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Conference Paper

Will asset-sharing improve wireless communications performance?

20th Biennial Conference of the International Telecommunications Society (ITS): "The Net and the Internet - Emerging Markets and Policies", Rio de Janeiro, Brazil, 30th-03rd December, 2014

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Clarke, Richard N. (2014) : Will asset-sharing improve wireless communications performance?, 20th Biennial Conference of the International Telecommunications Society (ITS): "The Net and the Internet - Emerging Markets and Policies", Rio de Janeiro, Brazil, 30th-03rd December, 2014, International Telecommunications Society (ITS), Calgary

This Version is available at:

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Will asset-sharing improve wireless communications performance?

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1. Overview

Nursery school teaches that sharing is always good. Share your toys with others, and both of you will have a more enjoyable experience. Recently, there has been substantial advocacy for gaining efficiency by increasing sharing of wireless assets. Sharing radio spectrum may allow the ether to carry more bits and reduce the need for additional spectrum to be licensed to mobile wireless (PCAST, 2012; Ofcom, 2013). Sharing network infrastructure may improve service quality and reduce cost – or even reduce negative aesthetic impacts from multiple antenna sites (GSMA, 2012; Industry Canada, 2004; Larsen, 2012; Nagle, 2009).

But economics and technology are not always so positive about sharing. While sharing an asset may be productively efficient because a single company's (or government agency's) use of the asset may not exhaust its potential productive capability; it is also possible that joint use of the asset makes it less valuable to both users. This could occur if one company's use of the asset interferes with the other company's use, or because other costs that must be incurred to employ the asset do not scale down with partial use of the asset. Further, it is also possible that asset-sharing may attenuate inter-company competition. If this is the case, even though sharing might reduce costs, it could result in undesirable less competitive pricing to customers or less innovative product designs.

The assets used to produce wireless communications services divide into three major categories. The first is radio spectrum, the second is physical network infrastructure and the third is the collection of assets used to create, market, bill and support communications services provisioned over the network infrastructure and its radio spectrum. An example of how

* The analyses and data presented in this paper are only intended to portray the U.S. mobile wireless industry on an approximate national average basis. They may not be representative of any particular U.S. geographic region or mobile operator, including AT&T. No proprietary AT&T data were used in performing these analyses. The conclusions developed in this paper are those of the author alone, and should not be construed as representing any official position of AT&T. Because of the preliminary nature of this draft, it should not be cited without the author's consent.

spectrum sharing may be beneficial is if a government agency wants to use a particular spectrum band for oceanic radar, while a communications company wants to use this same band to support agricultural telemetry services in the interior of the country. Because signals from these two services will not interfere, it is efficient for both uses to share this spectrum band. Similar sharing efficiencies may occur with network infrastructure. If two wireless communications companies wish to provide service in the same geographic area using different spectrum bands, it may be efficient for these companies to share the costs of constructing a tower on which they can both mount their radio antennas. More complete sharing may take place when companies share their full radio access and core network assets by arranging for their customers to “roam” on the other company’s network when they travel outside of their home region. Finally, it is also possible to share service creation, sales, billing and support assets – as may occur if a wireless network company provides wholesale services to resellers.¹

But it is also possible for asset-sharing not to be productively efficient. If instead of oceanic radar, the government agency wanted to use its radio spectrum band for aerial radar across the entire country, such use might interfere with agricultural telemetry in the interior – and shared use of the band may reduce the efficiency of both services. In the instance of network infrastructure, it could be that one company wishes to place a new tower at a location that is next to a tower already in use by a second company, or where the in-place tower lacks space for an additional antenna. If so, sharing in the cost of a new or expanded tower is not an efficient use of the second company’s funds. And in the roaming example, if one of the regional networks is already operating at full capacity, allowing customers of the other regional network to roam on it could result in reduced quality of service to its own customers.

Complicating further the evaluation asset-sharing is the possibility that sharing one type of network asset may make it more or less feasible/valuable to share other types of network assets. For example, it may be impossible for wireless companies to share a tower if the particular radio frequencies they use are harmonics that create intermodulation distortion. In contrast, if the frequencies’ harmonics do not generate intermodulation distortion, tower-sharing may become more feasible because the propagation characteristics of one of the companies’ frequencies favor the placement of its antennas at a different height on the tower than the other company’s antennas.

¹ For brevity, we will refer to the complete suite of wireless service creation, sales, billing and customer support assets as service provisioning assets.

It is also possible that when wireless assets are shared, inter-company competition may be inhibited, or be enhanced. For example, extensive use of roaming diminishes the opportunity for carriers to differentiate their services and to compete on the basis of product quality, or discourages additional facilities build-out (Larsen, 2012). On the other hand, cross-roaming by territorially disjoint companies may permit two regional carriers to enter the national services market, enhancing competition. Given that vigorous competition between multiple providers of wireless services contributes greatly to the dynamic efficiency of the mobile services market, sharing schemes that enhance competition should be favored, but ones that attenuate competitive incentives must be approached with caution – and their productive efficiency gains balanced against possible competitive efficiency losses.

For these reasons, it is essential to understand how different types and combinations of asset-sharing in the wireless industry may, or may not, improve market efficiency. Only after performing such an analysis is it possible to determine whether enabling (or requiring) sharing of these types or combinations of assets is likely to be a welfare benefit or burden.

This paper first examines the several general ways in which assets employed in the wireless industry may be shared. As noted, these assets generally divide into three classes: radio spectrum, network infrastructure and service provisioning. The paper describes in greater depth the potential ways in which each of these asset classes may be shared, both individually and in combination, and the technical feasibility of achieving effective sharing for each type and combination. Next, it presents an analysis of the likely economics of these various sharing possibilities. Finally, it examines the competitive implications of different sharing combinations, thus providing guidance as to whether particular sharing types or combinations should be encouraged, left as a commercial option, or possibly banned altogether.

2. Types of wireless sharing and their technical feasibility

Three major asset classes are required to provide wireless communications services: radio spectrum, network infrastructure and service provisioning.² But within each of these asset

² Note that in addition to well-known two-way wireless communications services such as cellular telephony or ship-to-shore radio, there are also many specialized wireless communications services such as weather radar, GPS, radio astronomy or navigational beacons. All require wireless spectrum and network infrastructure, but many of these specialized services may have little need for service provisioning since they are largely used by either a single user, or completely passive users.

classes there are subgroups of assets – each which may present different opportunities for sharing across providers, uses and users.

2.1. Radio spectrum

Perhaps the most well-known asset employed in providing wireless communications service is radio spectrum. These are the airwaves over which voice, data or other types of signals (e.g., radar “pings”) travel. Radio spectrum may be used for many purposes. Point-to-point (e.g., mobile wireless) communications is one purpose; point-to-area (e.g., television broadcasting) is another purpose; as is radar location-finding or cloud-probing. Still another purpose is heating items (e.g., microwave ovens).

Recently, there has been a great deal of discussion surrounding sharing of radio spectrum. Initiated in the European Union by the Radio Spectrum Policy Group (RSPG) and in the U.S. by the President’s Council of Advisors on Science and Technology (PCAST), both of these groups have issued reports that describe how spectrum may be shared by multiple uses and users. Generally, these reports conclude that greater total social value may be extracted from spectrum if its use is allowed (or mandated) to be shared.³

Spectrum may be separated, and thus shared, across service providers, uses and users in many different ways. A few of the most common separation/sharing methods are detailed below.

2.2. Frequency separation

Perhaps the most popular way for radio frequency spectrum to be separated among service providers, uses and users is by frequency band. In the U.S., the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) are responsible for designating the particular types of uses (e.g., broadcast television, mobile wireless, amateur two-way radio) permitted in different frequency bands of the electromagnetic spectrum.⁴ As a result of these frequency designations, we have the full expanse of the electromagnetic spectrum “shared” among many different services (e.g., AM radio, FM

³ See RSPG (2011), BEREC-RSPG (2011), Ofcom (2013) and Bazelon & McHenry (2014) for more detailed discussions about spectrum sharing.

⁴ The FCC controls the uses permitted for users in nongovernmental bands and the NTIA controls the uses permitted for spectrum users in government-reserved bands. Interestingly, prior to the establishment of the Radio Act of 1912, certain U.S. government interests thought it was impossible to impose effective frequency band-based separation of the spectrum absent complete monopoly control over all radio transmissions (Coase, 1959).

radio, VHF and UHF broadcast television, cellular mobile, Wi-Fi, GPS, weather radar, rocket telemetry). Further, within a particular service band, we may have separate frequency allocations for one provider versus another provider (e.g., TV channel 7 versus TV channel 8). A single provider may also employ Frequency Division Multiplexing (FDM) to allow a particular band to be divided up into sub-bands that may serve simultaneously multiple individual users.

While frequency-based separation is likely the most well-known method for spectrum sharing, it is also the most severe. Not only are entire spectrum bands reserved for different services or providers without taking account as to whether any other providers or services may coexist within these bands, but often spectrum must be left fallow between different bands to protect against signals from adjacent services or providers from leaking into the band with enough power as to cause interference to the authorized provider/service in the band.⁵

In any event, since all (or nearly all) of the electromagnetic spectrum useful under current communications technologies has been allocated to particular uses and/or providers, the only way in which reform of current frequency-based separation may increase the total usefulness of this spectrum is if frequency authorizations are rationalized and allocations currently held by less valuable services are transferred to more valuable services or to more efficient providers.

2.2.1. Geographic separation

Interference between signals reduces as the power of the interfering signal declines. This occurs as the distance from its transmitting antenna grows larger.⁶ Thus, by ensuring adequate distance separation between the antennas, it is possible for multiple uses or providers to share the same frequency band. While the classic example of spectrum sharing due to

⁵ This fallow spectrum between frequency use bands or different provider channels within a use band is called a “guard band.” Its size depends both on the power level of the adjacent signal (which is itself based on the emitted power from its transmitting antenna and the distance from this antenna) and on the robustness of the signal being protected. For example, if the signal being protected is of very low power because it is being transmitted from a distant satellite or if it employs a high-order modulation scheme to maximize its information throughput, it will suffer more severely from an interfering signal of a given power than if, say, it was a high power terrestrial signal employing a low-order modulation scheme. Such interference was a concern with the FCC’s proposed authorization to permit a U.S. company called LightSquared to offer terrestrial mobile wireless services in spectrum adjacent to that used by GPS satellites (<http://www.gps.gov/spectrum/lightsquared/>).

⁶ In an open vacuum, the power of a radio signal declines with the square of the distance from its transmitting antenna. In the earth’s atmosphere, signal strength declines even faster. Thus, if an interfering signal measured to have a power of 100 is remeasured at a location twice the distance from the interfering signal’s antenna, its power will decline to some figure less than 25 ($= 1/2^2 * 100$).

geographic separation is cellular communications service, this method is also employed to allow the reuse of television channels in different geographical areas. Indeed, it is even possible to use this method to reuse frequencies for wide ranging satellite signals. So long as it is possible to reduce transmitted power and still maintain adequate information throughput, there is next to no technical limit on how much geographical sharing/reuse can be extracted from a frequency band. As will be noted later, the limits to geographical reuse are given by the economics of shrinkage of coverage areas and the cost associated with deploying a denser antenna infrastructure.

2.2.2. Temporal separation

If wireless uses or users do not have usage needs that occur simultaneously, it is possible for these uses/users to share a frequency band by assigning each a separate slot of time when they will have exclusive access to band. Historically, this was done based on gross divisions of time (e.g., band employed for one use during the day and for another at night, or employed for rocket telemetry only during launches and available for another use at all other times). Today, perhaps the most important use of temporal separation is in multiplexed voice or data transmissions. By employing Time Division Multiplexing (TDM), a single channel with a wide bandwidth may be able to carry a large number of lower bandwidth individual signals.⁷ This is now a standard method by which mobile wireless companies use their frequency bands to serve multiple simultaneous telephone calls or data sessions.⁸ The technical ability to employ temporal separation is limited only by the full 24/7 occupancy capacity of the frequency band.

2.2.3. Between unlike uses

While a communications signal may not be able to tolerate interference from a signal of the exact same nature as itself, it is possible that signals that perform very different purposes may be able to coexist on the same frequency band without too badly impeding the usefulness of each other. For example, it is possible that a low power packet digital communications signal may be able to coexist on the same band as a high power sweeping radar signal. This is because the sweeping radar signal may only impinge on the packet digital signal for a brief moment every several seconds (or whatever the sweep interval is). Therefore, if the band in full

⁷ TDM achieves this by assigning each individual signal a separate time slot during which it can utilize the channel for its transmissions.

⁸ TDM is a characteristic of second generation (2G) and above mobile wireless services. First generation mobile wireless services (1G) employed only FDM.

communications use can support a gross throughput of 1000 packets/second, then this radar impingement may cause, say, only five packets of the signal to be corrupted (and, thus, resent) every second. Hence, radar interference degrades the communications throughput by only 0.5%. Further, because the digital communications signal is so low power, it may degrade the radar signal only by a tiny amount. Thus, sharing the frequency band between these two dissimilar services can be highly efficient because each service can function quite well in the presence of the other.

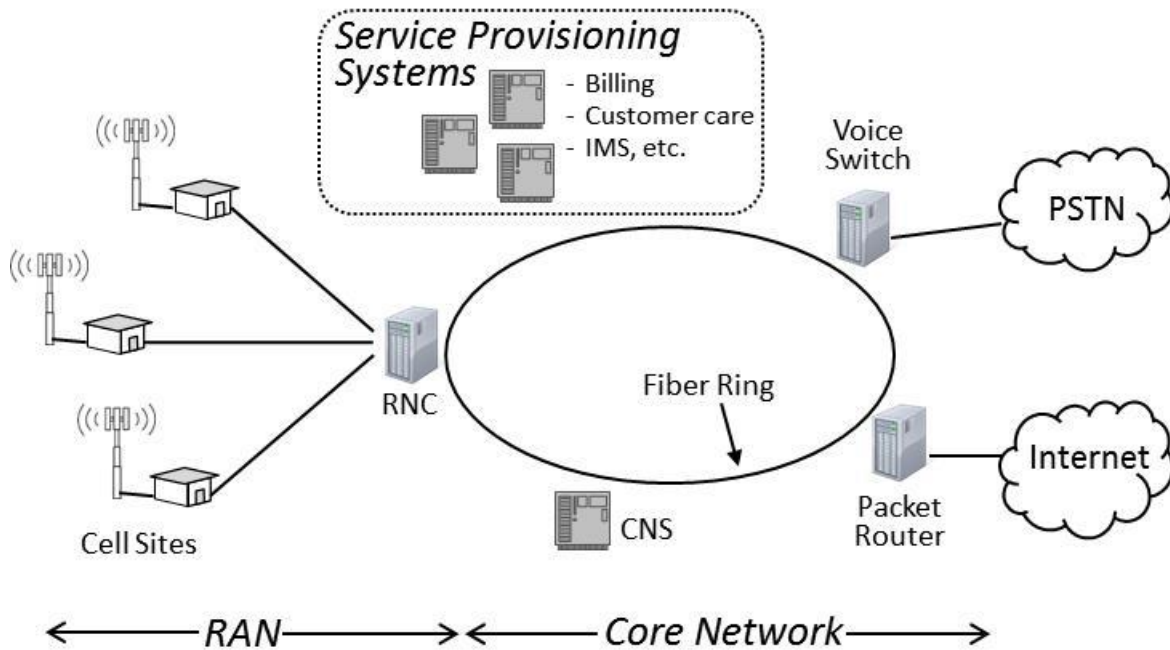
But while radio spectrum may be shared between dissimilar uses, it is far less likely that supporting network infrastructure will be interchangeable across dissimilar uses. For this reason, the balance of this paper analyzes sharing only across a single use type – cellular mobile wireless service. While this restriction does limit the generality of the analysis, given the huge and growing nature of cellular mobile wireless service, examining only sharing of mobile wireless infrastructure still offers great insight.

2.3. Network infrastructure

Radio spectrum alone is not adequate to provide wireless communications services. To send communications signals over spectrum, you need network infrastructure – the towers, antennas, transceivers, cables, switches, routers, billing computers, etc. that enable wireless services to be offered to users. For convenience, we divide infrastructure into three segments: (1) Radio Access Network (RAN); (2) core network and (3) service provisioning/billing/support systems. Within the RAN segment, we further divide between two infrastructure type classes: passive and active. These network components are illustrated in Figure 1 and described, below.⁹

⁹ See BEREK-RSPG (2011), GSMA (2012), Meddour, et al. (2011) and Mölleryd & Markendahl (2013) for a more complete discussion of various possible infrastructure sharing architectures and methodologies.

Figure 1: Mobile wireless network schematic



2.3.1. Radio access network

The RAN infrastructure of a mobile wireless system consists of cell sites, towers, antennas, cabling, transceivers, power equipment, backhaul circuits and Radio Network Controllers (RNCs).

The passive portions of this RAN infrastructure consist of the real estate occupied by the cell site; the transmission tower on which the antenna is located; the huts or cabinets that house the radio transceivers; and the power equipment. The active infrastructure elements are those whose electronic state is changing throughout a wireless transmission. These include radio antennas and transceivers; the RAN backhaul circuits (wired or microwave) and their transmission equipment; and the RNC. These particular components of RAN infrastructure are displayed in Figure 2.

Figure 2: Mobile wireless RAN infrastructure



2.3.1.1. RAN passive infrastructure sharing

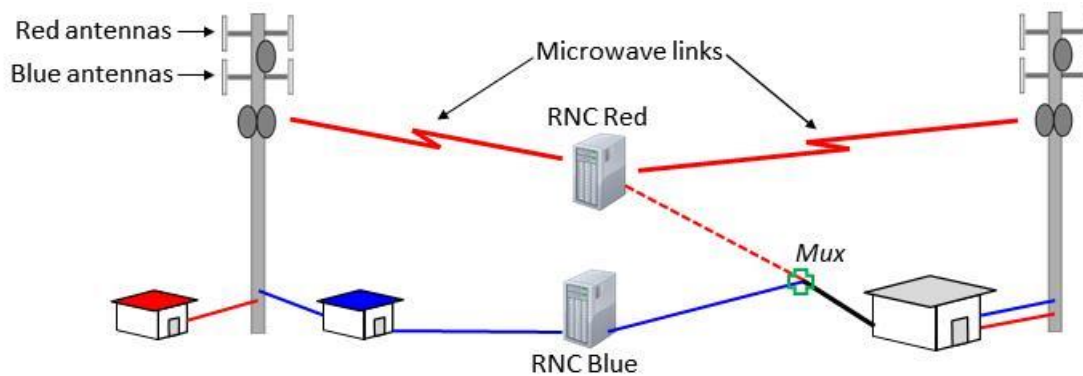
Generally, it is technically quite easy to share passive RAN infrastructure. One of the most common forms of wireless sharing is site and tower sharing.¹⁰ Indeed, independent tower companies own about 100,000 cell sites in the U.S. – or nearly one third of the 2013 total of 304,360 U.S. mobile wireless cell sites.¹¹ These independent tower companies then lease antenna space on their towers to wireless companies. In addition, they may supply a shared equipment hut and/or electrical power to their tenants. Wireless companies may also share site and tower space through joint-ownership or condominium arrangements – or simply by the wireless company that owns the site acting like an independent tower provider and leasing space on its tower to other wireless companies. This type of arrangement is displayed on the left side of Figure 3. It depicts a single cell site where a tower and its real estate is shared by two mobile networks (called Red and Blue). Each network has located an equipment hut at the site.

¹⁰ While it may be possible to place multiple towers on a single cell site and share just the cell site real estate, this is less common as it may require an extremely large site.

¹¹ CTIA (2014) reports 304,360 mobile wireless cell sites in operation as of December 2013. Counts of independently owned towers are provided by WirelessEstimator.com (http://www.wirelessestimator.com/t_content.cfm?pagename=US-Cell-Tower-Companies-Complete-List). Crown Castle is the largest independent U.S. tower supplier at 53,000 installations (<http://investor.crowncastle.com/phoenix.zhtml?c=107530&p=irol-newsArticle&ID=1963510&highlight>); American Tower the next at 28,000 sites (<http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NTM4NjY2fENoaWxkSUQ9MjI4MTMxfFR5cGU9MQ==&t=1>); and SBA is the third largest at about 15,000 sites (<http://files.shareholder.com/downloads/SBA/3477046199x0x738083/84696963-e260-4cd2-9f39-d997c216171b/03.25.14 - Annual Report - 2013 Marketing Wrap with 10K - Low Res.pdf>).

The Red network uses microwave transmission for backhaul to its RNC while the Blue network is shown as using a wireline fiber, copper or coax link. The right side of Figure 3 depicts a somewhat different passive RAN sharing arrangement where not only the tower and its real estate are shared, but where an equipment hut and possibly the power equipment contained within it are shared, too. This side of the figure also shows two different backhaul schemes for the Red network. It might use microwave similar to as used on the left side of the figure, or it might use wireline (shown in dashed red), possibly shared on an initial transmission segment with the Blue network.¹²

Figure 3: Sharing passive RAN infrastructure



Note that just because in many instances it seems feasible to share passive RAN infrastructure, this is not always the case (Industry Canada, 2004). Zoning regulations may preclude the construction of a tower tall enough to support multiple antennas or site sizes may be so restricted in ground space that the placement of multiple transceivers or adequate backup power supplies is impossible.

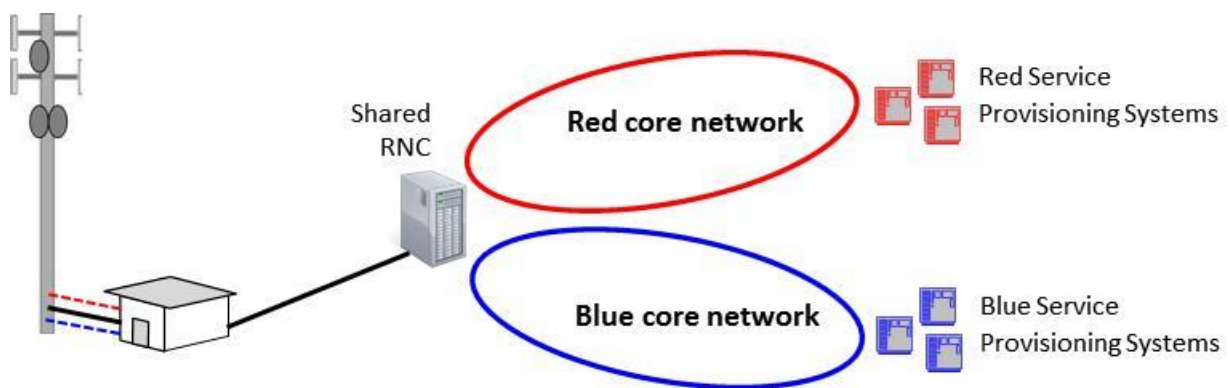
2.3.1.2. RAN active infrastructure sharing

It is also possible to share the active elements of RAN infrastructure. The degree to which this is possible depends on the radio technology employed by the sharing parties. If it differs among the parties (e.g., HSPA vs. CDMA), the only sharable portions of the active RAN may be its backhaul links. But if the technology is the same, greater sharing is possible. For

¹² Given that wireline backhaul is generally sourced from a local fixed network operator, this partially-shared backhaul transmission configuration is easy to arrange. For example, the Red and Blue networks agree to jointly purchase a 100 Mbps Ethernet circuit from the cell site to the nearest node on the fixed network and multiplexing (Mux) service at this node to separate the circuit into two 50 Mbps Ethernet circuits – one directed to Red’s RNC and the other directed to Blue’s RNC.

example, certain antennas and transceivers may support simultaneous use by multiple networks and it is possible to merge traffic destined to/from multiple providers' RNCs onto shared backhaul links. To the extent that several wireless providers share the active infrastructure of a RAN, the RNC for this RAN may be shared as well. Figure 4 displays two possible configurations for active RAN sharing. In both of these configurations the RNC and passive portions of the RAN are shared. In one configuration, represented by the solid black line connecting the equipment hut to the tower, the transceivers in the hut generate a single communications signal for the tower's antennas to transmit. This signal will be sent to users of both the Red and Blue networks. In the other configuration (represented by the dashed red and blue lines between the hut and the tower), the transceivers generate two separate communications signals – one for transmission to Red network users and the other for transmission to Blue network users.¹³

Figure 4: Sharing active RAN infrastructure



An important point to note is that if active RAN infrastructure is shared, it is likely not efficient for its accompanying passive infrastructure not to be shared. Transceivers and backhaul serving one cell site and tower are unlikely to be capable of feeding an additional distant cell site and/or tower.

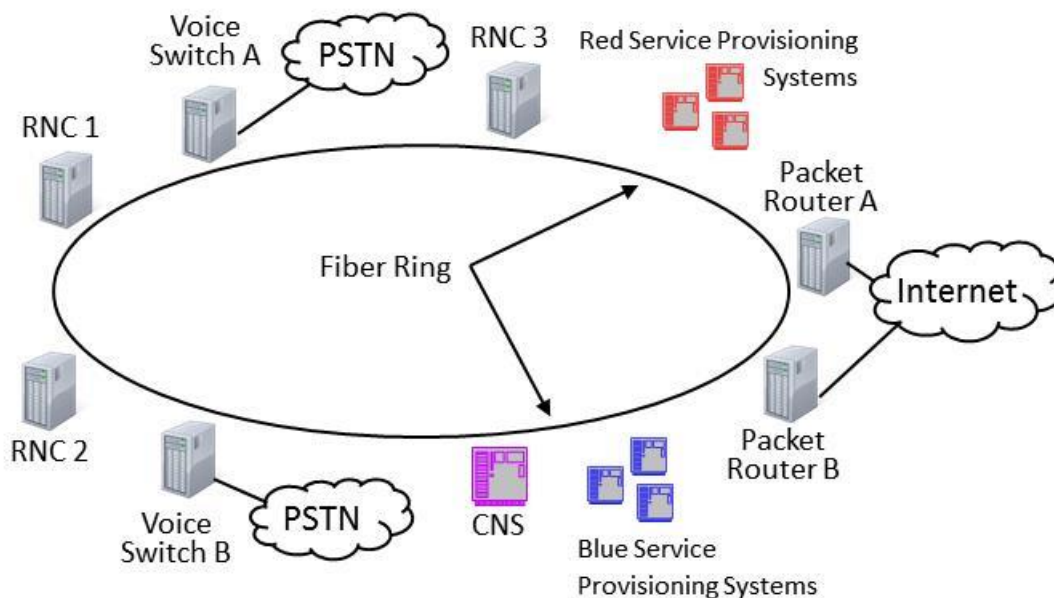
2.3.2. Core network sharing

Core networks consist of the transmission paths; switching and routing equipment that allow traffic from one RAN to interconnect with other RANs, to the Public Switched Telephone Network (PSTN) or to the Internet. In addition, core networks also generally host the network

¹³ In addition to the mentioned configurations, there are many other possible arrangements for passive and active RAN sharing. Discussion of these is beyond the scope of this paper. See BEREC-RSPG (2011), Meddour, et al. (2011), GSMA (2012), Brydon (2013), Larsen (2012), NEC (2013) or Vornpuan (2010) for fuller descriptions of alternative configurations.

authentication, control, diagnostic and maintenance systems used to manage and maintain traffic across the mobile carrier's network. These items are displayed in Figure 5. Just as with active RAN elements, the degree to which core network elements are sharable depends on the similarity of the technologies employed by the sharing parties.

Figure 5: Core network sharing



While it is possible to share core networks while maintaining some network service quality differentiation, it is difficult. Figure 5 depicts a core network where the elements portrayed in black or grey are shared between the Red and Blue service providers. The most complex elements of the core network for sharing purposes are the items denoted CNS (for core network systems). As noted, these network authentication, control, diagnostic and maintenance systems are used to manage entry to the mobile network, to manage traffic across the network and to keep it in good repair. While it is likely that the traffic management, control and repair system components of the CNS will be shared if the core network links and controls shared RANs, voice switches or data routers, it is possible that each mobile service provider may maintain separate user authentication systems. These would include items like Home Location Registers (HLRs) that provide the core network with information about what users are authorized to connect to the mobile network and what mobile services they are entitled to access. Because HLRs may be shared or separate, the CNS icon in Figure 5 is depicted in purple – the color obtained when Red and Blue are mixed.

2.3.3. *Service provisioning sharing*

Rather than sharing just the transmission, switching and routing assets associated with wireless networks, it is also possible to share the service provisioning assets (e.g., service creation, sales, billing and customer care) associated with fully operational and sellable wireless services. Service provisioning sharing may take several forms. Perhaps the most complete form is providing network services for full resale by a Mobile Virtual Network Operator (MVNO). It is possible that less than full sharing of service provisioning assets may be involved if the MVNO deploys certain of its own service provisioning assets such as a billing system. It is also possible for wireless service providers to share certain ancillary or overhead activities such as government reporting and lobbying.¹⁴ Indeed, it is also common for different wireless services to share customer devices such as multi-SIM smartphones or tablets that contain Wi-Fi radios along with mobile wireless radios (e.g., HSPA or LTE).

3. Economic feasibility/desirability of wireless asset sharing

The economic feasibility of various types of asset sharing place depends on the relative total service cost of employing shared network assets versus assets that are dedicated to a single use type or service provider (Larsen, 2012).¹⁵ If a particular asset sharing arrangement (after incorporating all relevant costs including those associated with unshared assets and coordination) results in lower total costs across the sum of the sharing partners' services, then sharing is an economically feasible and desirable option. If an asset sharing arrangement lowers the total cost of the sum of the partners' services, but results higher costs for at least one of the partners, it still remains an desirable arrangement – but in order for it to proceed, it may require the benefiting partners to compensate the partner whose costs have risen to induce his participation in the sharing arrangement.

Note that it is necessary to evaluate the effects of the asset sharing arrangement on the total cost of the produced service, and not just on the costs associated with the particular

¹⁴ Examples of this could be the use of a trade association like CTIA-The Wireless Association to report certain statistics to the government or to provide a vehicle for joint participation in government regulatory proceedings such as FCC dockets or World Radiocommunication Conferences (WRCs).

¹⁵ It is also possible that employing shared assets to produce a service may not alter total costs, but will have an effect on the quality of the produced service. For example, sharing spectrum between a radar system and a communications system may result in periodic static in the communications messages degrading their intelligibility. For convenience, we will equate this reduction in communications service quality (and customer willingness to pay for the service) as equivalent to an increase in cost necessary to provide a communications service of unimpaired quality.

component being shared. This is because sharing any particular component may have an effect on the use-efficiency of other service components, even if those other components are not shared. To evaluate the relative total cost of employing assets on a shared versus dedicated basis, one must know both the degree to which a particular sharing arrangement increases or decreases the quality-equivalent costs for each service component, and the contribution to total cost associated with each component.

3.1. Component share in total cost

As noted earlier, the major components of wireless service are spectrum, RAN, core network and service provisioning assets. Each of these assets has an associated capital cost (CAPEX) and an associated annual operating cost (OPEX).¹⁶ For illustrative purposes, the following analysis provides a very rough breakdown of the approximate average contribution of each of these components to the total cost of U.S. mobile wireless networks.¹⁷

3.1.1. Spectrum

Based on Clarke (2013), we assume that U.S. networks are currently employing about 426 MHz of built-out spectrum. For convenience, assume this is composed of roughly 50 MHz of cellular spectrum, 14 MHz of SMR spectrum, 130 MHz of PCS spectrum, 90 MHz of AWS-1 spectrum, 60 MHz of 700 MHz spectrum, 10 MHz of PCS H-block spectrum and 72 MHz of EBS/BRS spectrum.

There are several ways to value these spectrum allocations. For discussion purposes, we could use the FCC proceeds from its auctions of SMR, PCS, AWS-1, 700 MHz and H-block spectrum. These allocations total 304 MHz of spectrum and yielded about \$55 billion in auction revenues.¹⁸ If one assumes that an auction today of the cellular spectrum would yield about as much as the FCC's 2008 auction of 700 MHz spectrum, this would add \$19 billion to the previous total. Assuming an additional \$6 billion in capital leases for the EBS/BRS spectrum in use raises the total figure up to a round number of \$80 billion. But because the PCS auctions took place twenty years ago and the AWS-1 auctions were eight years ago, and because it would be easier

¹⁶ If there are no recurring lease costs for spectrum licenses, as is typical in the U.S., the spectrum component of wireless service may have zero associated OPEX.

¹⁷ Note that any operational decision by wireless carriers as to asset sharing will be based on the marginal (not the average) effects of sharing each of these components on the total cost of the service.

¹⁸ See the FCC's Auctions homepage (http://wireless.fcc.gov/auctions/default.htm?job=auctions_home) for detailed information as to the quantities of spectrum offered in these auctions and the revenues earned.

to deal in round numbers, the values of these allocations could be marked up. Hence, for very rough illustration purposes, assume that the current value of U.S. mobile wireless spectrum in use is on the order of \$100 billion.¹⁹

3.1.2. *Infrastructure*

CTIA (2014) reports cumulative CAPEX for U.S. wireless carriers since 1985. The figure as of December 2013 is roughly \$400 billion. Fully \$370 billion of this investment has taken place since digital 2G services were introduced in the mid-1990s, thus these investments are likely still in active use. But a further adjustment to this figure must be made. CTIA statistics report only the CAPEX expended directly by U.S. mobile wireless carriers, and not that of non-service provider companies that may lease infrastructure to U.S. wireless carriers. The most significant of these infrastructure providers are independent companies that build tower capacity for the wireless industry. As noted earlier, just the three largest of these companies report providing nearly 100,000 towers to the U.S. wireless industry – or about one third of the total U.S. cell sites in use as reported by CTIA.²⁰ When these investments are added to CTIA's figures, it seems reasonable to assume that roughly \$400 billion in cumulative gross CAPEX supports the current U.S. mobile wireless industry.

It is useful to apportion this cumulative wireless industry CAPEX between RAN passive, RAN active, core network and service provisioning infrastructure. Unfortunately, there is scant information available to make such a parsing.²¹ Thus, for discussion purposes, we will assume that 40% of the \$400 billion total (\$160 billion) is passive RAN infrastructure, 25% (\$100 billion) is active RAN infrastructure, 20% (\$80 billion) is core network infrastructure and 15% (\$60 billion) is service provisioning infrastructure.²²

¹⁹ This figure of \$100 billion for 426 MHz of spectrum, which we assume for illustrative purposes, would equate to an average value of roughly \$0.75 per MHz*Pop.

²⁰ To the extent that some of the towers currently owned by independents were originally constructed by a wireless carrier, the CAPEX costs for these towers would be included in CTIA's cumulative figures. Otherwise, the CAPEX associated with these independent towers is incremental to CTIA's figures.

²¹ Some rough percentages are suggested in BERC-RSPG (2011), Meddour, et al. (2011) and in Mölleryd & Markendahl (2013), but these figures may not be current or accurate for the U.S. mobile wireless industry.

²² Some data also exist in the form of prices paid by independent tower companies for towers purchased from mobile wireless operators. It is speculated (Bloomberg, 2014) that tower companies may bid on the order of \$6 billion for 12,000 towers from Verizon. This suggests a price of \$500,000 per tower – similar to the price of \$533,333 implicit in our hypothesized \$160 billion figure for RAN passive infrastructure.

An apportionment of annual OPEX is useful, too. Assume annual U.S. wireless service revenues are \$200 billion.²³ If mobile wireless gross investments of \$500 billion require an average Annual Charge Factor (ACF) of, say, 20% to cover their depreciation, return and taxes; this suggests that \$100 billion of the \$200 billion in revenues is required to support capital investments.²⁴ The remainder may be attributed to OPEX. For discussion purposes, assume that spectrum bears no OPEX, and that 20% of the \$100 billion total OPEX (\$20 billion) is attributable to RAN passive infrastructure, 25% (\$25 billion) is attributable to RAN active infrastructure, 20% (\$20 billion) to core network infrastructure and 35% (\$35 billion) to service provisioning infrastructure.

Overall illustrative shares of CAPEX and OPEX are shown in Figure 6, below.

Figure 6: Illustrative overall cost shares of wireless assets

Asset class	Gross CAPEX		Annual OPEX	
	(billions)	% share	(billions)	% share
Radio spectrum	\$100	20%	\$0	0%
RAN passive infrastructure	\$160	32%	\$20	20%
RAN active infrastructure	\$100	20%	\$25	25%
Core network infrastructure	\$80	16%	\$20	20%
Service provisioning infrastructure	\$60	12%	\$35	35%
Totals	\$500	100%	\$100	100%

3.2. Efficiency of sharing

The first thing to note is that all dollar figures and share percentages in Figure 6 (even though they are extremely imprecise) are “large.” This suggests that if sharing of any of these cost categories is technically feasible, it is quite possible that this sharing could generate significant overall economic benefits even if it causes some diminution in efficiency in other

²³ CTIA (2014) reports 2013 wireless industry service revenues to be \$190 billion. But since company reporting to CTIA is voluntary and amounts to only about 95% of the U.S. wireless industry, this figure may be grossed up to \$200 billion.

²⁴ Note that this is an illustrative average ACF for the overall mobile wireless industry. Because spectrum does not depreciate, it would likely have a smaller individual ACF than this average. Similarly, because service provisioning infrastructure is largely computers and software, it likely depreciates faster than, say passive RAN infrastructure, so would have an individual ACF larger than the overall industry average.

categories. In contrast, if a cost category is *de minimis*, it is more likely that even a small negative effect on other categories' efficiency will swamp any efficiency benefits that might be gained from sharing that cost category.

The following subsections will discuss both the degree to which each of the listed cost categories may be shared efficiently, as well as the effect this sharing is likely to have on the efficiencies of other cost categories. By doing this, we may establish not only the most valuable categories to share, but also the favored and disfavored combinations of shared cost categories.

3.2.1. Radio spectrum

As displayed in Figure 6, spectrum constitutes a very significant portion of total network costs. As a result, if it is feasible to share it efficiently, there will be private economic incentives to do so depending on the nature of the spectrum user and its licensing. If the users are commercial entities and the spectrum is licensed flexibly so it may be transferred between users and/or users, these users will be very sensitive to any cost incentives to share and can be expected to strike mutually beneficial private bargains to enable such sharing (Coase, 1959, 1960). The same incentives may not apply to users who are noncommercial entities or whose spectrum is not flexibly licensed. In these instances, the spectrum controlled by such users or under such licensing conditions bears no opportunity cost. As a result, the entities controlling such spectrum will always choose (or be required) to dedicate it entirely to their own purposes. For example, government users of spectrum have been assigned a mission, and currently have no option to release their spectrum for use by others and be remunerated for it.²⁵ Therefore, so long as that spectrum provides *any* value in meeting the government agency's mission, the agency will not share out this spectrum no matter how high an incremental value it may have in external shared use.²⁶ Similarly, if the spectrum employed by a commercial entity is not flexibly licensed, its current users may be unable to offer it (for remuneration) either to other service providers or for other uses. This essentially freezes the spectrum in its current use with its

²⁵ Indeed, the Miscellaneous Receipts Act (available at http://www.law.cornell.edu/uscode/text/31/3302?qt-us_code_temp_noupdates=0#qt-us_code_temp_noupdates) prevents government agencies from benefiting from any commercial shared use of their spectrum because any payments they receive for its use must be deposited immediately with the Treasury for general U.S. government use.

²⁶ Proposals have been offered for creating a market for government agency spectrum use. See PCAST (2012) and Bazelon & McHenry (2014).

current user and eliminates the possibility of it being shared regardless of the potential efficiency of this action.²⁷

As noted in sections 2.1.1 and 2.1.2, to the extent that frequency- or geographic-based separation is feasible, these forms of sharing may not always be economically efficient. This may occur, for example, if the extra cost to deploy a separate transceiver and antenna exceeds the spectrum cost savings from sharing a small frequency band; or if the cost of the additional cell site necessary to effect geographical separation exceeds the value of the increased network capacity enabled by the separation. But to the extent that frequency bands are adequately wide and geographic license areas are adequately broad, frequency or geographic-based separation, despite causing some increase in RAN infrastructure cost, commonly does not overwhelm the cost savings from sharing the asset. Indeed, we do see extensive amounts of sharing of these two natures, both between uses and between providers. Mobile wireless frequency allocations are interspersed with frequency allocations employed in other uses such as aerial navigation, and the same mobile wireless frequencies are shared across different providers in different regions of the country.

Temporal separation, discussed in section 2.1.3, is also interesting. If we are considering sharing among like uses, temporal separation can occur efficiently only if each provider cannot exhaust the capacity of the spectrum band with just its own use; or if each provider's customers have very different time patterns for their usage. The latter is unlikely for mobile wireless; but the former may be possible in rural areas with a very low density of demand. But while this is possible, it is questionable whether spectrum availability is the limiting factor to providing service in rural areas. Rather than spectrum being scarce in these areas, it is commonly RAN infrastructure that is relatively expensive on a per-customer basis. While towers, antennas, transceivers and backhaul circuits may cost pretty much the same in rural areas as in urban ones (although real estate may be cheaper), there is limited demand density in these areas. Therefore, it may be challenging to find a favorable business case for RAN deployment even if spectrum is freely available. So while it may be economic for providers to share spectrum in these areas, this is likely to be the case only to the extent that these providers also share their RAN infrastructure. Otherwise we are in the situation where the "cheap" asset (spectrum) is being shared, but the "expensive" one (RAN infrastructure) is not.

²⁷ Possible ways to "unfreeze" current spectrum allocations are tools such as limited term licenses or incentive auctions, etc.

It is between unlike uses that pure spectrum sharing (without infrastructure sharing) seems most likely to be economic. Only when there are unlike uses is it reasonable to expect that there may be temporal differences in peak demands, or minimal value in also sharing infrastructure.²⁸

3.2.2. Passive RAN infrastructure

Passive RAN infrastructure may constitute the largest category of mobile wireless costs, thus it may offer the largest opportunity for economic cost sharing. The major components of passive RAN infrastructure are the real estate used by the cell site, the tower on the site, the equipment huts or cabinets and the power equipment. Each of these components is generally scalable, with larger capacities coming at a smaller unit cost than smaller capacities.²⁹ As a result, the economic advantages of sharing passive RAN infrastructure are likely to be limited only by zoning restrictions on tower sizes or real estate size limitations on the ability to place larger equipment huts/cabinets or more massive power equipment. Indeed, given that independent tower companies already supply about a third of all U.S. cell sites and many operator-owned towers may also be shared, it is clear that mobile wireless operators have sought to exploit intensively these efficiencies.³⁰ Further, aside from dealing with some coordination issues associated with active equipment placement and maintenance at the cell site, there seem to be few negative effects from passive RAN sharing on the operating efficiency of any other category of wireless asset.

Note that in contrast to spectrum sharing, the greatest efficiencies from passive RAN infrastructure sharing seem to derive from sharing between like uses. This is because the required passive RAN infrastructure for mobile wireless is relatively generic across different providers and different mobile wireless technologies. Various analyses have suggested that by sharing, passive RAN infrastructure CAPEX and OPEX costs may be reduced by up to 50%, which by itself could lower total network CAPEX and OPEX by 15%; and when the possible benefits

²⁸ PCAST (2012) provides some examples.

²⁹ For example, a tower holding twice the number of antennas as a smaller tower is unlikely to be double the cost. A larger equipment hut usually costs less per cubic foot than a smaller one. And larger power supplies have a lower cost per kilowatt of output than smaller ones.

³⁰ Because no mandatory RAN infrastructure sharing requirements are imposed on U.S. mobile wireless carriers, the existence of this sharing can be attributed fully to the operation of a competitive market that incents providers to seek out all possible cost efficiencies. Rather, the only mandatory sharing requirements on U.S. mobile wireless carriers are for the provision of voice and data roaming (FCC, 2011).

from active RAN sharing are added, total savings could mount to 30%.³¹ Whether passive RAN infrastructure sharing also suggests that active RAN infrastructure should be shared in concert is a more complex question (Larsen, 2012).

3.2.3. Active RAN infrastructure

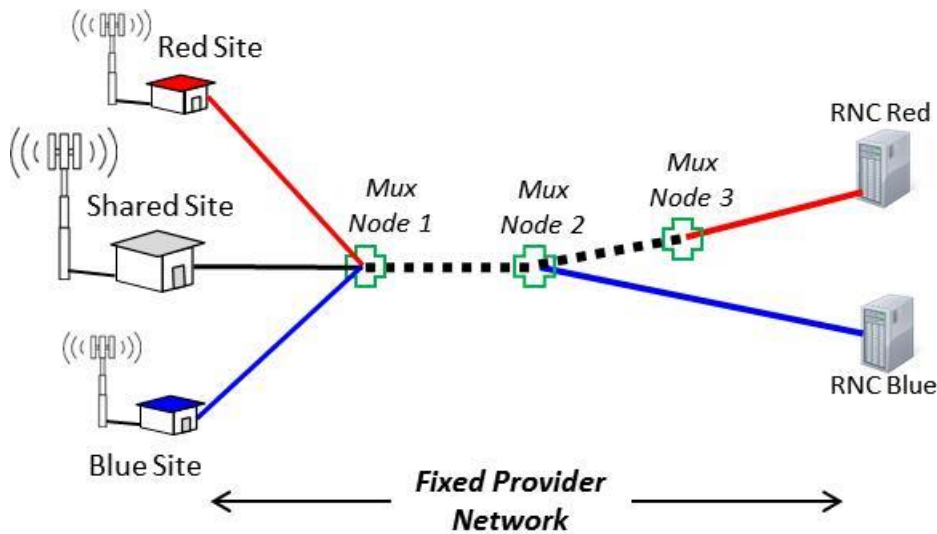
Active RAN infrastructure consists of antennas, radio transceivers, backhaul circuits and RNCs. While these items are potentially sharable, the economic case for their sharing in the absence of higher-order sharing (i.e., of core networks or service provisioning) is more idiosyncratic.

Assuming compatible technologies, antennas and transceivers generally are tuned and optimized to specific frequencies. While it is possible for these pieces of equipment to accommodate multiple frequency bands, it typically is only at higher cost or with some decline in their technical efficiency. This raises the likelihood of disputes between the sharers as to whose technical needs are paramount and who should bear the burden of suboptimality. It seems unlikely that RNCs would be shared unless all other elements of the active RAN are shared.

While complete backhaul circuits would not likely be shared unless the RNC is also shared, the cell site-terminating segments of backhaul circuits might be shared out to some point of disaggregation where they are routed to separate RNCs. Indeed, this is exactly the architecture shown in the lower right of Figure 3. The most expensive segment of a backhaul circuit is generally the “last mile” link to the cell site. By sharing this link out to some intermediate multiplexer where the circuit is then split between the two mobile networks, substantial cost savings may be obtained. In any event, sharing between customers is implicit in the operations of fixed providers of high capacity data or voice circuits. These fixed providers install high capacity facilities, and sell individual circuits (either physical or virtual) on these facilities to multiple customers – allowing each customer to purchase its needs at a price less than what the customer might pay if it installed its own end-to-end facilities dedicated exclusively to its use.

³¹ See, generally, BEREC-RSPG (2011), GSMA (2012), Meddour, et al. (2011) and Vornpuan (2010) for examples of savings percentages from passive and active RAN sharing. These percentage savings figures for sharing likely assume that the technologies being employed by sharers are completely compatible so that the active RAN can be shared as fully as the passive RAN.

Figure 7: Backhaul sharing



This sharing is illustrated in Figure 7. The fixed provider provisions last mile facilities dedicated to the Red network to the Red cell site, facilities dedicated to the Blue network to the Blue cell site, and facilities shared between the Red and Blue networks to the Shared cell site. Once these facilities reach multiplexing node 1 on the fixed network, they are combined with each other and with the circuits provided to other customers subtending that node and are sent across the fixed network to multiplexing node 2. At this point the circuit to the Blue network is split off and sent to its RNC and the remaining traffic continues on to multiplexing node 3 where the circuit to the Red network is split off and sent to its RNC. Note that the above suggests that other than for backhaul, it is unlikely that the active RAN will be shared unless the passive RAN is shared as well.

3.2.4. Core network infrastructure

Core networks operate at the highest levels of traffic aggregation within mobile networks. They consist of the very high capacity transmission links connecting RNCs, voice and data switching centers, the Internet “cloud,” the PSTN and centralized databases and control equipment. Because the facilities that comprise core networks are accessed by nearly all traffic touching the mobile network, the operator has the opportunity to size these component facilities to closely match its total needs – and often the needs of the total mobile network outstrip the

capacity of even the largest these individual component facilities, thus multiples of these components may be deployed to provision a single core network.³²

Sharing of core networks is implicit when the core network owner offers wholesale capacity to MVNOs. It is also implicit in the concept of wholesale-only networks. But note that while core network facilities may effectively be shared if their owner offers them to MVNOs in conjunction with spectrum and RAN facilities, it seems unlikely that these facilities would ever be shared without including their subtending RANs and spectrum.

3.2.5. Service provisioning infrastructure

While the core network hosts the intelligence infrastructure facing the mobile network, the service provisioning infrastructure provides the intelligence that faces the customer. This includes marketing, sales, customer support and billing systems. Other than for pure service resale situations (where the retailer acts only as a sales agent for the underlying network), it is unlikely that service provisioning infrastructure would be shared among providers.

4. Competitive implications of wireless asset sharing

While in many instances, asset sharing could offer sharers attractive opportunities for cost savings, this may or may not end up benefiting customers. In general, if markets are competitive, efficiency gains enjoyed by wireless service providers will be passed along to their customers in the form of lower prices or higher quality services. Cost savings enjoyed by government-owned wireless systems should also be passed on to the public in the form of reduced government taxes, or improved levels of government services.

But wireless asset sharing may reduce wireless providers' ability to differentiate their products or their incentives to invest in superior product quality – such as would be offered by deploying denser or higher speed networks. Such concerns are likely to be most acute when the sharing occurs among providers competing to offer similar services to similar customers.³³ If this occurs, it may be possible that this attenuation of competition between sharing wireless

³² In economic terms, this means that core network facilities may exceed greatly the minimum efficient scale of such facilities. As a result, no reduced unit costs are available from sharing these facilities with another provider. Of course, it is also possible that diversity/security concerns may require multiple units of these core network facilities to be installed prior to them reaching minimum efficient scale. If this is the case, sharing these facilities with an additional network may offer some unit cost savings.

³³ If the sharing entities provide extremely different services (e.g, GPS versus mobile phone), or if their customer sets are completely different (e.g, airlines using aeronautical radio versus personal smartphone users), sharing is less likely to reduce incentives to innovate and compete.

providers could reduce customer welfare, possibly by even more than sharing's cost savings improve the profitability of providers.

While evaluating the trade-off between cost savings and competition attenuation is inherently an empirical exercise, it is important to at least understand what types of asset sharing have the greatest potential to influence the level of competitive rivalry.³⁴

4.1. Radio spectrum

While it may seem that if the sharing of radio spectrum is technically feasible and economically efficient it should not have a significant influence on the vitality of inter-provider competition, this may not always be the case. This is because spectrum is to some degree substitutable with RAN infrastructure as a component in the production of wireless services. If spectrum is scarce to a provider, it can substitute for this lack by densifying its RAN infrastructure so as to achieve more intensive “reuse” of its spectrum. But difficulties may arise if two providers share their spectrum, but not their RAN infrastructure. If this occurs, each provider may attempt to over-use the shared input (spectrum) in order to economize on the use of its dedicated input (RAN infrastructure). This tragedy-of-the-commons scenario can result in lower quality services being provided to the customers of both providers.

Of course such a situation need not arise if the as part of their spectrum-sharing agreement the two providers include requirements that each must limit the degree to which it attempts to exploit the shared spectrum resource, and to instead deploy additional RAN infrastructure when specified spectrum constraints are reached.

4.2. RAN infrastructure

RAN sharing is often advanced as a way to achieve both greater mobile network coverage and to improve competition by making it economic for networks to be extended to costly-to-serve rural areas, and for multiple providers to offer service in these areas (GSMA, 2012). In addition, RAN sharing may also allow increased competition and capacity in urban areas where effective cell site locations are scarce and expensive. Whether these benefits will be realized will depend on the ability of providers employing shared network assets to differentiate their services and to compete based on these differences.

³⁴ BEREC-RSPG (2011, ¶32) provides a very useful list of the various generic factors (e.g., number of competitors in the market, exclusivity of the sharing agreement, level of information exchange, etc.) that would influence any evaluation of the welfare desirability of a network asset sharing arrangement.

As noted in section 3.2.1, sharing of spectrum is likely to be most efficient when RAN infrastructure is shared as well. Of course if this occurs, it becomes difficult for the providers to differentiate their services and to compete on product quality. Fully shared RAN infrastructure means that both providers will be offering their customers the same network technology (e.g., HSPA+ or 4G LTE) and the same coverage topology. As a result, product quality will be identical across providers, with differentiation based only on price or other service provisioning attributes. However the degree to which inter-provider competition may be affected will depend on whether just passive infrastructure is shared, or whether active infrastructure is shared, too.³⁵

Sharing of only passive RAN infrastructure is likely to have the least deleterious effect on inter-provider competition – because while cell sites and towers are shared and the coverage topology of the sharing providers may be similar, service quality could still differ significantly.³⁶ This is because the active RAN infrastructure and spectrum band have substantial influence over quality attributes. If spectrum is not shared, then service quality may differ between the providers if one operates in low-frequency spectrum while the other operates in higher-frequency spectrum. The low band provider (assuming it operates from the exact same cell sites as the higher-band provider) will tend to have better signal propagation out to the extremes of the cell site service area and better in-building propagation within the service area.³⁷ Further, if one provider is employing 10 MHz blocks for its signals while the other provider is using only 5 MHz blocks, data transmission capacities and speeds will be higher for the first provider's service.

If both passive and active RAN infrastructures are shared along with spectrum, product differentiation will be based strictly on service-provisioning attributes. These could include items such as price plans, device choices, usage quotas and customer service. While these features may differentiate significantly different wireless providers in the eyes of consumers, they may provide less of a basis for long-term differentiation than that provided by no RAN sharing, or sharing just of passive RAN infrastructure. This is because it tends to be quicker and

³⁵ As noted in section 3.2.2, is unlikely that active RAN infrastructure would be shared if passive is not also shared.

³⁶ See <http://www.iphoneincanada.ca/carriers/rootmetrics-study-big3-montreal-toronto-vancouver/> for a discussion of how service quality differs in Canada between Bell and Telus because their infrastructure sharing is limited to the passive RAN.

³⁷ But if the service area is capacity-constrained, these propagation characteristics of low band spectrum may not be desirable and higher band spectrum offering greater capacity may be preferred.

easier for providers to imitate the service-provisioning characteristics of another provider than it is to imitate the service quality characteristics offered by a superior RAN infrastructure (e.g., 4G LTE over 3G, or fewer coverage gaps and/or dropped connections). Upgrading the coverage and density of a RAN is typically a multiyear and highly capital-intensive process. Further, even after network performance has been improved, customer perceptions are slow to change and typically lag significantly the actual quality improvements in the network.

Example of Canada

Canada offers an interesting example of the interplay of RAN sharing issues and mandates on the evolution of market competition. Prior to 2008, Canadians in any particular province were generally served by a mix of three providers drawn from the several national providers Rogers, Bell Canada and Telus, as well as regional providers in Manitoba (MTS) and in Saskatchewan (SaskTel). In 2008, Industry Canada auctioned new AWS spectrum with a set-aside of 40 MHz reserved for new competitors. The set-aside spectrum licenses were largely won on a provincial basis by entrants Wind, Mobilicity, Shaw, Vidéotron and Eastlink.

As these entrants were building out their networks, they were met by a change in the competitive landscape. Previously, Telus had generally just served western Canada and Bell had just served eastern Canada. As a result, each lagged national leader Rogers, which also had the iPhone. To meet this challenge, Telus and Bell, who each used CDMA technology, decided to deploy a shared iPhone-compatible HSPA RAN – with Telus taking the construction lead in the west and Bell in the east. By late 2009, this new shared network was ready – just as the AWS entrants were beginning their own services. So instead of generally facing just two national providers in each market, the AWS entrants now faced three.

While the viability of these new competitors was always in question, there was little doubt that their economic situation was not enhanced by Bell and Telus' shared HSPA RAN. Indeed, concurrent with its auction of the AWS licenses, Industry Canada issued rules making tower-sharing and the provision of roaming mandatory across carriers, subject to technical feasibility and commercial compensation – with roaming available for five years within a carrier's license area and for ten years outside this area. These sharing mandates, though, proved inadequate to encourage all entrants to build out their in-area facilities or to prevent the demise of many of the entrants. Perhaps as a result, Industry Canada in 2013 issued further roaming and sharing requirements that extended these requirements indefinitely, both outside and inside an applicant's licensed service area. Whether these expanded sharing requirements will revitalize competition or continue to constrain it remains to be seen.

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4.3. Core network

Given that core network functions are relatively generic across different networks and typically provide little product differentiation, the sharing of just core network functions is likely competitively benign. But as earlier noted, core network sharing is unlikely to occur absent the sharing of its subtending RANs and the spectrum they use. If this complete combination is

shared, such a network can be considered a wholesale network – providing services to retail mobile carriers.³⁸ The effect on competition of such networks is complex, and will depend on several characteristics.

The first question is whether this wholesale network competes against several other networks to provide similar services to the same customer set, or whether it enjoys a monopoly. In the U.S., for example, LightSquared was to be a wholesale-only network that would have provided LTE services to retail mobile carriers in competition with several other LTE networks. In contrast, several other countries have proposed to devote their LTE spectrum blocks to a monopoly entity known as a “single wholesale network” (SWN).³⁹ This arrangement would require any mobile carrier wishing to offer retail LTE services to hire wholesale service from the SWN. Proponents argue that SWNs permit broader network coverage and superior spectrum use efficiency. Opponents point to empirical data suggesting that countries with competition among multiple physical networks have more quickly deployed new technologies and achieved broad coverage and take-up more quickly than countries with only a single mobile network.⁴⁰ Another complicating question is how SWNs will be regulated, given that they will have monopoly power. Without answers to these questions, it is difficult to determine the net effect on consumer welfare from wholesale spectrum/RAN/core network combinations.⁴¹

³⁸ It is also possible that the shared network could sell services itself, in competition with its “customer” networks. This is the case with EE in the UK. EE is a joint venture network owned by T-Mobile and Orange. It sells wholesale services to each of its parents, but also markets its own retail services directly. See, [http://en.wikipedia.org/wiki/EE_\(telecommunications_company\)](http://en.wikipedia.org/wiki/EE_(telecommunications_company)), <http://www.telecoms.com/50560/the-big-switch-on-the-marriage-orange-and-t-mobile-networks-and-the-birth-of-4g/> and <http://shop.ee.co.uk/devices/orange-tmobile>.

³⁹ See GSMA (2014). Several countries proposing this structure are Mexico, Rwanda, Kenya, Russia and South Africa. For example, see <http://www.sct.gob.mx/despliega-noticias/article/firman-sct-e-ift-convenios-para-red-compartida-en-la-banda-de-700-mhz/>.

⁴⁰ See GSMA (2014) for a fuller discussion of SWN issues.

⁴¹ It will be especially interesting to see how competition evolves under network sharing in the UK. As noted earlier, two of the UK’s five previous mobile networks (T-Mobile and Orange) have created a full infrastructure-sharing joint venture, EE. Two others, O2 and Vodafone, have since announced they will enter a full RAN-sharing arrangement, but will not combine core network functions (see, <http://blog.vodafone.co.uk/2012/11/20/better-coverage-fewer-masts-your-complete-guide-to-our-network-joint-venture/> and <http://www.theregister.co.uk/2012/06/07/vodafone/>). And the fifth network, 3 UK, has a RAN sharing agreement with EE (see, <http://www.mobileworldlive.com/ee-three-take-passive-route-4g-network-sharing>).

4.4. Service provisioning

If service provisioning infrastructure is shared in addition to all other subtending infrastructure, it is likely that the mobile services provided under such an arrangement will appear to be no more differentiated than different service quantity packages (e.g., minute, text and/or data quotas) or different brands offered by the same company. As a result, sharing at this level is likely not to yield significant inter-offer competition. While the potential cost savings from employing a single physical network to support these different service packages is large, the key issue is whether there are several other physical networks offering similar services to the same sets of customers. If so, the cost saving benefits may outweigh any diminution in customer competition. But if all that exists is a single physical network offering different service packages or brands, even if its costs are potentially less the lack of competitive pressure from rivals may well result in operational inefficiencies, managerial slack, and an overall loss of dynamism. As a result, the shared network's potential cost efficiencies will not be realized and consumer welfare will suffer.

Sharing in the form of roaming also may be a two-edged sword. While roaming may allow carriers, particularly nascent ones without expansive networks, to quickly offer service across a broad region, this sharing may also dull their incentive to build out their own networks. In particular it is natural to expect that any new mobile carrier will seek first to build its network facilities in low-cost, high-demand areas. But in areas where costs are high or demand is scarce, the new carrier will likely prefer to purchase roaming services from an existing carrier. This attraction will be even more acute to the extent that the carrier providing the roaming services is required to offer such services on an averaged cost basis. Not only does the new carrier seeking roaming avoid deploying its own network in high-cost, low-demand areas, but it gets to purchase these services at a price that reflects the existing carrier's network-wide average costs, as opposed to the higher costs specific to these geographies.⁴²

5. Summary

Based on this and other analyses, it would seem that asset-sharing would offer wireless service providers an important tool to reduce costs and/or expand output. But if asset-sharing

⁴² See <http://www.crtc.gc.ca/eng/archive/2014/2014-398.htm> for an example of the complexities associated with determining whether or not a roaming arrangement is "fair."

is so valuable, why don't we see more of it? There are likely many reasons (Larsen, 2012). They would include:

- Sharing is often difficult to implement. It requires substantial coordination and compromise between parties, whose preferences and interests do not always align.
- The assets nominated for sharing may not be that scarce, at least at the present moment. Spectrum may be adequate, real estate for cell sites available, and backhaul priced favorably.
- The scale at which wireless companies operate already allows them to exploit fully all scale economies. Thus, the company may be already replicating efficiently-sized facilities for its own purposes, and has no excess capacity to share with others.
- Technologies are not standardized, so that it is not technically feasible for a company to share its assets with other companies that don't also share its technology.
- Employing unshared assets to produce differentiated services that better meet specific customer quality preferences – and to have the opportunity to monetize this extra customer value in pricing, outweighs the value of cost savings from asset sharing.

These considerations may explain why infrastructure asset sharing (other than for passive RAN) appears to be more popular in Europe than in the U.S.⁴³ In particular, U.S. wireless companies generally exceed European ones in size and network capacity, thus they may have more fully exploited scale economies without resort to sharing. Further, mobile wireless technologies and spectrum frequencies have been more diverse in the U.S. than in Europe – where these items have been subject to mandatory standardization. Thus the European situation may be one that permits less product differentiation than in the U.S., but provides increased technical possibilities for sharing.

As noted, the potential cost savings of wireless asset sharing must be balanced against the potential to attenuate competition – both through the lessening of competitive rivalry and by depressing the ability of providers to differentiate their services on the basis of coverage or product quality. These concerns may be the least with respect to sharing of spectrum or passive RAN infrastructure, but become more acute when active RAN infrastructure, core networks and

⁴³ See GSMA (2012), Larsen (2012), Mölleryd & Markendahl (2013) and Vornpuan (2010) for lists of existing sharing arrangements.

service provisioning become shared. More empirical study of sharing agreements and their competitive and cost effects must be gathered before precise conclusions can be drawn.

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Draft of November 3, 2014