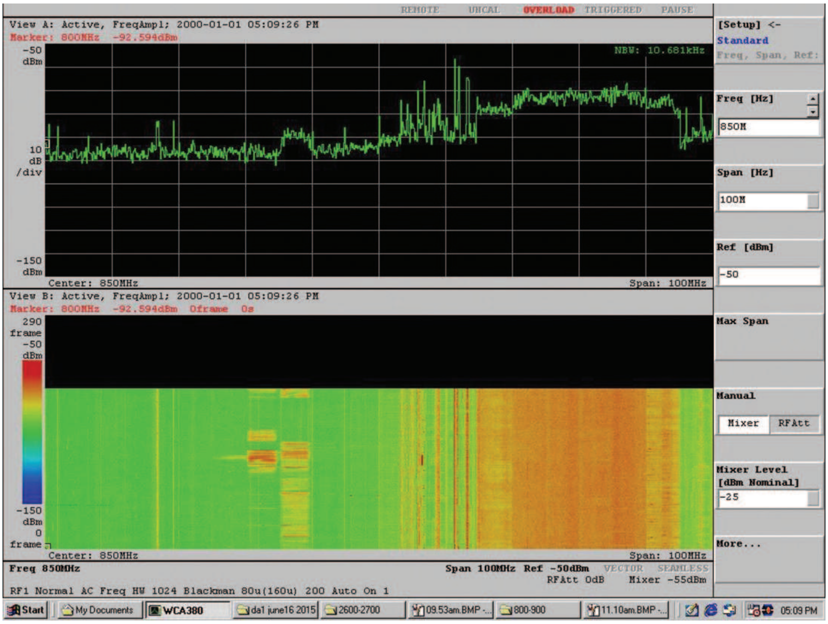

FIGURE 6 Cellular—June 16, 2015, 17:09 (center 850 MHz).

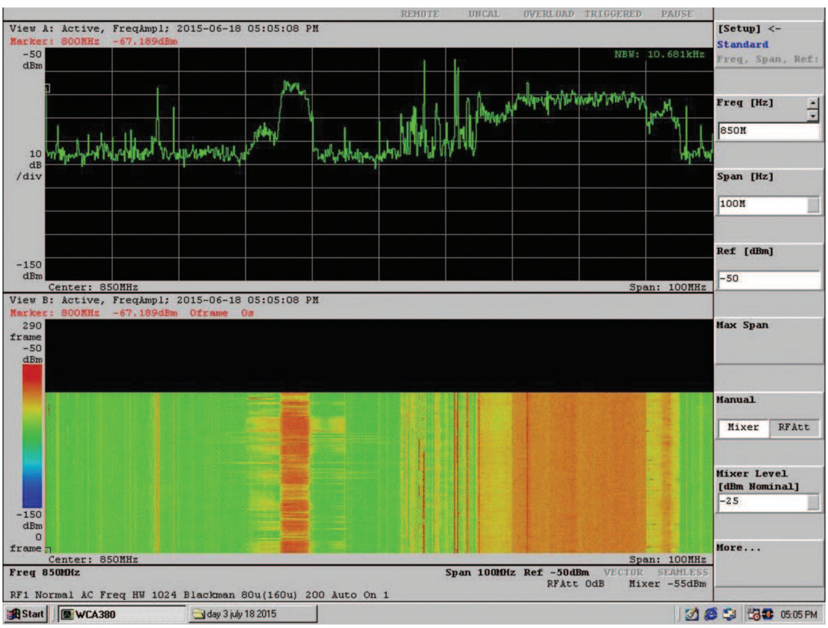

FIGURE 7 Cellular—June 18, 2015, 17:05 (center 850 MHz).

usage on this band, we analyzed a 100 MHz span from 800 to 900 MHz. In the figures that follow for this band, 850 MHz is the center line.

Interpreting the data: the analyzer indicates regular usage on the right side of the screen. The first section, 869–877 MHz (to the right of the 850 MHz center line), is licensed to Rogers and shows sporadic, generally not high-density usage. The heat map portion (lower) shows only intermittent high-density red. These are the frequencies where in 2015 Rogers still operated GSM (second generation) mobile systems—phones that preceded the smartphone data deluge and are often just voice. The Bell frequencies further to the right demonstrate consistent strong usage and high density. The data shows little change between 2013 and 2015.

Personal Communication Services (Figures 8–11)

This spectrum also predates the auctioning approach to spectrum assignment in Canada. In 1995, licenses were awarded via administrative process. In a bit of Canadian spectrum policy foreshadowing, the PCS licensing procedure was an unsuccessful effort to bring new players into the mobile sector. Two of the main PCS spectrum winners, Microcell and Clearnet, were later bought by Rogers and Telus respectively. Public Mobile paid for its PCS spectrum in 2008 but was acquired by Telus in 2013.

Rogers (Tx): 1930–1941 MHz; 1970–1971 (also used by Fido, a Rogers discount service)
Bell (Tx): 1945–1948; 1960; 1962; 1965–1967; 1985–1987
Telus: (Tx) 1950
Public Mobile (Tx): 1990

Note that the spectrum analyzer output in Figures 8–11 shows these frequencies in GHz (1 GHz = 1000 MHz), and the center line is at 1.95 GHz (1950 MHz).

Interpreting the data: there is strong use of the PCS frequencies. Telus, which showed less usage on the chart with its center line 1.95 frequency in 2013, had gained strength by 2015. Public Mobile on the far right (independent in 2013 but owned by Telus in 2015) is active though clearly not as strong as the major incumbents. Bell and Rogers have consistent high-density traffic.

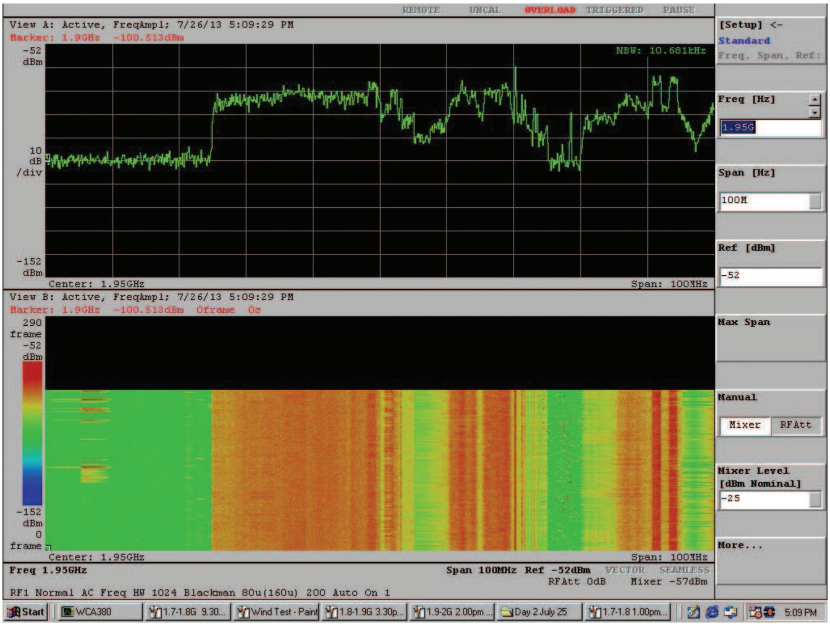

FIGURE 8 PCS—July 2, 2013, 17:09 (center 1950 MHz).

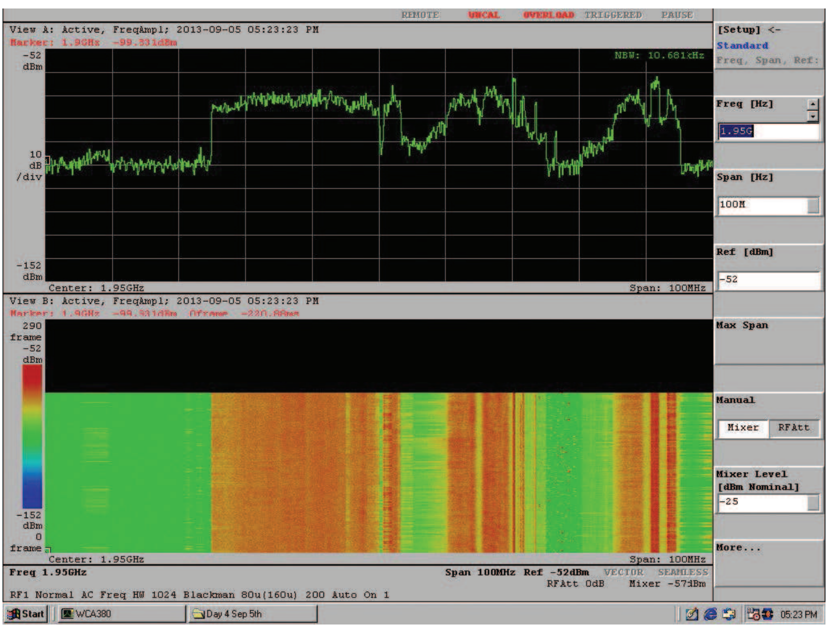

FIGURE 9 PCS September 5, 2013, 17:23 (center 1950 MHz).

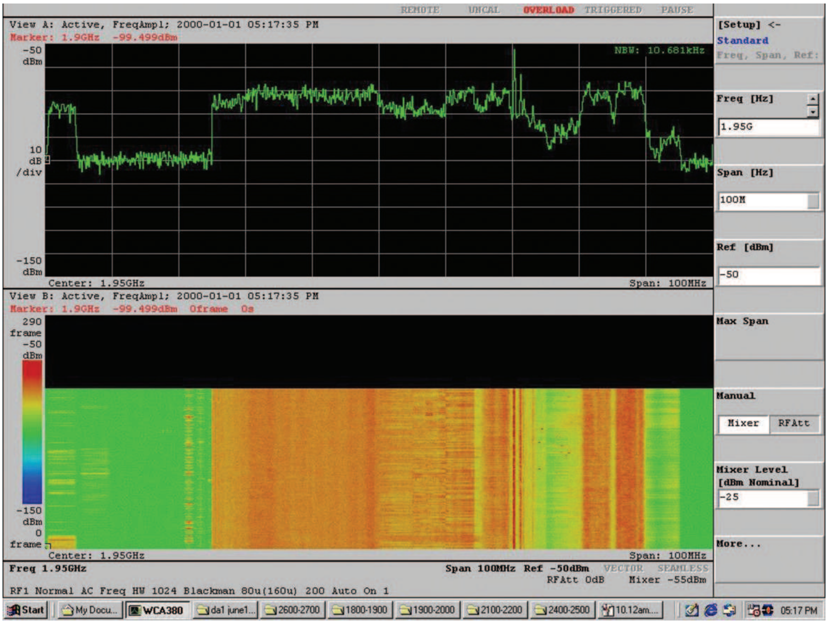

FIGURE 10 PCS—June 16, 2015, 17:17 (center 1950 MHz).

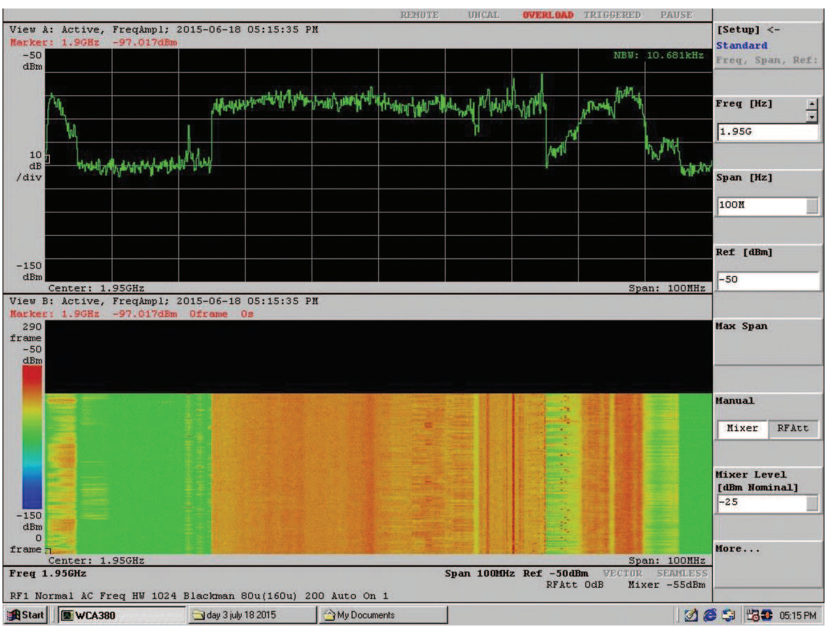

FIGURE 11 PCS—June 18, 2015, 17:15 (center 1950 MHz).

Advanced Wireless Services (Figures 12–15)

This spectrum is particularly controversial because Rogers and Bell had not launched here in 2010, the time of the last spectrum inventory conducted by Industry Canada. The AWS spectrum was awarded via auction in 2008 with approximately 40 percent of the spectrum set aside for new entrants (incumbents could not bid). The start-up companies Wind (now operating as Freedom Mobile) and Mobilicity launched with spectrum acquired via this set aside.

Rogers (Tx): 2115 MHz
Wind (Tx): 2120
Mobilicity (Tx): 2130
Bell (Tx): 2145; 2150

Interpreting the data: There has clearly been growth in the AWS frequencies in the two years between readings. Wind and Mobilicity frequencies are more active in 2015, as visualized by the higher levels of red in the heat map, though the density of use is somewhat less than Rogers and Bell.

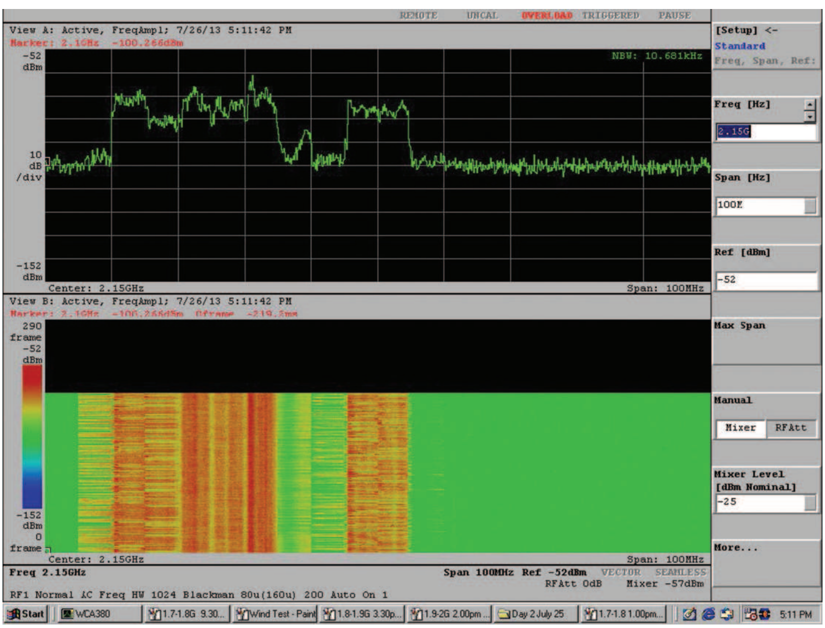

FIGURE 12 AWS—July 26, 2013, 17:11 (center 2.15 GHz/2150 MHz).

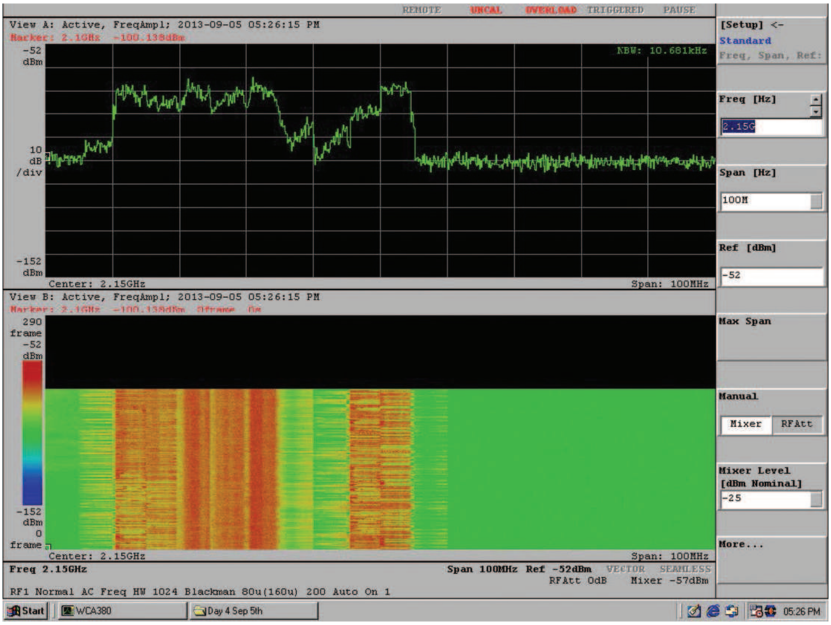

FIGURE 13 AWS—September 5, 2013, 17:26 (center 2150 MHz).

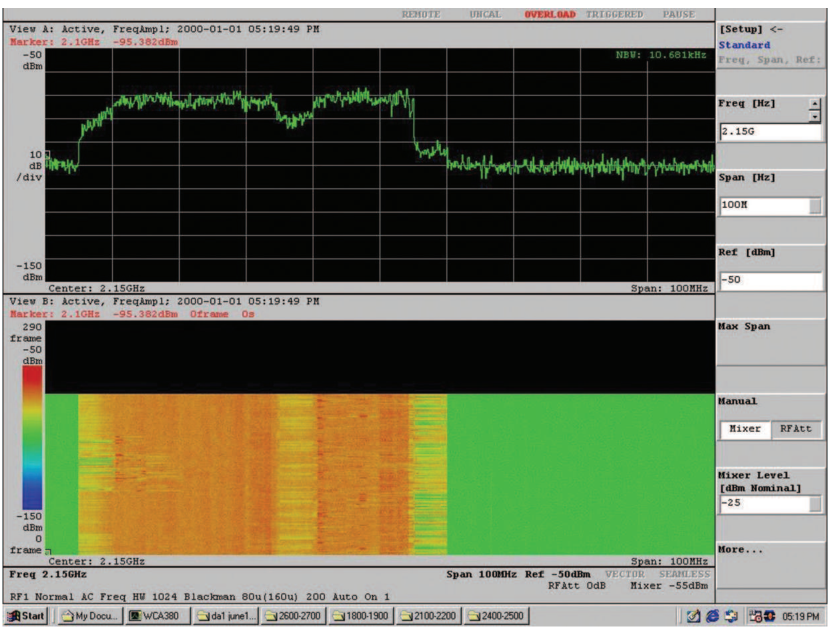

FIGURE 14 AWS—June 16, 2015, 17:19 (center 2150 MHz).

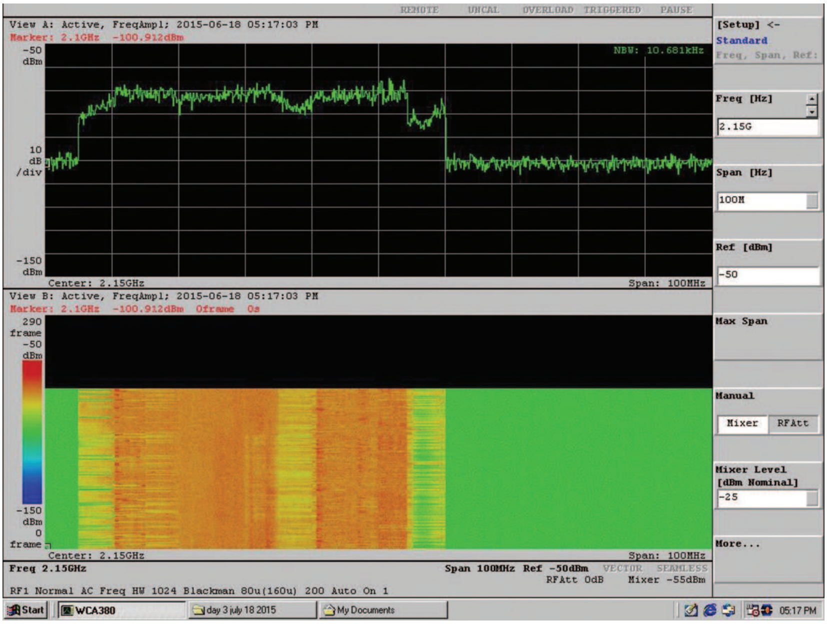

FIGURE 15 AWS—June 18, 2015, 17:17 (center 2150 MHz).

Mobile Broadband Services (Figures 16–18)

No spectrum licenses went through as long a policy incubation period as the MBS (700 MHz). In order for these frequencies to be auctioned, a large portion of the OTA television broadcast sector had to be shifted to free up space. The strong propagation properties of the 700 MHz band mean signals can travel further, through barriers, with fewer towers required. The readings for MBS were only conducted in 2015, so we offer readings over three days to demonstrate consistency.

Rogers was by far the most active in the 700 MHz auction, spending over $3.2 billion of the $5.2 billion raised in the auction. This was reflected in the study location where Rogers was the sole operator licensed to deploy on the 700 MHz frequencies. The activity of mobile providers in the spectrum analyzer in the middle to left is exclusively from Rogers licenses.

Rogers (Tx) 731.5–737

Interpreting the data: Rogers had been aggressively promoting its new LTE as the first in Canada and by the summer of 2015 it was clearly in use on the 700 MHz band in the study location. The majority of its license traffic demonstrates dense usage.

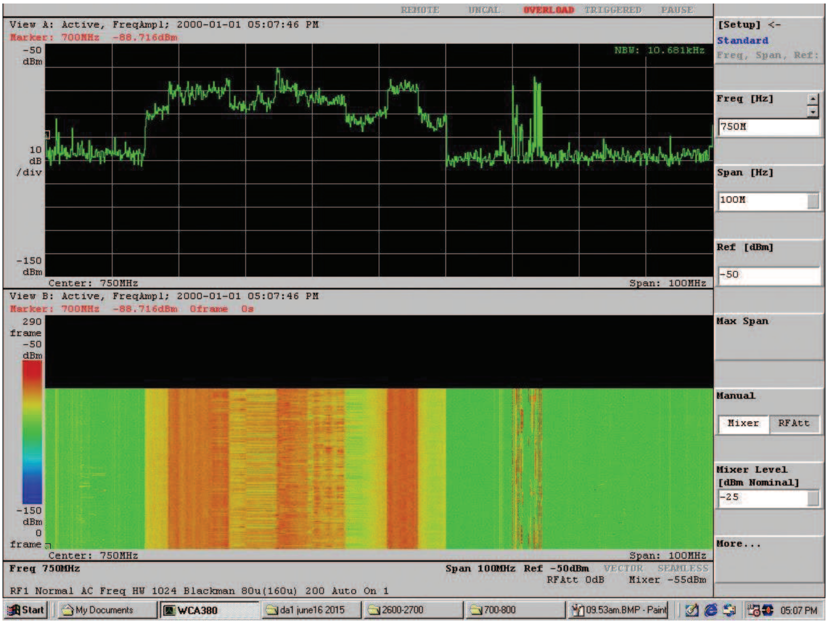

FIGURE 16 MBS—June 16, 2015, 17:07 (center 750 MHz).

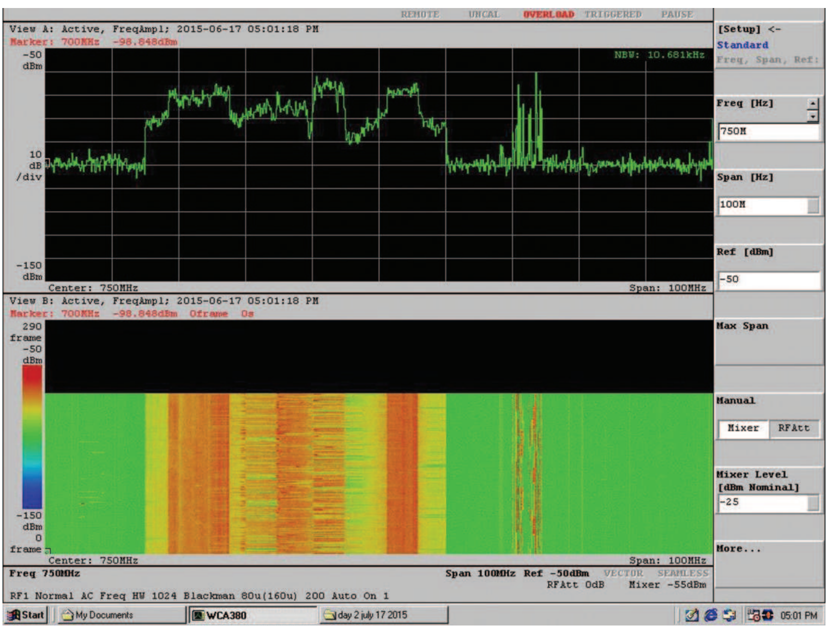

FIGURE 17 MBS—June 17, 2015, 17:01 (center 750 MHz).

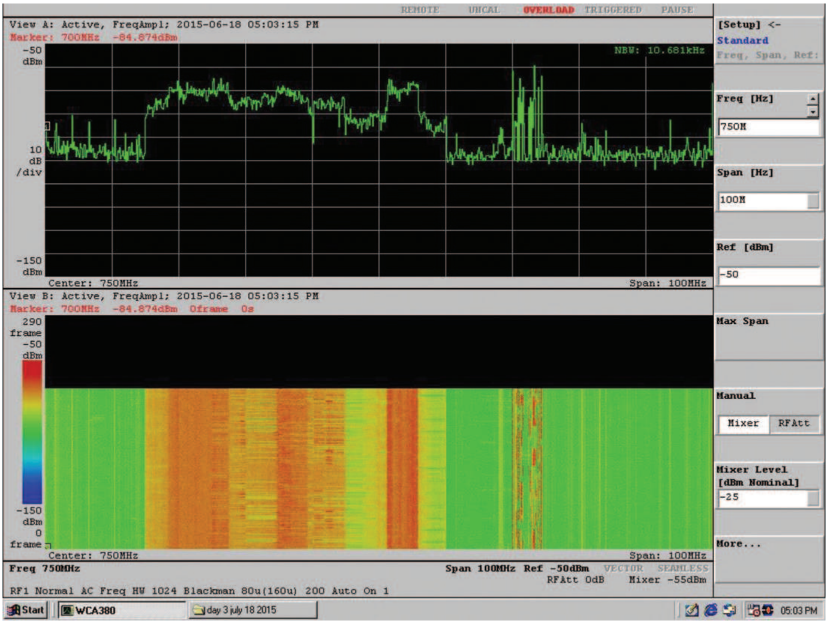

FIGURE 18 MBS—June 18, 2015, 17:03 (center 750 MHz).

Results

With these analysis charts, this article attempts to bring visibility to the spectrum, what Parks refers to as "infrastructure intelligibility."[56] We have thrown some paint on mobile technology's invisible force.

It is important to emphasize that these results are not presented with a pretense of precise scientific accuracy. For example, transmissions from the tower to the receiver are much stronger signals than receiver to tower and will certainly appear more prominently in the readings. We also cannot account for all activity visible on the charts since there are other uses allocated on these bands beyond mobile broadband. However, the readings were consistent enough to indicate patterns that speak to the deployment of licensed spectrum in urban Canada.

The data clearly demonstrates that mobile operators have indeed launched services in Canada's busiest urban center, including the AWS frequencies, which had been reported largely idle in the 2010 Canadian Spectrum Inventory. The 2015 measurements also showed activity on the recently auctioned 700 MHz MBS channels. The density of traffic varied

56. Parks, "Technostruggles," 67.

but the data indicated that the hypothesis that the spectrum was being "warehoused" (owned but not deployed) was proven untrue in this downtown area. Rogers showed less traffic on its cellular frequencies; however, there is reason to expect technology in this band will be sunset in the years to come, allowing for use of newer, more popular devices. In one of the most urban sites in Canada, there was clearly strong traffic in all licensed bands.

However, the data revealed something unexpected for us. The usage measured in the preceding images was taken from examining the transmission (Tx) frequencies—the spectrum used to transfer data from the tower to the handheld device. This is what one would use if surfing the Internet on a smart phone.

Something much different appeared when examining the Rx frequencies—the spectrum used for uploading data from devices to the antenna tower. The following images emphasize the Rx frequencies in the same bands at approximately 17:00 on the days of the experiment.

Cellular: Rx: 824–849 MHz (left side of the screen, Figures 19–22)

Rogers 842–832 MHz
Bell 837–841 MHz

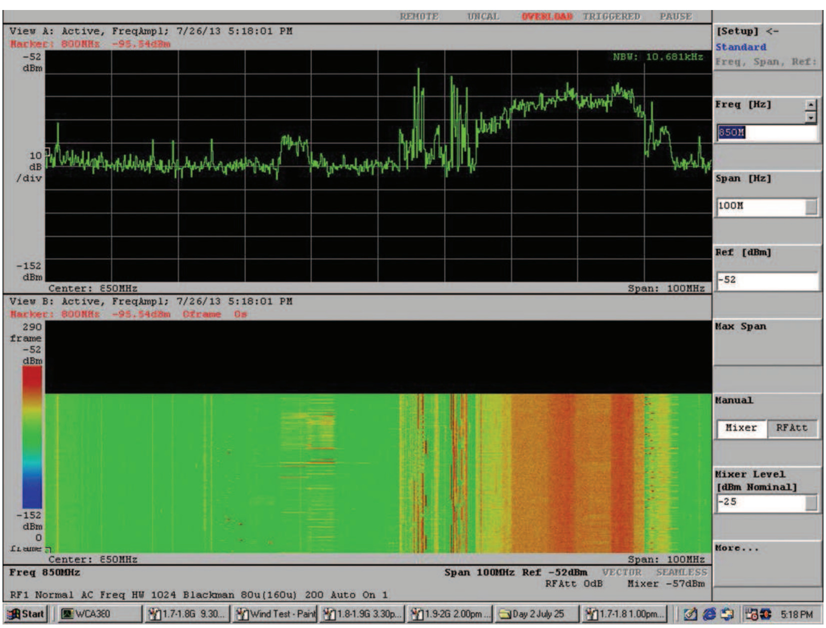

FIGURE 19 Cellular—July 26, 2013, 17:18 (center 850 MHz).

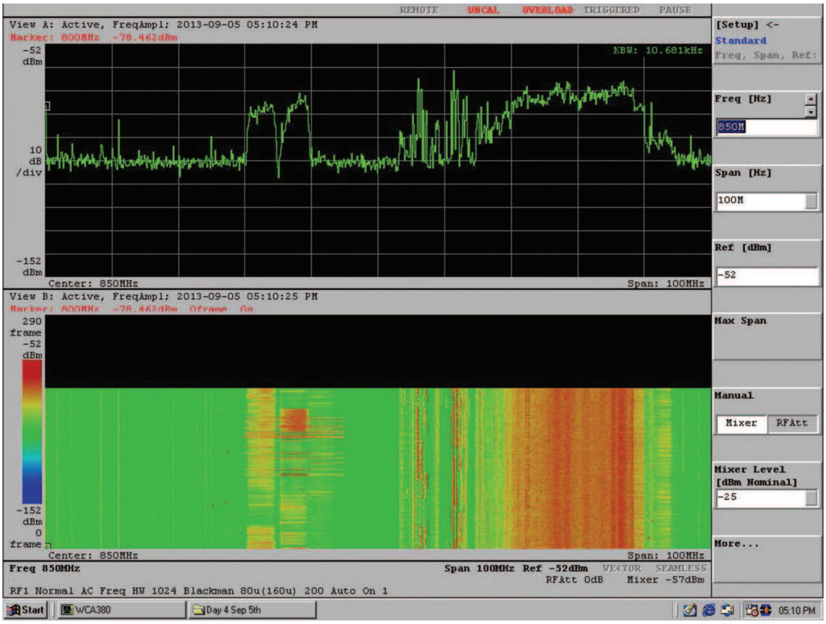

FIGURE 20 Cellular—September 5, 2013, 17:10 (center 850 MHz).

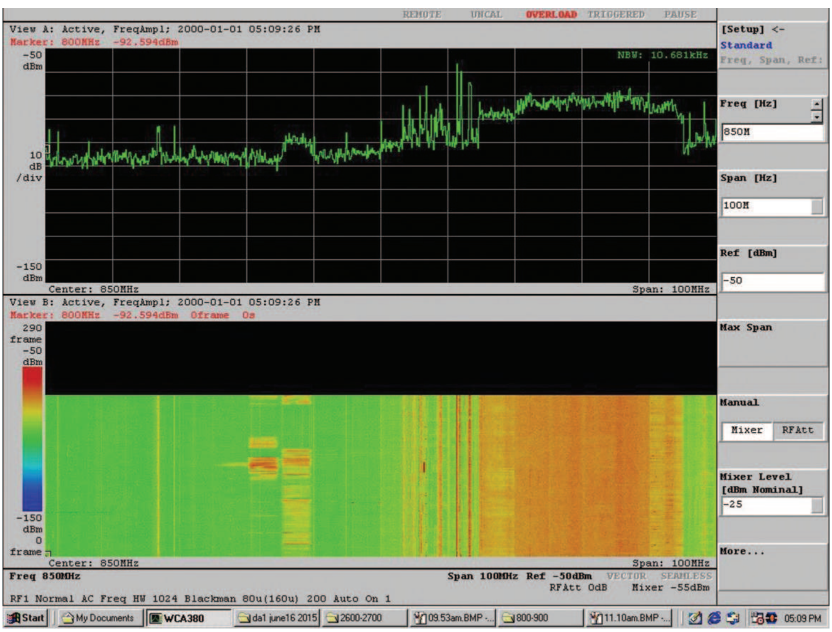

FIGURE 21 Cellular—June 16, 2015, 17:09 (center 850 MHz).

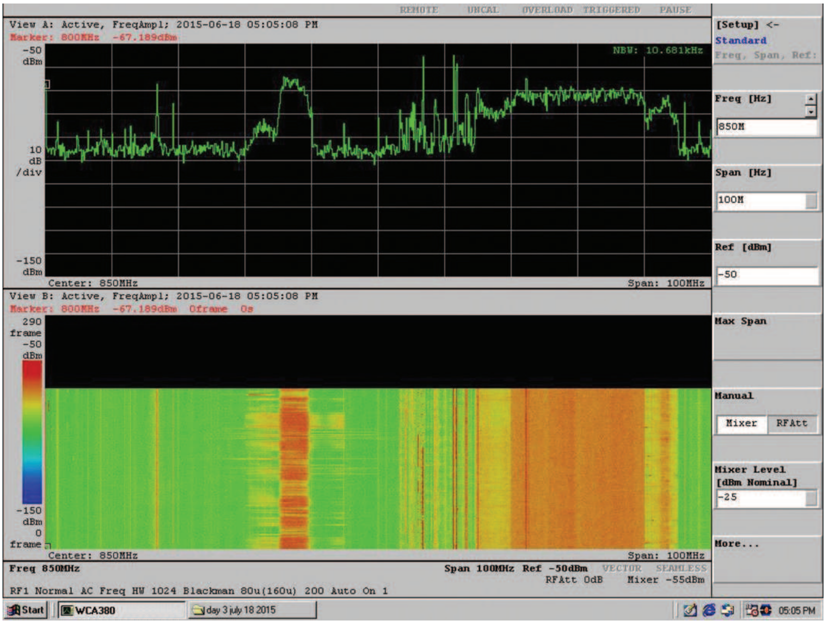

FIGURE 22 Cellular—June 18, 2015, 17:09 (center 850 MHz).

Personal Communication Services Rx (1850–1915 MHz, Figures 23–26)

Fido (Rogers) 1850–1861 MHz
Bell 1866–1887, 1902–1907 MHz
Rogers 1890–1892

Advanced Wireless Services Rx (1710–1755 MHz, Figures 27–30)

Rogers 1715 MHz
Wind 1720 MHz
Mobilicity 1730 MHz
Bell 1747.5 MHz

Mobile Broadband Services Rx (698–716, 777–787 MHz, Figures 31–33)

Rogers 701, 707 MHz

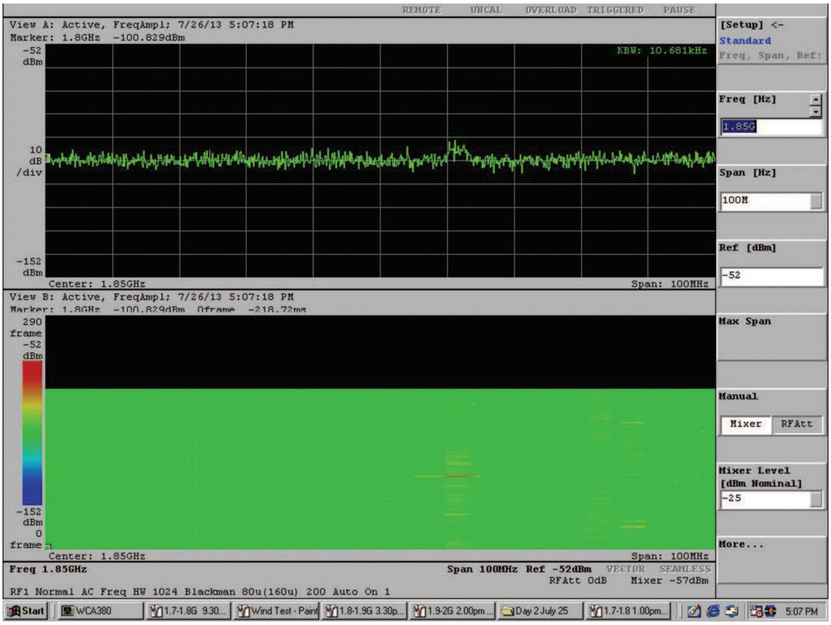

FIGURE 23 PCS—July 26 2013, 17:07 (center 1850 MHz).

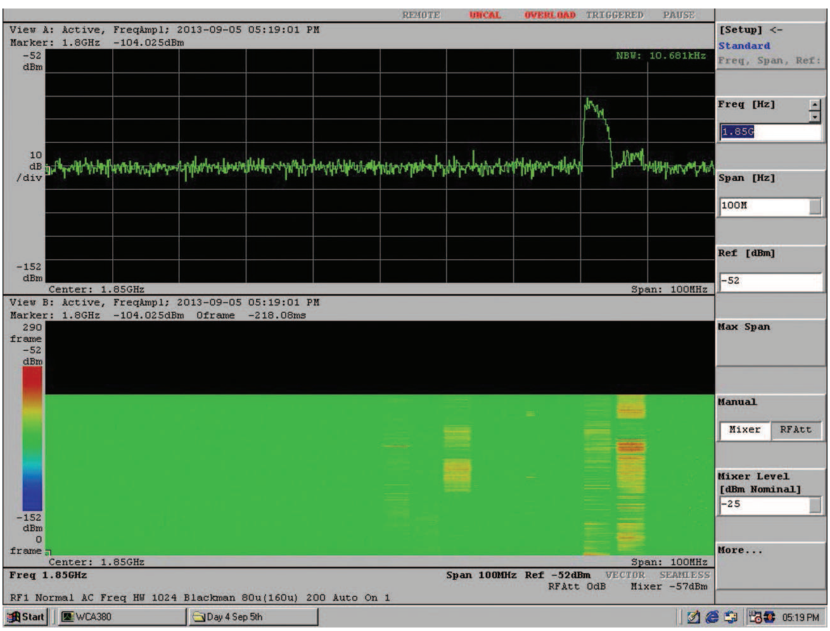

FIGURE 24 PCS—September 5, 2013, 17:19 (center 1850 MHz).

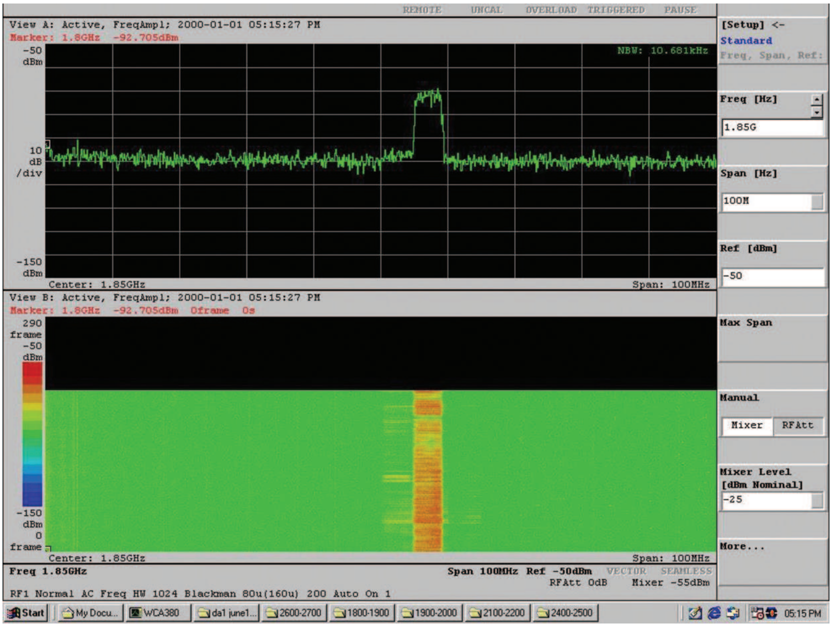

FIGURE 25 PCS—June 16, 2015, 17:15 (center 1850 MHz).

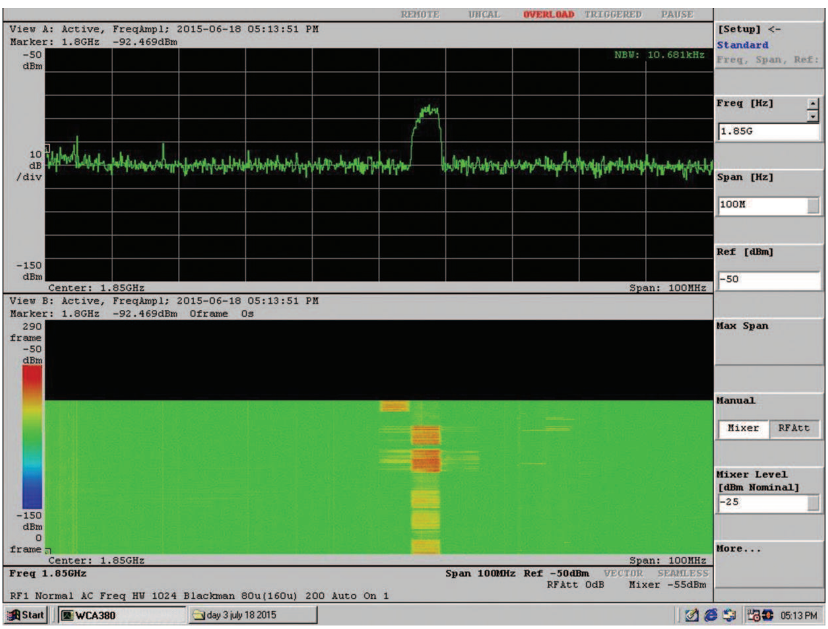

FIGURE 26 PCS—June 18, 2015, 17:13 (center 1850 MHz).

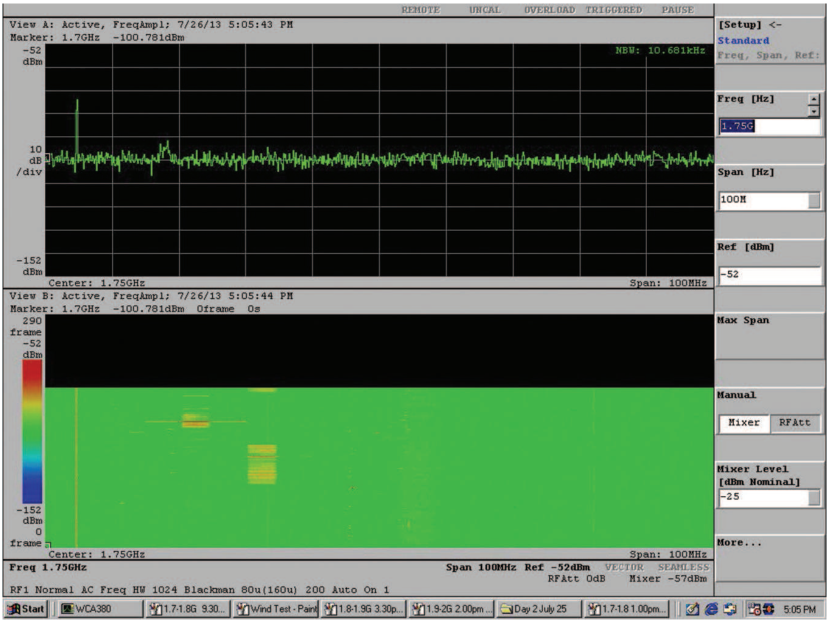

FIGURE 27 AWS—July 26, 2013, 17:05 (center 1750 MHz).

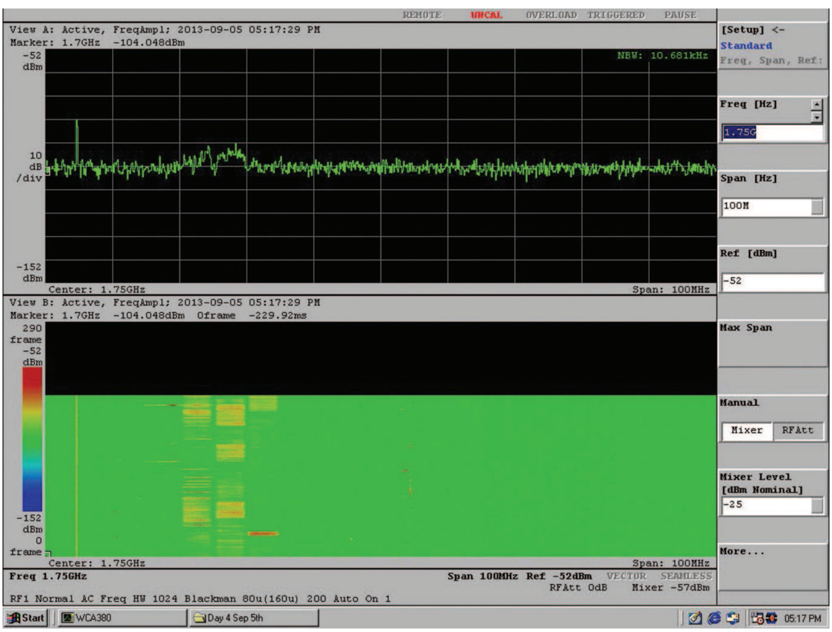

FIGURE 28 AWS—September 5, 2013, 17:17 (center 1750 MHz).

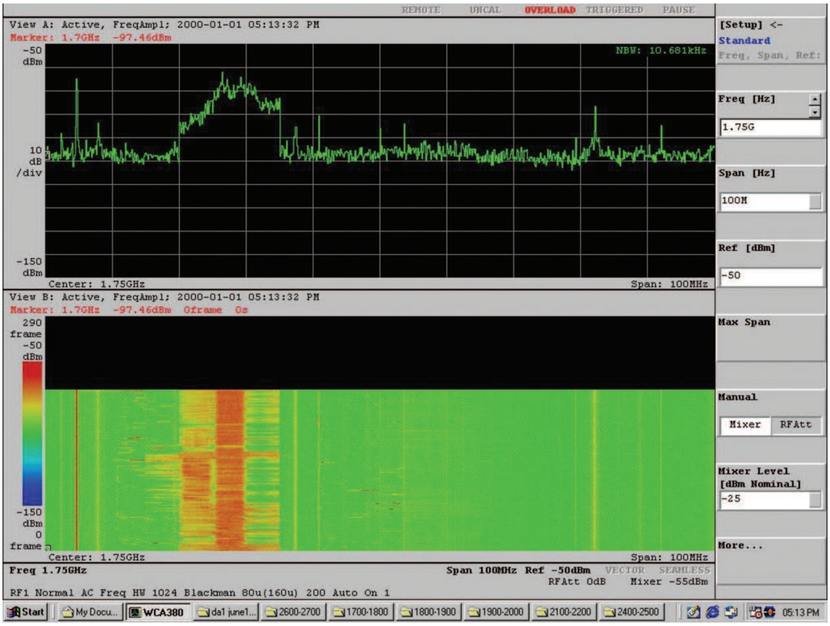

FIGURE 29 AWS—June 16, 2015, 17:13 (center 1750 MHz).

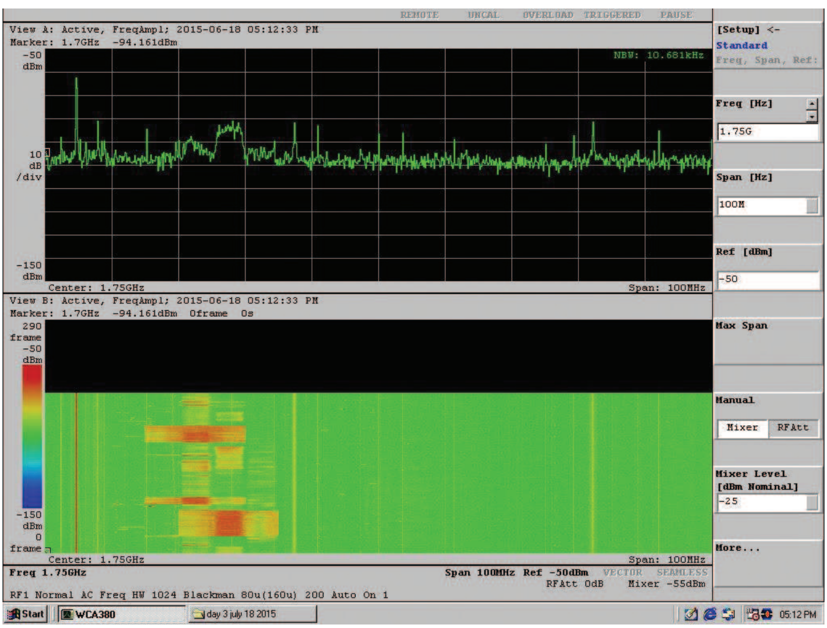

FIGURE 30 AWS—June 18, 2015 (center 1750 MHz).

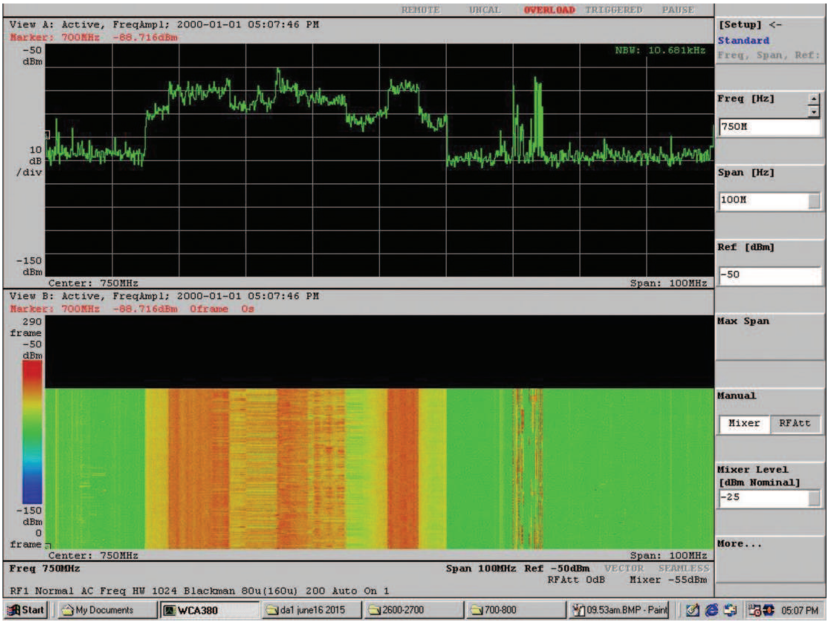

FIGURE 31 MBS—June 16 2015, 17:07 (center 750 MHz).

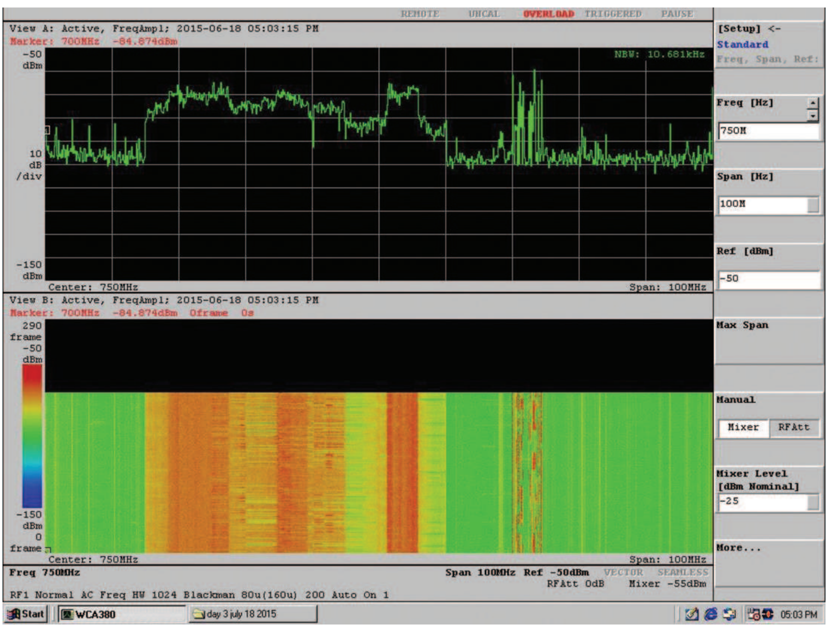

FIGURE 32 MBS—June 18, 2015, 17:01 (center 750 MHz).

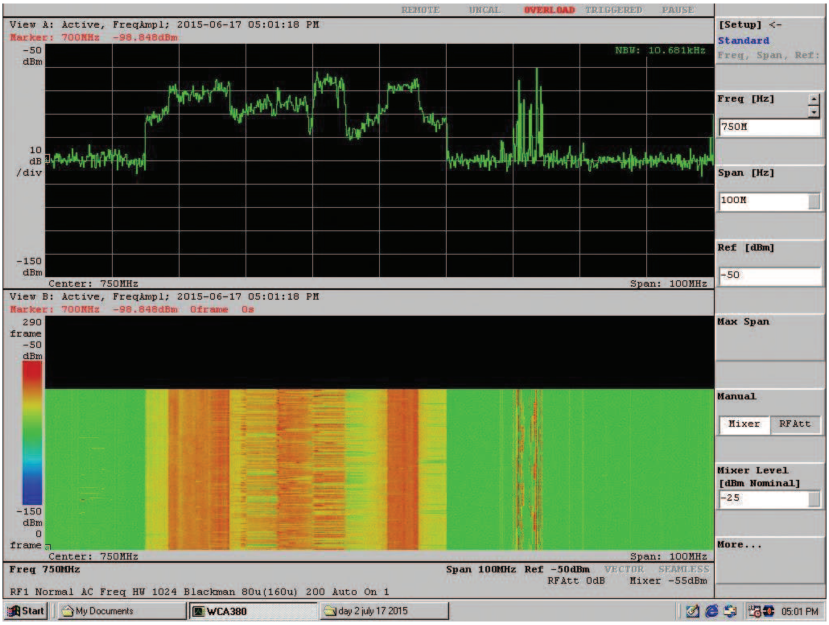

FIGURE 33 MBS June 17, 2015, 17:01 (center 750 MHz).

Rx Results

> Voice communications has little or no growth. . . . But it set the pace on how we use spectrum. It requires paired spectrum and low latency. And notice 3G, which was supposed to be a data service, is constructed as if it was voice—it's paired, symmetric spectrum. And it's a terrible waste of spectrum. . . .[57]

For three of the four licenses, the spectrum analyzer data clearly demonstrated far less traffic on the Rx frequencies. The MBS has more Rx traffic than other frequencies but it is still less than Tx traffic on this band (the MBS band is largely used for newer LTE technology). In an unexpected development of the project, what the measurements showed were licensed providers using the frequencies they were assigned; however, there were dramatic inefficiencies in overall spectrum allocation. There is little or no activity on many of the reception frequencies for the antennas at the study site. While people may wish to browse the Internet or check email, very few upload data-heavy files

57. Marcus.

such as video or music. This information is of great consequence for questions of spectrum scarcity since the allocation of spectrum in most jurisdictions still puts equal weight upon reception and transmission (i.e., 10 MHz up and 10 MHz down). The uplink/downlink legacy technology is proving a hindrance to more efficient spectrum governance in the age of mobile broadband.

The dual channel approach to spectrum (i.e., separate Rx/Tx) is a holdover from the pre–smart phone era, when voice calls constituted the bulk of mobile traffic. Voice traffic causes little strain on network capacity and is generally predictable: we speak and listen in relatively equal measure. The standard for this is known as frequency-division duplex (FDD) technologies, with separate downlink (listening) and uplink (speaking) channels operating on separate frequency bands—hence, "paired spectrum."[58] Our data indicates that the days of relatively equal transmissions of data in the uplink and downlink channels are gone.

The FDD structure we have deployed for decades appears to be an inefficient legacy of the voice era. It is a clear example of what Sandvig calls "a technological system's 'inertia' or 'trajectory'" where a technological path is determined in the early years of a device's development, even though this path may be later proven inefficient.[59]

The paired spectrum approach is, in short, an ineffectual use of the key foundation of our modern mobile infrastructure. If there is truly a capacity crunch in mobile broadband, instead of throwing more spectrum at the problem, one of first initiatives should be to implement a standard that does not underuse half the assigned frequencies.

There are alternatives. Parks and Starosielski write, "critical analysis of infrastructure involves interrogating the standards and formats necessary to route content across these systems. . . ."[60] Mobile communications offers alternatives to the established order that allow for more efficient uses of spectrum. The LTE (4G) standard, currently being deployed in Canada (and internationally), allows for the option of either the traditional FDD approach or time-division duplex (TDD). This is an important technological shift, as TDD can allow for uplink and downlink on unpaired spectrum, vastly reducing the amount of spectrum required.[61] TDD has proven benefits but has barely begun to make an impact in wireless infrastructure.

58. Liopiros.

59. Sandvig, "The Internet as an Infrastructure," 98.

60. Parks and Starosielski, 5.

61. Dahlman, Parkvall, and Skold, 7.1.6.1.

This shift in standards could have a major impact on the spectrum crisis debate. According to small cell manufacturer Accelleran, "Combining traditional FDD with an optimized TDD small cell layer could increase the overall spectral efficiency by 38% and increase downlink capacity by 77%."[62] While some online activities such as video conferencing and social media benefit from symmetrical spectrum allocation (FDD), the majority of popular high bandwidth usage applications such as video streaming are asymmetric services (you do not uplink to Netflix).

If spectrum capacity is truly at a crisis level, there are other areas to look to in order to maximize efficiencies.

- Current Canadian OTA television spectrum licenses receive 6 MHz of spectrum and are terribly underused in Canada. Mobile broadband providers Bell and Rogers also have numerous OTA licenses via their vertically integrated television properties (CTV and CityTV respectively).
- Smaller cells, where the transmission has a far shorter radius, can use far less spectrum and have growth potential in urban centers but were in limited use in Canada at the time of this study.
- Spectrum sharing options need to be researched and developed.
- Newer LTE technologies are much more efficient than previous generations of mobile technology. Older systems need to be phased out.
- Also, growth of fiber deployment improves efficiency since all mobile traffic eventually goes to a wire. According to 2015 Organisation for Economic Co-operation and Development (OECD) statistics, Canada is not in the top twenty countries in the world for percentage of fiber connections in total broadband subscriptions.[63]

Conclusion

> . . . distribution infrastructure is a crucial battleground: competing visions of society are made manifest within seemingly technical struggles, yet they are also modified by the inertia of technology.[64]

62. Accelleran, 2.
63. OECD.
64. Sandvig, "The Internet as the Anti-Television," 241.

Spectrum is an invisible industrial battleground. As Sandvig notes, once you cut past the jargon of wireless technology, questions of exclusive access to the airwaves reveal themselves that are not simply attributable to the age of the iPhone.

The data collected demonstrated that major Canadian mobile operators were clearly using their licensed spectrum in 2013 and 2015, at least in the center of urban Canada; however, the evidence is also clear that the traditional paired spectrum approach is a woefully inefficient allocation method for the supposedly scarce resource of spectrum. If we are indeed near a spectrum crunch (a highly contested theory), then a more sustainable approach is to move toward data and away from the traditional call and response of the telephone. Our study demonstrates strong usage in the city center, but only on half of the allocated frequencies. Equal upload and download allocation appears unsustainable.

Recommendations

1) **Information concerning spectrum usage should be publicly accessible and regularly monitored.** The public has a right to know how the public resource is being used.

   Too many apocalyptic predictions of our mobile data infrastructure go unchallenged by governments. Across the globe, the state has shown little appetite to bring quantitative measurements to address this key dilemma. As the European authors of the 2015 book *Understanding Spectrum Liberalisation* note, "the lack of resources within modern spectrum regulators allows outlandish predictions to go underscrutinised."[65] Mark MacCarthy of the Aspen Institute wrote of spectrum policy in the United States: "The government cannot efficiently manage a resource it does not measure."[66] Similar concerns are true for Canada, where the last radio spectrum inventory was released in 2010. Whether or not the announced Canadian Spectrum Analytics Center ever materializes, government regulators should be providing clear, regular, publicly accessible updates on the usage of the publicly owned spectrum resource.
2) **The traditional paired spectrum approach is inefficient.** Governments worldwide need to explore ways to maximize value from the spectrum.

65. Sims, Youell, and Womersley, 148.
66. MacCarthy.

Our data show that the traditional FDD leads to idle frequencies. TDD, which uses only one frequency channel appears to be the better overall choice, but FDD is far more widely implemented because of prior frequency spectrum assignments and earlier technologies. It appears that FDD will continue to dominate mobile broadband for the foreseeable future, but we recommend that governments pursue a single-channel approach or enforce a more efficient use of spectrum. With the explosion of data and voice over Internet, coupled with the flat growth of voice, there is increasingly little reason to continue with the dual-frequency approach. If spectrum is truly becoming scarcer, an important step is to move away from the twin-frequency regime and instead make TDD more widely adopted as spectrum is reallocated and repurposed.[67]

3) **There are other avenues to be explored** before locking further vast quantities of public spectrum into long-term private licenses. Approaches such as spectrum sharing, small cell deployment, updating inefficient legacy technologies, and adding fiber to existing networks can all increase data traffic without requiring extensive spectrum deployment.
4) **Further academic research is necessary**. This study makes no claim to settle the "spectrum crunch" debate, only to make clear the often contrasting positions and to offer data from one urban location. We hope more studies like this one will be undertaken, so independent research can help fill in the substantial gaps in public knowledge.

As consumers of mobile technologies, as well as owners of the public spectrum resource, citizens have a double interest in ensuring the radio spectrum is used wisely and efficiently. Demand for mobile data is clearly booming. In the center of a large Canadian city, license holders demonstrate considerable traffic on their assigned frequencies. However, it is also clear that regulators and industry must look past legacy technologies and offer much more creative paths to maximize spectrum efficiency before there can be any legitimate discussion of a spectrum crisis.

67. Chen et al.; Rathi et al.

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