TV White Space Technology
for Rural Telecommunications
COMMUNITY EXAMPLES

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Introduction

When the government's Rural Broadband Initiative (RBI) is completed in 2016, 65,000 households will remain on satellite or 3G broadband solutions a fraction of the speed of broadband available in cities and towns. For these households, the RBI will actually serve to increase the digital divide.

Cellular carriers claim the release of 700MHz Digital Dividend spectrum will help them provide better service to rural populations, but new spectrum on existing towers will do little to help households without existing or planned cellular coverage. Maps used throughout the document show the planned extent of RBI towers at the conclusion of the five-year deployment, and show large gaps in coverage. Hundreds more towers need to be installed across remote districts to provide service for them, without a new technology and appropriate radio spectrum, those towers will not be viable technically or commercially.

Television Whitespace Technology (TVWS) is a disruptive wireless broadband innovation which challenges a basic tenet of radio licensing: that radio spectrum should be sold or leased for exclusive use. In the eyes of TVWS developers, spectrum isn't a scarce resource to be locked up and traded by wealthy corporations, it's an abundant resource that should be fully used wherever possible.

TVWS is an inexpensive, light weight technology - priced closer to wireless broadband equipment than it is to the cellular equipment typically used to cover rural and remote communities. Through its use of television spectrum TVWS can allow broadband coverage far more effectively than technologies like Wi-Fi while emitting just four watts of power - orders of magnitude less than a typical cellular tower.

New laws in the United States passed to bridge the digital divide have enabled the development of TVWS. Using the technology, wireless broadband providers are now able to take advantage of unused television spectrum, while the rights of broadcasters are preserved. In the most straightforward example of TVWS use, if a television broadcaster isn't using their spectrum in a particular area, and if its use for broadband wouldn't compromise a broadcast elsewhere, that spectrum is available for use delivering wireless broadband in a dynamic yet controlled way.

To evaluate the potential utility of TVWS in New Zealand, three rural communities that will be missed by the RBI have been identified. A discussion is made of the cost and complexity of servicing rural and remote communities, and the existing telecommunications technologies used to service the communities are reviewed. Radio coverage models are constructed simulating common, off the shelf Wi-Fi technology and new TVWS equipment. The models are then compared for coverage potential of each technology. A review is made of how TVWS might benefit the communities, and conclusions are drawn about how the technology could be useful in bridging the digital divide.

The Communities

The map below plots broadband coverage across central New Zealand at the end of the five-year RBI rollout. Red, orange, and green areas indicated fixed line broadband, and blue indicates 3G wireless broadband. The map is an optimistic view of data released by Chorus and Vodafone; houses within coverage areas will have a good chance of access to broadband, but no guarantees.
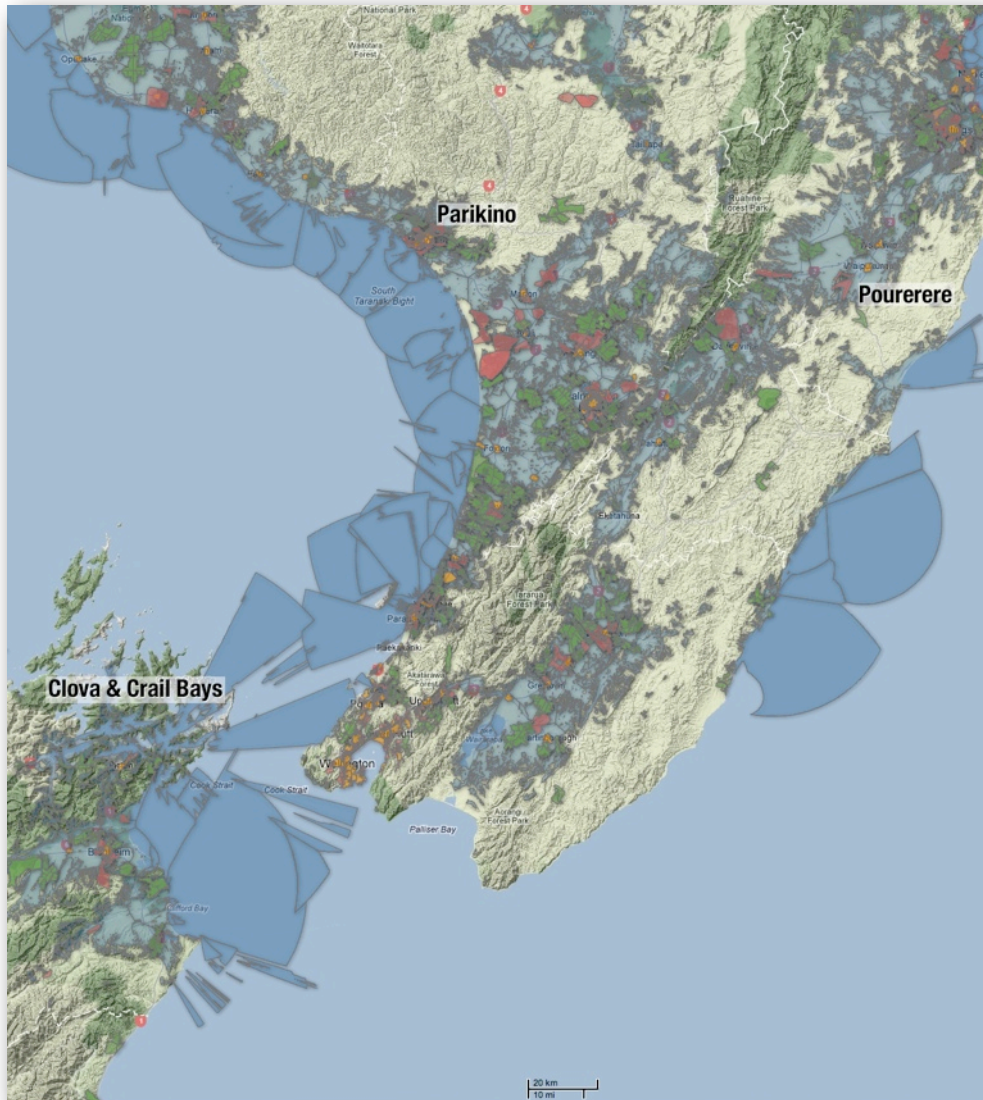
Clova & Crail Bays in the Marlborough Sounds, Parikino in the Whanganui River Valley, and Pourerere in Central Hawkes Bay are all small communities with well maintained roads, electricity networks, and telephones via copper cables from Chorus, but no potential for broadband beyond satellite. They all have a need for broadband, but none has an easy or obvious solution that is both technically and economically feasible. Each community will be evaluated to determine how TVWS might be useful in the delivery of broadband.

Servicing Rural and Remote Communities

Rough territory, long serpentine roads, and access that can be cut off by flooding or slips are characteristics of much of rural New Zealand. These factors serve to make broadband delivery difficult. In 2002, Canada's Communications Research Centre quantified just how difficult it is to serve rural populations, and charted their data in a submission to the IEEE's working group on 802.22, a TVWS technology. In a representation of their data below, the X-axis shows population density, the colored lines represent different communications technologies, and the Y-axis is a measurement of the relative cost and complexity of deploying those technologies.
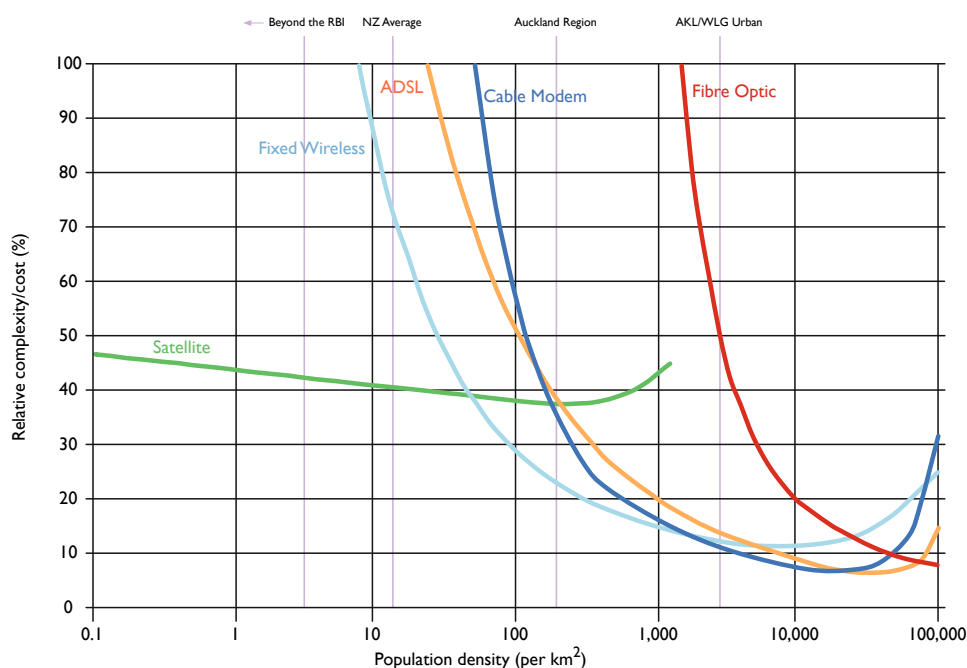
In Canada, as shown in the diagram above, it's less complex and expensive to use satellite than any other technology for broadband once the population density drops below 65 people per km^2. When the data was compiled in 2002 it wasn't practical at all to use fixed wireless for population densities below 8 people per km^2.

Fixed wireless broadband has significant speed and throughput advantages over satellite, so a major goal of TVWS technology development has been to shift the cost/complexity curve for fixed wireless to the left, allowing for less use of satellite in areas of lower population density.

Fixed Line Connectivity in New Zealand

Thanks to a history of state ownership of telecommunications and the later introduction of universal service legislation at the time of the privatization of Telecom, virtually all properties in New Zealand are connected to the Chorus telephone network with copper cables. Those cables don't always have modern infrastructure upstream of them, as several different modes of backhaul (a connection to the nearest urban area) are employed.

Houses connected directly to a fibre-fed exchange or cabinet might have fast, fixed-line broadband. Rural houses connected to an exchange or cabinet with a copper backhaul might have broadband that's barely faster than dial-up. Still others have radio backhaul connections that don't even support dial-up connectivity, and still won't even after the completion of the RBI. All these modes of fixed line communications backhaul and their capabilities are described in detail in Appendix A.

With copper technology everywhere and fixed line calling guaranteed at a regulated price, rural New Zealand is well provided for when considering basic telephony. On the broadband front however, New Zealand has no concept of universal access, and the RBI doesn't change this. In areas without RBI coverage, service prices and speeds are highly variable and will remain that way.

Rural and Remote Cellular, Wireless, & Satellite Technologies

Where fixed-line broadband isn't available, market driven solutions are. Such alternatives include cellular, fixed wireless, and satellite. Together these services provide the potential for service almost everywhere - at a price. Each of these technologies and their capabilities are detailed in Appendix B, with a special emphasis placed on Wireless Internet Service Providers, their technologies, and the radio spectrum they use to provide services.

TV White Space Technology

Television White Space Technology (TVWS) allows broadband providers access to licensed TV spectrum where it's not in use, while protecting spectrum owners from interference. It challenges a basic tenant of radio communications: that spectrum is a scarce resource to be divided in to small slices, with rights to each slice exclusively licensed to a particular operator. TVWS is the first commercialization of a range of technologies that will eventually include cognitive radios - software defined radios that can dynamically find and use white space in any part of the radio spectrum.
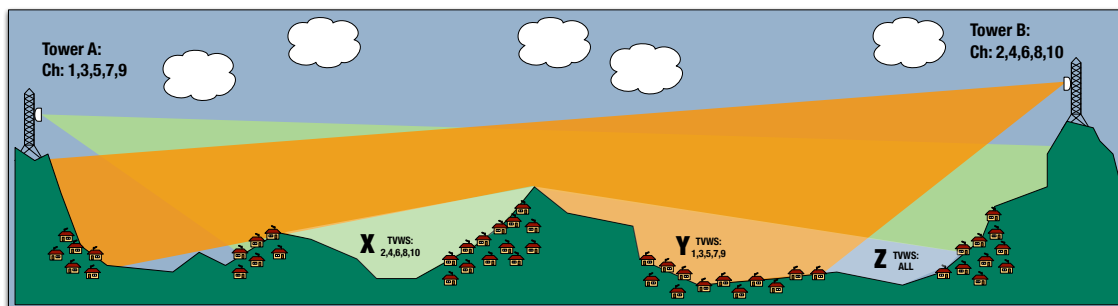
TV White Spaces

White Spaces are places where spectrum is licensed but not in use, due to technical, geographic, or economic causes. From a technical standpoint, adjacent transmitter towers often alternate use of TV channels to prevent high power television broadcasts from interfering with each other, as demonstrated by the towers and channels used in the diagram below.

	Mt. Egmont Taranaki	Mt. Jowett Whanganui	Wharite Palmerston N.
Channel 1		■	
Channel 2	■		■
Channel 3		■	
Channel 4	■		■
Channel 5		■	

Geography plays a major role in White Spaces. Where hills or mountains block radio signals, white spaces exist. Economics is yet another barrier to full utilization of the radio spectrum. While a large urban market may have the advertising revenue to support dozens of broadcast channels, rural markets can rarely sustain more than a handful.

The diagram above illustrates a typical television broadcast configuration and resulting white spaces.

Tower A transmits on odd channels, and some of its coverage area is obstructed by terrain. Tower B

transmits on even channels, and again some of its coverage is obstructed.

The three most obvious white spaces regions are:

- X: Households receive from only from Tower A, and channels 2,4,6,8, &10 are unused
- Y: Households receive from Tower B, and channels 1,3,5,7, & 9 are unused
- Z: Households don't receive any terrestrial broadcasts, instead using satellite for TV. All channels are unused.

Any unused channel in a particular area is available to TVWS users.

TV White Space Spectrum in New Zealand

The conversion from analog to digital broadcasting in New Zealand will free up an immense amount of spectrum as digital channels only take up 17% of the amount of spectrum as analog ones. When the last analog transmissions end in November 2013, most spectrum in the Ultra High Frequency (UHF) will be unoccupied. A further block will be freed up by the shut off of Very High Frequency (VHF) television services. Together these bands have 242MHz of spectrum available, 2.5 times what will be auctioned as a part of the 700MHz Digital Dividend spectrum block.
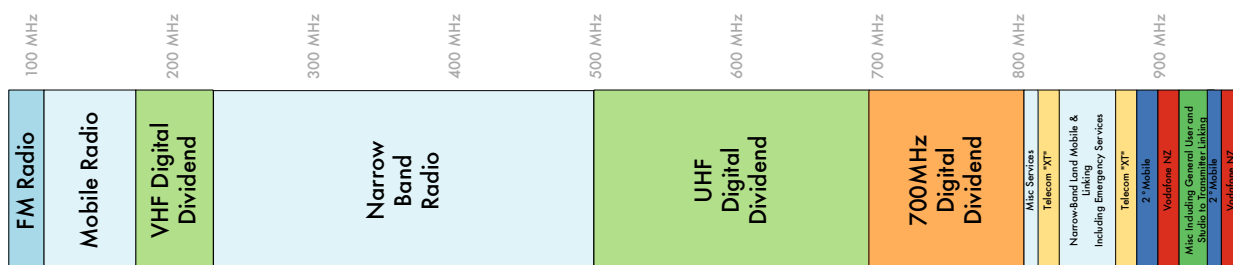
White Spaces Technology

TVWS has emerged as a result of United States Federal Communications Commission (FCC) regulations allowing for use of TV white space spectrum on a non-interfering basis. Wireless base stations using TVWS connect over the Internet to a database of licensed transmitters and their coverage areas, and are allowed use of channels in particular areas where they will not interfere with licensed users. Several companies including Google plan to run transmitter databases enabling TVWS use. Future TVWS technologies will use a combination of real-time spectrum sensing and geo-location databases to determine whether or not radio spectrum is in use before transmitting.

TV Spectrum Properties

At 602MHz, an average TVWS channel in the UHF band, the radio waves are around half a meter long. These waves are not affected by rain fade, and propagate well through vegetation. As discussed in Appendix D, 602MHz will travel through trees at least four times better than the popular Wi-Fi band at 2400MHz. As the waves are larger than than the majority of tree leaves in New Zealand, wave reflections are unlikely. A pair of trees in the path between a house and a tower would make

very little difference to broadband performance, and unlike Wi-Fi spectrum, which can stop working if beamed through a wet tree or one shifting in the wind, there are no cases where UHF TV spectrum will be affected by weather conditions.

Due to such robust radio properties, White Space spectrum is ideal for use in rural environments, where trees are frequently planted around houses for shelter, and used as wind breaks in pastures.

TV White Space UHF Radio Equipment

The first standard for using TV White Spaces for broadband, 802.22, was ratified by the IEEE in July 2011. An IEEE working group is also set to adapt Wi-Fi for TVWS use, a standard that when ratified will be called 802.11af. To date no open standards equipment has come to market, however a consortium of manufacturers are producing equipment using a proprietary technology standard called "Weightless". These initial proprietary solutions are good, but still years away from reaching the sophistication and price points of today's Wi-Fi and WiMAX devices.

From a cost standpoint, TVWS equipment will be priced at or around that of other wireless broadband technologies, making it an order of magnitude less expensive than a typical cellular installation. Base stations may cost a few thousand dollars, while subscriber units should cost no more than a few hundred. This makes it very well suited to serving households in low population density areas where a tower might only cover fifty houses.

The equipment modeled in this study is the Carlson Wireless RuralConnect Generation II Base Station and Customer Premises Equipment. The Carlson units are based on the Weightless standard, and are currently in trials in the United States, including a significant deployment on the Yurok Native American reservation in California. The radios have an indoor terminal connected to an outdoor antenna by coaxial cable, and use an antenna very similar in appearance to a TV aerial.
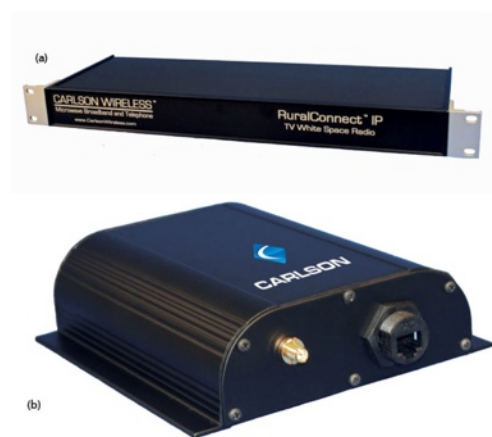
The speeds and receive sensitivities provided by the Carlson Wireless equipment are good, but not groundbreaking. At 2.66 bits/Hertz, their spectral efficiency matches that of 802.11a/g Wi-Fi, meaning that for a similar amount of spectrum used, the two technologies will have similar performance. Given the low population densities these units are meant to cover, a typical solution would provide committed speeds an order of magnitude higher than those available from Vodafone's RBI product. It is expected that as standards based equipment comes to market, higher performance devices will be released by Carlson and a host of other vendors, bringing improvements in both coverage and throughput.

Community Studies Methodology

Three communities are evaluated to determine how TVWS might be useful in delivering broadband. In each study a region and community are introduced, and existing fixed line and cellular telecommunications resources are reviewed. A detailed map of the RBI build around the community is shown with individual properties plotted on the map. A tower site is selected, a determination is made of what TVWS spectrum is available, then models are shown of potential coverage using both existing Wi-Fi technologies and TVWS.

Tower Selection

A good tower is one with potential for coverage, potential for backhaul, electricity, and established access via road or track. In order to find such a location, existing radio licenses from the Ministry of Economic Development's (MED) Radio Spectrum Management (RSM) database are plotted on a terrain map to find where other providers have found success in the past. Household address points sourced from LINZ and Vodafone's RBI coverage as published by the MED are overlaid so that the best existing tower for the area can be quickly determined.

Available Spectrum

TV White Space spectrum is simply television spectrum that's not in use in a particular place at a particular time. To determine what spectrum is available, the nearest television towers to each community are plotted on a map, and the frequencies they use to transmit - extracted from an MED database - are plotted. Path studies are then calculated between the community tower location and the nearest TV broadcast towers using a radio link modeling tool. Micropath's Pathanal imports terrain data from NASA Shuttle Ray Topography Mission and plots radio waves between two points. If one or more significant obstructions exists between one or more nearby TV broadcast towers and the proposed community tower, there is likely to be spectrum available for a TVWS broadband service.

Modeling Wi-Fi vs. TVWS Broadband

The Wi-Fi revolution has powered most successful rural wireless providers. Wi-Fi radios, more technically defined as IEEE 802.11 radios, are at the heart of almost all off-the-shelf wireless broadband equipment. For this reason, Wi-Fi based wireless broadband coverage is modeled as a baseline against which to compare the use of TV White Space spectrum.

Coverage modeling of Wi-Fi and TVWS was carried out using a wave propagation and radio network planning tool called ProMan. The tool imports a terrain map called a Digital Elevation Model (DEM) and a database of land utilization (Clutter), both licensed from GeographX at a resolution of 20 meters. The software tool projects rays from a transmitter point and diminishes or deflects their energy based on the terrain and clutter. It is the same type of tool and quality of data

used by cellular companies to provide coverage maps like the ones published on the Telecom, Vodafone, and 2Degrees web pages. Specific settings used in the modeling are included in Appendix C, and power levels are discussed in Appendix E.

A single antenna at each base station is modeled for the sake of simplicity. In a real-world situation, additional antennas on different channels could be added to increase capacity or coverage from the same tower.

While the prediction tool models performance across existing hills, paddocks, lakes, forests, pine plantations, and vineyards, with its 20m resolution it does not usually pick up individual trees, wind breaks, or plantings around houses. This means that many coverage prediction results will be subject to checks on the individual house level.
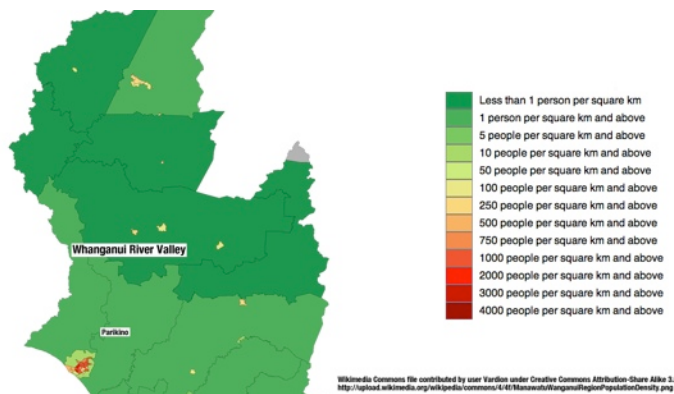
Parikino, Whanganui River Valley

The Whanganui river valley consists of rugged hilly territory with a few thousand residents, most of whom live in small settlements along the river or State Highway 4. Māori consider the region to be Te Atihaunui a Pāpārangi, which is bounded by Taumarunui in the North, Kai Iwi Stream in the West, and the Whangaehu River in the South.

Image Copyright 2012 Google Retrieved from http://maps.google.com/ on 6 August 2012

Population density across the region averages fewer than 5 people per square kilometer, with concentrations in Waiouru, Ohakune, Raetihi, Taumarunui, and Pipiriki. Pastoral farming, tourism, and commercial forestry are the main industries. Throughout much of the area, it would be unrealistic to commute to work in larger towns such as Whanganui or Waiouru.

Parikino

Although only 18km by road outside of the centre of Whanganui, Parikino is as isolated as communities far up the Whanganui River. There are fewer than 30 households in this part of the valley today, but the area is rich in culture and history. The Pungarehu and Parikino Marae are

centres of large, extended communities. As seen in the photograph, trees abound in the valley, often growing to heights of 20m.

Fixed Line Communications: Parikino

Parikino is in the Makirikiri telephone exchange area, and is fed by copper pairs either from a Chorus rural exchange known as MIK/G, or a radio hut known as MIK/L. In either case, given the distance from the nearest cabinet - more than five kilometres - it is unlikely ADSL service is available. The rural exchange is backhauled via 2mbps copper links, and the radio hut is backhauled via a narrow-band radio technology called CMAR (explained in appendix A), so even if Parikino were closer to either, the backhaul required for ADSL isn't in place.

Although fibre will be passing MIK/G as part of the RBI, the exchange is not scheduled for an upgrade. The photo below shows the Chorus Rural Exchange MIK/G.


Image Copyright 2012 Google Retrieved from http://maps.google.com/ on 6 August 2012

Cellular Communications: Parikino

The entirety of the Whanganui River Valley from Parikino through to Taumarunui is lacking in cellular coverage at road and residence level from both Telecom and Vodafone. By driving a steep hill track around 1.5km from Parikino, ascending between 150-250M above the level of the river, weak coverage can be had on both networks. Cellular telephony is only a part of life for residents when they leave their communities.

Rural Broadband Initiative Coverage: Parikino

The map below of RBI coverage shows households in yellow, Vodafone coverage in blue, and Chorus ADSL2+ coverage in red (cabinetized), orange (exchange-based), and green (RBI). Chorus multi-access radio links are drawn in purple. Some spill-over Vodafone coverage could be available along the river near Parikino from a tower to be erected with RBI funding, but the area is not particularly targeted for coverage, and any benefits would be minimal.
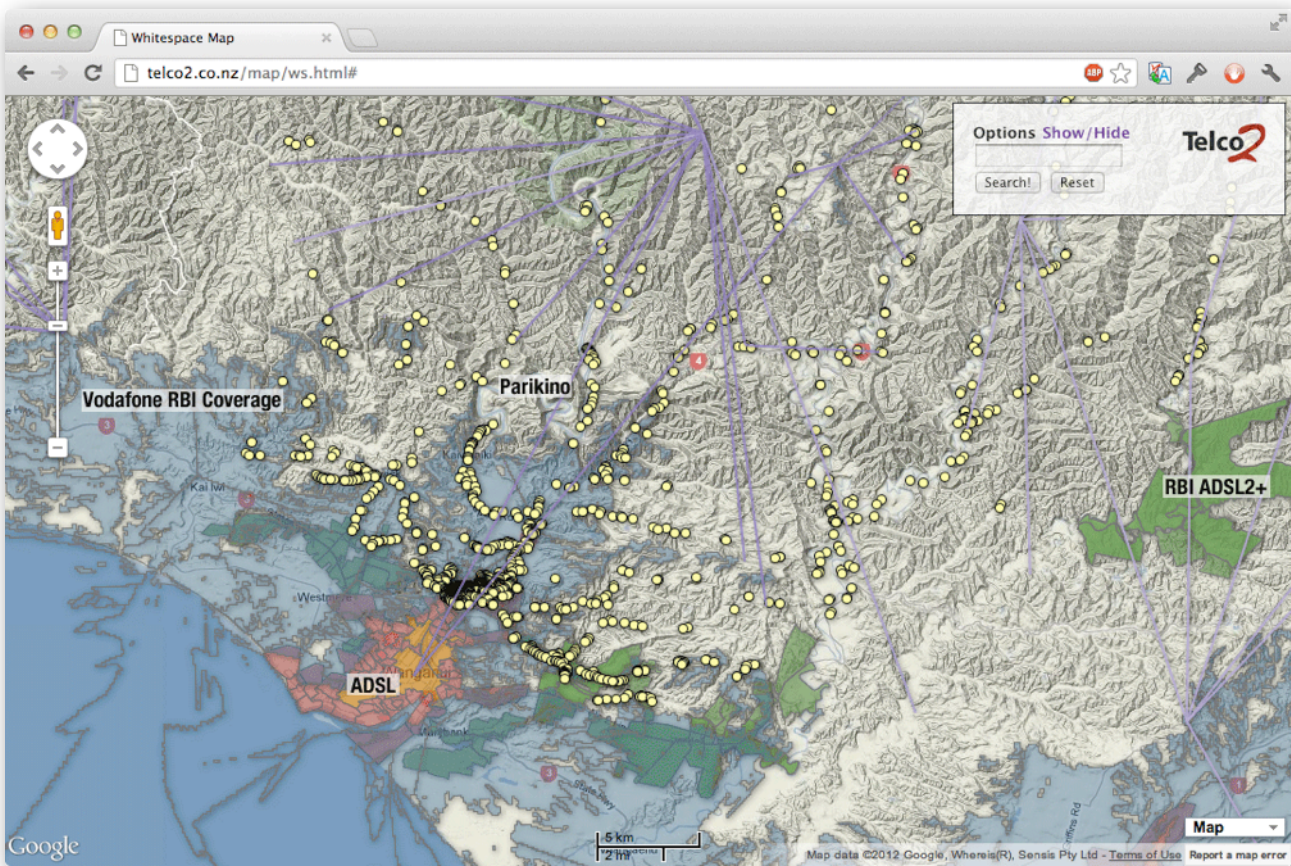

## Tower Selection: Parikino

No active radio site in the Parikino area meets the "ideal tower site" requirements for coverage, backhaul, access, and power availability, however one registered but unused site appears to come close. Parikino (MED Radio Spectrum Management Site ID 26080) was established in 2003 for Woosh Wireless, who had planned to install a tower with coverage of the Parikino stretch of the Whanganui river. The site is at the top of a block of forestry plantation pine, less than 50M from the nearest road and less than 500M away from the closest power lines. It has clear line of sight to Bastia Hill in Whanganui, a radio site with fibre and several major backhaul carriers present.

TV White Space Availability: Parikino

The nearest television towers to Parikino are Mt. Jowett in Whanganui, Wharite outside Palmerston North, and Mt. Egmont, just South of New Plymouth. The map to the right has these towers labeled. Two of the three towers have significant land obstructions between them and the proposed radio site, as illustrated in the diagrams on the next page. While the terrain maps shown don't constitute a formal radio study, they are a good indication that TV channels from Mt. Egmont and Wharite won't be in use at Parikino.
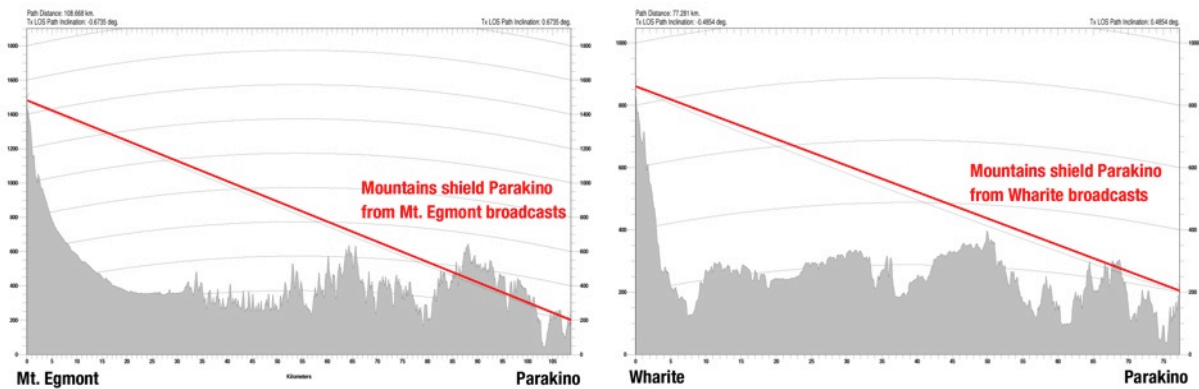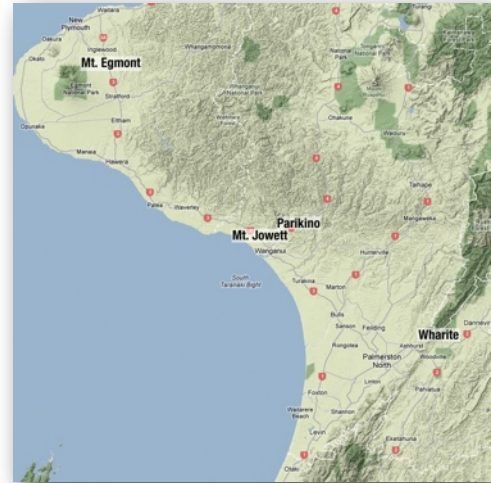
Mt. Jowett in Whanganui differs from the two other towers in that it has direct line of sight to Parakino, as show below.
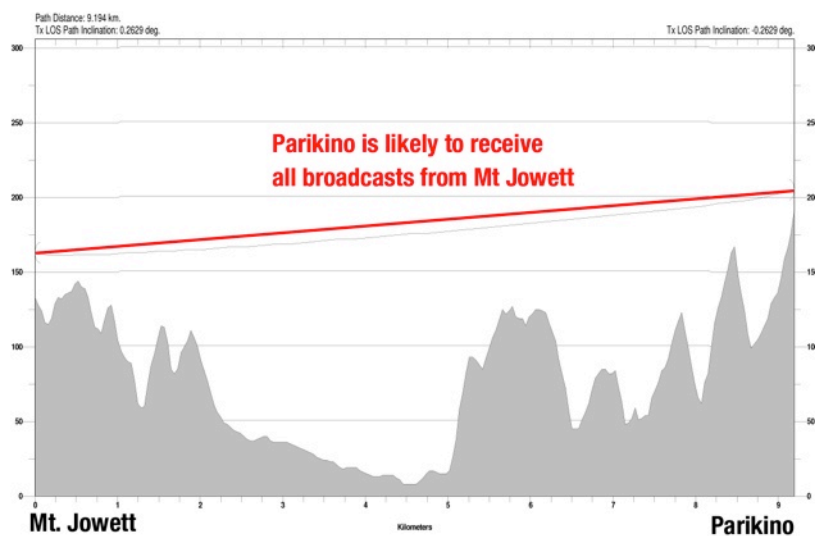
The table below shows the analog and digital TV channels in use at each of the nearby towers. Analog channels are orange, and digital ones are green. Eleven channels are in use at Mt. Jowett now, leaving 88MHz of spectrum free for TVWS transmission.

After analog shutoff on the 30th of November 2013, all of the orange blocks in the table below will be removed from service. At that time a total of 120mHz of UHF spectrum could be available for TVWS use in Parikino - as shown in blue in the far-right column. Even providing extra protection to broadcasts at Mt Jowett by protecting adjacent channels, Parikino could have 80MHz of spectrum - almost as much as the entire 700MHz Digital Dividend band.

|	Mt. Egmont	Mt. Jowett	Wharite	Parikino
534 - 542		orange		blue
542 - 550	orange		orange	blue
550 - 558		green		
558 - 566	orange		orange	blue
566 - 574	green	orange		blue
574 - 582	orange		green	blue
582 - 590		orange		blue
590 - 598	orange		orange	blue
598 - 606		orange		blue
606 - 614				blue
614 - 622				blue
622 - 630			green	blue
630 - 638		green		
638 - 646				blue
646 - 654		green		
654 - 662				blue
662 - 670	green			blue
670 - 678			green	blue
678 - 686		green		

Broadband Coverage Predictions

The maps below shows a prediction of the effective coverage of Wi-Fi and TVWS from the tower site at Parikino, with good service achievable (from highest to lowest signal levels) in magenta, orange, and green areas, and a potential for weak service in turquoise areas. Service definitions and color level steps for each technology are defined in Appendix C.
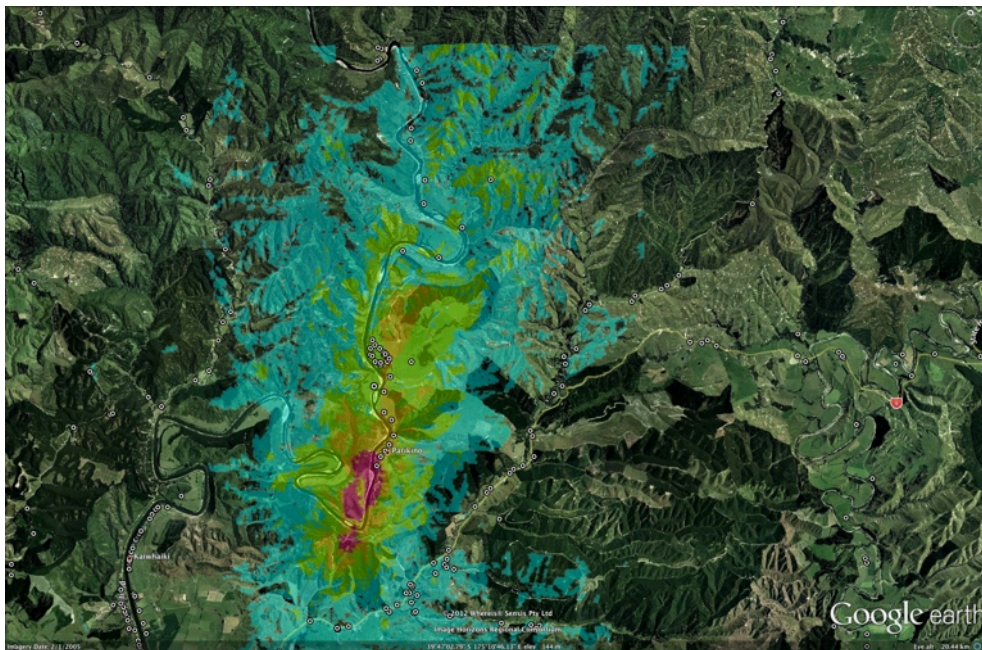
Wi-Fi Results

TVWS Results
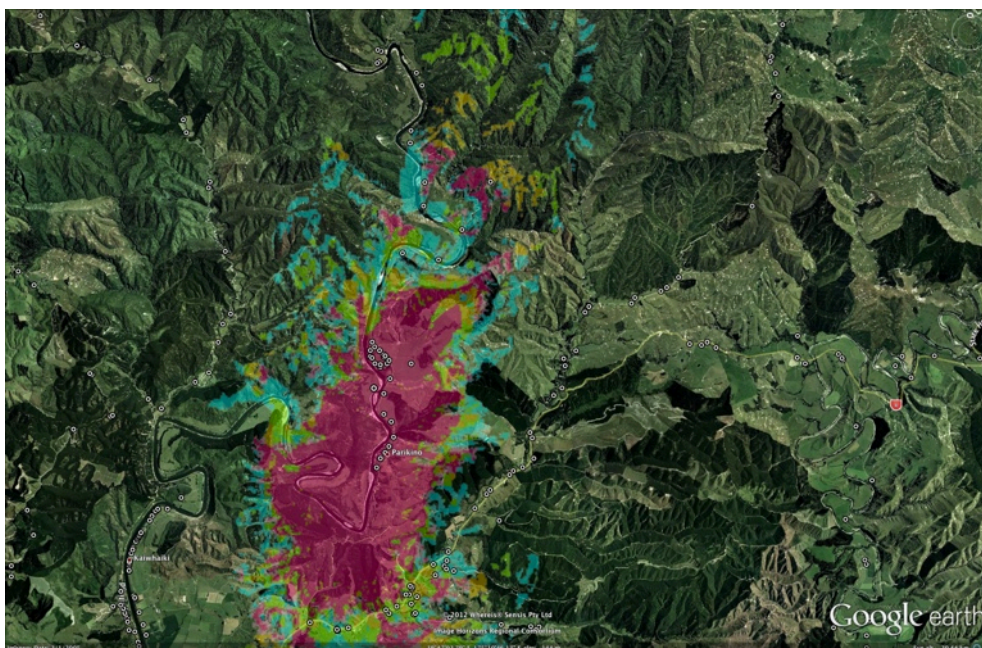
Wi-Fi Technology vs. TVWS

The table below shows the number of households in Parikino and nearby Whanganui River Settlements that could receive an acceptable wireless broadband service using traditional Wi-Fi or using TVWS broadband. The numbers take into account position of houses, but not whether individual houses have trees between them and the tower. If a house in the "good signal if unobstructed" category has trees around it, it probably won't be able to get service. If it's in a "good with trees" category, Wi-Fi subscribers will likely lose service when it rains due to reflections of waves off wet leaves, while TVWS users will not suffer any service degradation.

Likely coverage is an estimate that assumes availability for 10% of weak if unobstructed, 20% of good if unobstructed, and 100% of good with tree obstructions.

Parikino	Wi-Fi	TVWS
Weak Service if Unobstructed	9	4
Good Service If Unobstructed	14	0
Good Service with 10m Trees	13	1
Good Service with 20m Trees	1	27
Likely Coverage	17.7	28.4

TVWS broadband has a significant advantage in likely coverage for the community of Parikino.

All of the households in the targeted community could be serviced by a single TVWS transmitter, and some households further up the river valley could achieve coverage. Additional repeaters on different channels every ten kilometres along the river could provide complete coverage of the valley without exhausting the available radio spectrum.

For Parikino it is likely that TVWS would be a good solution for providing broadband, and far better than using an existing fixed wireless broadband technology.

Clova & Crail Bays, Marlborough Sounds

Around a hundred people live in the area of Clova & Crail Bays and another hundred live around Kenepuru Sound, just a few kilometres to the south. While the Marlborough region as a whole has nearly 45,000 residents, the Sounds themselves, due to their isolation, have very few permanent residents. The Marlborough Sounds are traditionally the land of the Te Tau Ihu tribes, though Europeans have comprised the majority of residents since the late 1800s.

Image Copyright 2012 Google Retrieved from http://maps.google.com/ on 6 August 2012

Population density across the region averages fewer than 5 people per square kilometer, with concentrations in Picton, Havelock, and Okiwi Bay. Two-thirds of the region's population live in its only city, Blenheim. Year-round residents of the Sounds are engaged in commercial fisheries and aquaculture, forestry, tourism, and some pastoral farming. A large number of remote residences are seasonal accommodation, and may not have electricity, let alone telecommunications services.
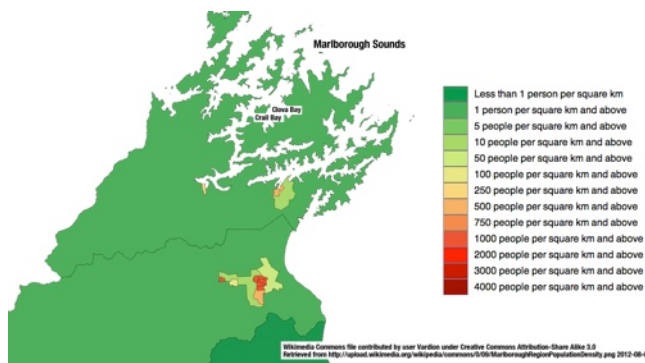
Clova & Crail Bays

The households considered in this study are on the mainland and accessible by road but are still very isolated. Havelock, the nearest town, is only 23 kilometres in a straight line, but the drive covers

86 kilometres and can take two hours. The land and water are intensely developed, with pine plantations covering most hills and dozens of aquaculture installations off the near shores.

Fixed Line Communications

Clova and Crail Bays are in the Pelorus Sound exchange area (PLO), and are fed by copper pairs to CMAR stations PLO/MW, PLO/MV, and PLO/MU. These stations are connected via radio to a tower at Kauauroa, which is linked by microwave to a fibre-backhauled tower at Rahotia. No broadband is supported on CMAR connected households.

Cellular Communications

Telecom's XT network provides good to fair coverage for recreational users of the Sounds, but limited coverage for the residents who live on land in the area. Fortunately most residents can find good coverage within a few hundred meters of their houses. Vodafone's coverage is from a tower further away, and is poor to non-existent across the bays considered. Coverage will not improve as a result of the RBI.

Rural Broadband Initiative Coverage

Some Sounds communities will be receiving upgraded ADSL2+ as a part of Chorus RBI upgrades, but Clova and Crail Bays are not among them.
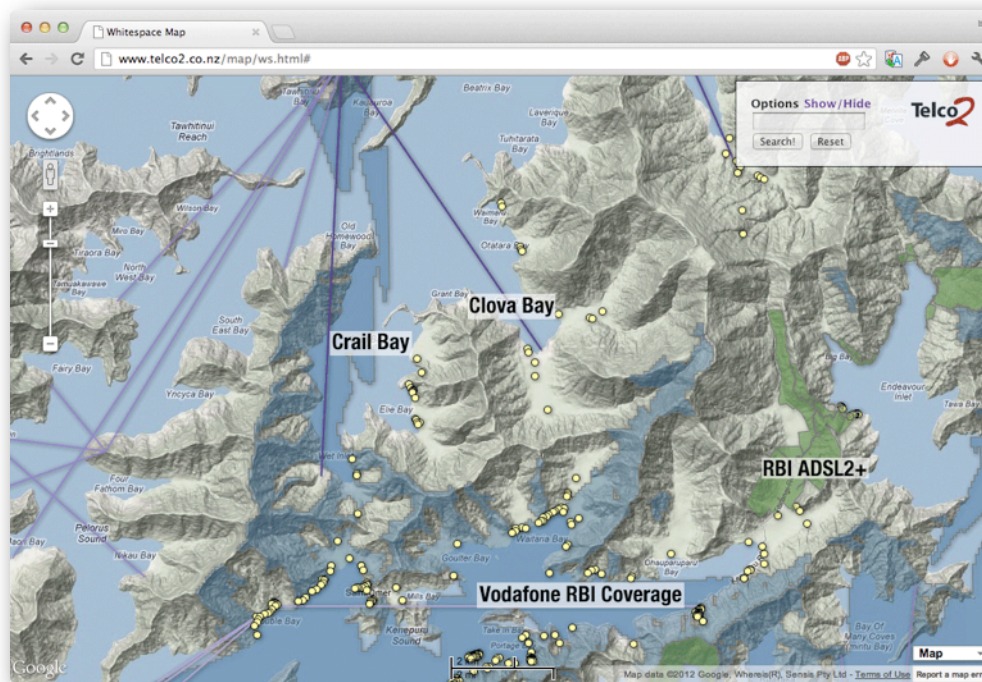
The map above shows households in yellow, Vodafone coverage in blue, and Chorus RBI ADSL2+ in green. Multi-access radio links are drawn in purple.

Tower Selection

The Chorus radio tower at Kauauroa is the obvious choice for providing service to Clova and Crail Bays, as it has sweeping views of both bays and a 4WD track connecting it with a large pier at Richmond Bay. It is unlikely the site has mains power, but it is known that a good radio linking path exists between the site and a fibre-backhauled tower at Rahotia. The image below shows a view of the bays from the tower site.
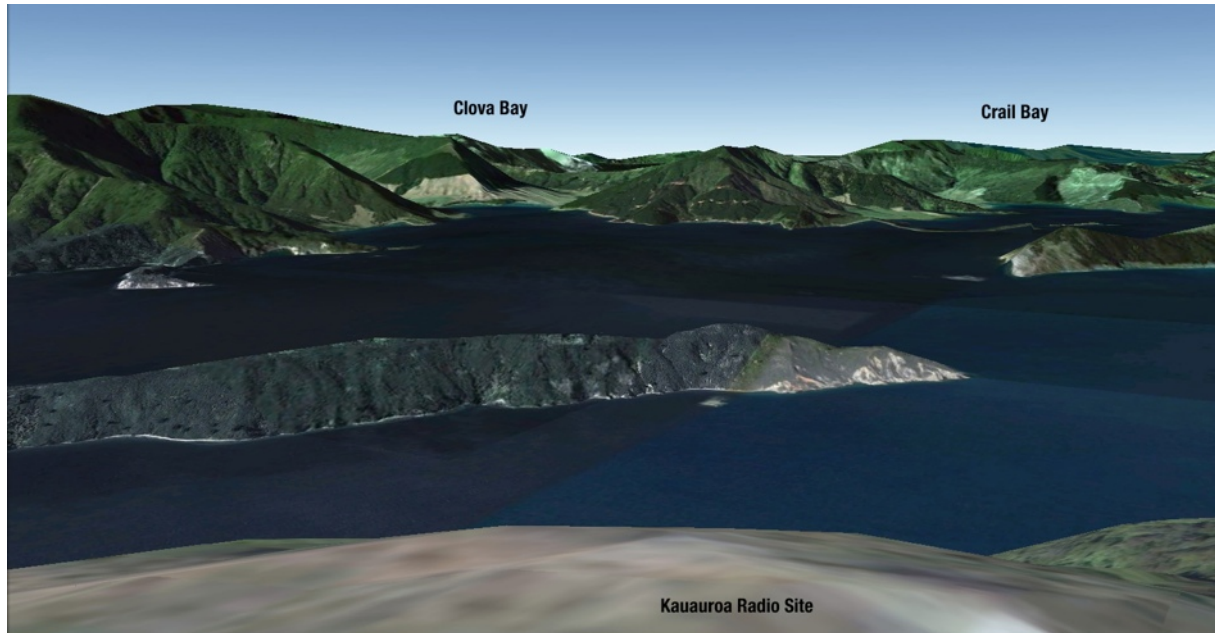
Map Data Copyright 2012 Google

TV White Space Availability

The nearest digital television towers to Kauauroa are Botanical Ridge (Kaka Hill) in Nelson, Mt. Kaukau in Wellington, and Baxters Knob in Porirua. All three broadcast towers are separated from Kauauroa by significant physical obstructions. It is assumed that no UHF broadcast television is available in the sounds at all, and that all channels would be available to a TVWS operator. The path plots below show the geographical obstructions that prevent television signals entering the Sounds.

Botanical Hill   Mt. Kaukau   Baxters Knob
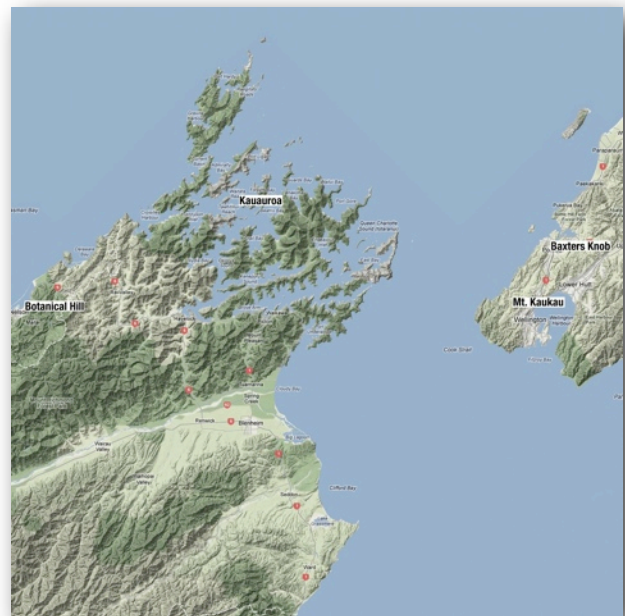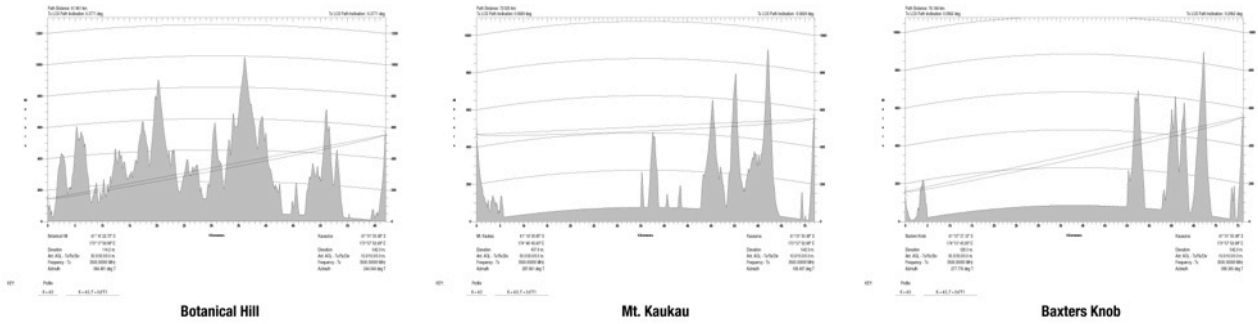
Due to obstructions and the distance between the TV transmitters and the tower site, no television signals are received at Kauauroa or the Clova or Crail Bay reception sites. The entire range of channels is free as illustrated below.

	Botanical Hill	Mt. Kaukau	Baxters Knob	Kauauroa
534 - 542			▇	▇
542 - 550	▇	▇		▇
550 - 558			▇	▇
558 - 566	▇	▇		▇
566 - 574			▇	▇
574 - 582		▇	▇	▇
582 - 590			▇	▇
590 - 598		▇		▇
598 - 606	▇		▇	▇
606 - 614	▇			▇
614 - 622				▇
622 - 630	▇			▇
630 - 638				▇
638 - 646	▇		▇	▇
646 - 654				▇
654 - 662		▇		▇
662 - 670				▇
670 - 678			▇	▇
678 - 686				▇

Broadband Coverage Predictions

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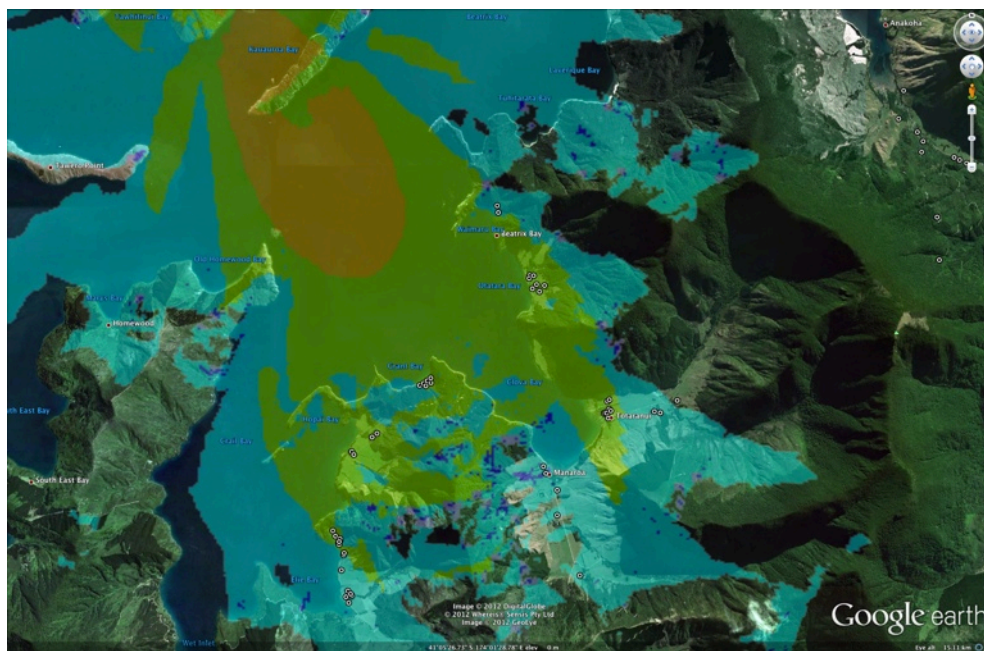
Wi-Fi Results

TVWS Results
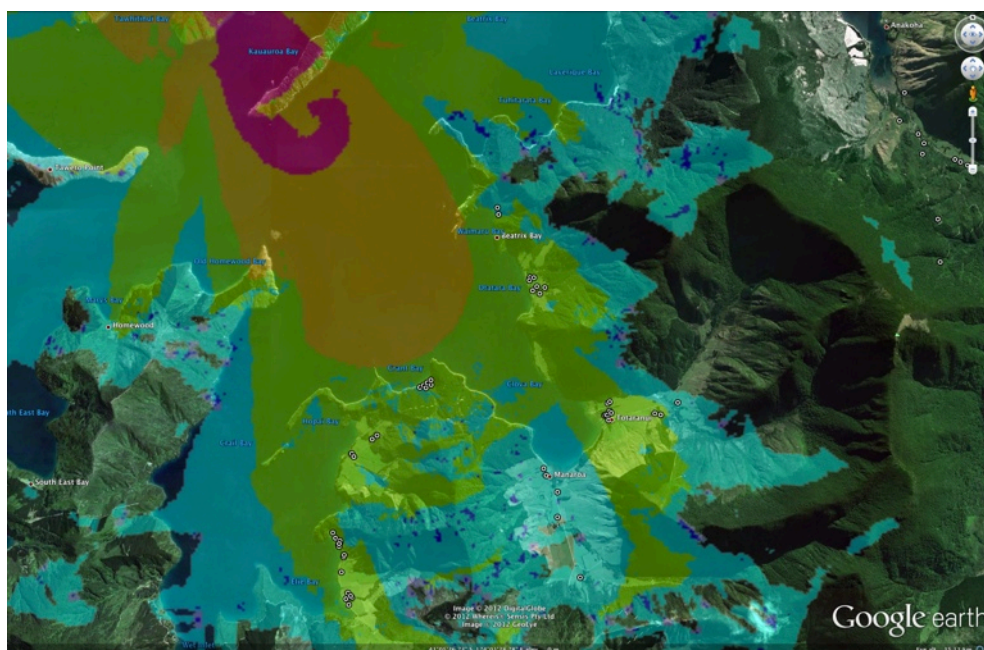
Wi-Fi Technology vs. TVWS

The table below details the number of households in each of several scenarios that could receive an acceptable wireless broadband service using traditional Wi-Fi or using TVWS broadband. The numbers take in to account good signal if unobstructed position of houses, but not whether individual houses have trees between them and the tower. If a house in the "good signal if unobstructed" category has trees around it, it probably won't be able to get service. If it's in a "good with trees" category, Wi-Fi subscribers will likely lose service when it rains due to reflections of waves off wet leaves, while TVWS users will not suffer any service degradation.

Likely coverage is an estimate that assumes availability for 10% of weak if unobstructed, 20% of good if unobstructed, and 100% of good with tree obstructions.

Clova & Crail Bays	Wi-Fi	TVWS
Weak Signal if Unobstructed	14	11
Good Signal if Unobstructed	34	41
Good Signal with 10m Trees	0	0
Good Signal with 20m Trees	0	0
Likely Coverage	8.2	9.3

TVWS has only a slight advantage in likely coverage for these bays in the Sounds.

Both technologies would be relatively ineffective in this scenario, as tree cover is dense around most properties. The cause of this lack of performance for both technologies is distance and power. Both radios are modelled at 4 Watts. Technologies that are restricted by regulations to very low power typically have non-line of sight coverage of five or six kilometres. In this case the nearest households are nine kilometres from the tower, and the most distant are near to fourteen.

Small cellular transmitters in the Marlborough Sounds like Vodafone's mast on Arapawa Island have emitted powers of nearly 250 Watts. Larger towers can radiate more than ten times that.

Allowing a TVWS device to operate at 25 Watts, well within its design specification but still a tenth of the power of a small cell site, would improve coverage dramatically, likely shifting all 52 households into full coverage.
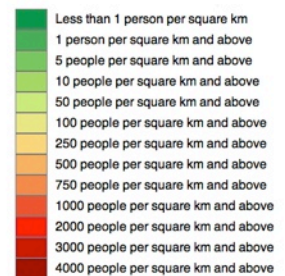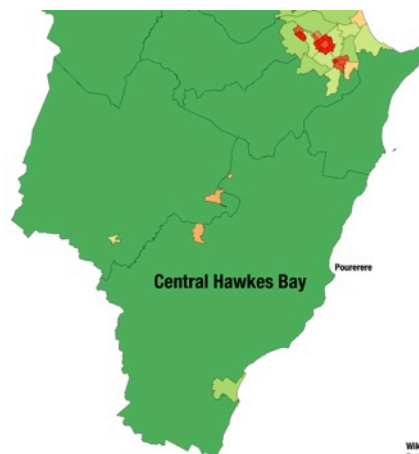
Pourerere, Coastal Hawkes Bay

Around 3,000 people live in the coastal district of Central Hawkes Bay, extending around 70km from Te Apiti Station in the North to Herbertville in the South, and between 10-20km inland. The area is the home of Ngāti Kahungunu, and across the greater region Māori make up around a quarter of the residents.

Image Copyright 2012 Google Retrieved from http://maps.google.com/ on 2 May 2012

The population density averages fewer than 5 people per square kilometer, but this is skewed by clusters of residences at beach communities such as Karikau, Porangahau, and Pourerere. In actuality, the density across much of the district is fewer than one person per square kilometer.

Less than 1 person per square km
1 person per square km and above
5 people per square km and above
10 people per square km and above
50 people per square km and above
100 people per square km and above
250 people per square km and above
500 people per square km and above
750 people per square km and above
1000 people per square km and above
2000 people per square km and above
3000 people per square km and above
4000 people per square km and above

Wikimedia Commons file contributed by user Vardion under Creative Commons Attribution-Share Alike 3.0
Retrieved from http://commons.wikimedia.org/wiki/File:HawkesBayRegionPopulationDensity.png 2012-05-02

The main economic force of the coastal area is pastoral farming, and farming support, with some commercial forestry in the south. Residents who commute to work in nearby towns are still likely to work in farming related industries.

Pourerere

Thirty-four kilometres of winding country roads separate the settlement of Pourerere from Waipawa, the nearest town. Along most of the route, there are stretches of multiple kilometres between small clusters of houses. Available telecommunications resources in the town are poor, even by the standards of remote areas.

Fixed Line Communications

Telecommunications in the coastal area of Central Hawkes Bay was developed mainly with the use of Multi Access Radio (CMAR). Local copper loops are connected back to cabinets or huts, which are linked to high sites using narrow band radio at 1.5GHz. These links support voice and data communications up to 9,600 baud. A few isolated pockets of ADSL1 exist, using copper or radio backhaul. The availability of these services is unknown as Chorus does not publish coverage details. With no fibre backhaul available in the region, speeds are very slow.

The photo below shows the radio backhaul link for the Pourerere area, MED license ID 167934.

Image Copyright 2012 Google Retrieved from http://maps.google.com/ on 2 May 2012

Cellular Communications

The topography of Central Hawkes Bay is such that residences cluster along roads, typically in valleys. Tree cover in the valleys and around many houses makes direct wireless communications difficult. As the region is made up of a large number of even-sized hills and valleys, it is extremely hard to cover with traditional cell sites. Current cellular coverage is restricted to hilltops in most of the district, and the nearest good coverage is around 20km away. Vodafone have planned a tower to the South as a part of the Rural Broadband Initiative (RBI) that will cover Porangahau and two nearby valleys. When completed, the nearest cellular coverage to Pourerere will be a hilltop around 5km to the west.

Rural Broadband Initiative Coverage
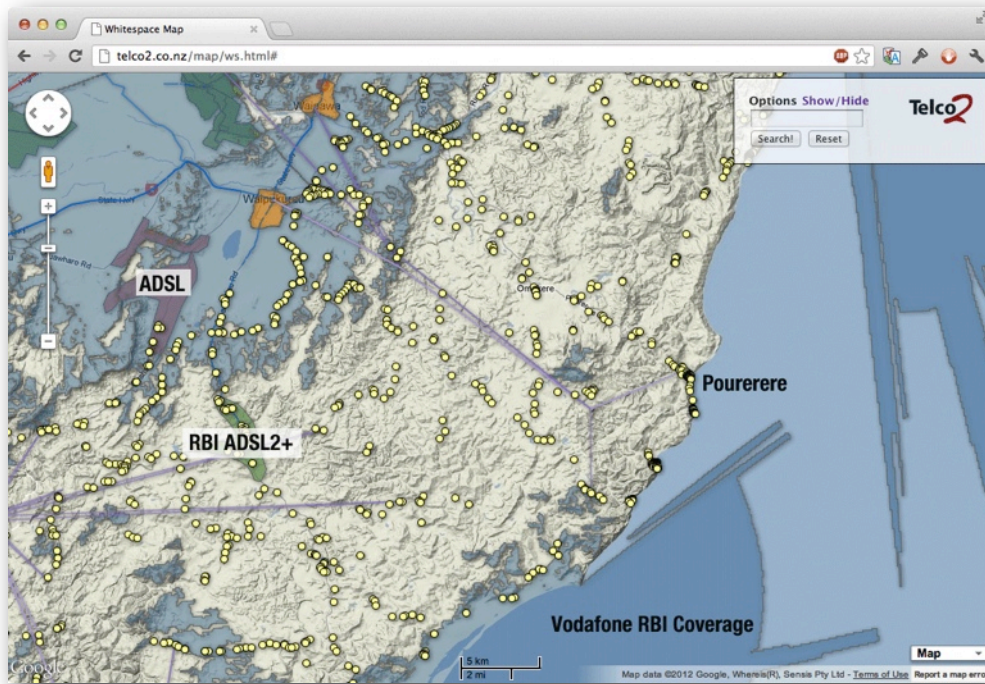
The map above shows home address points in yellow, Vodafone coverage in blue, and Chorus ADSL2+ coverage in red (cabinetized), orange (exchange-based), and green (RBI). Multi-access radio links are drawn in purple.
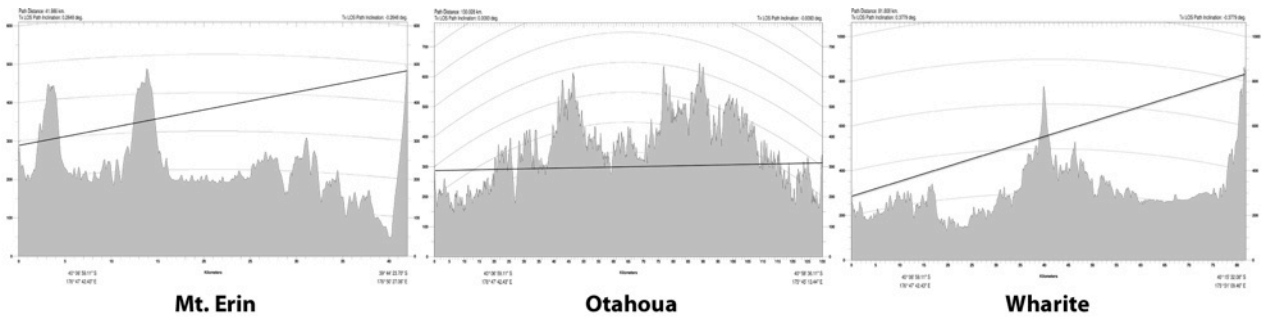
Tower Selection

French Hill, a small Chorus-operated radio site on private property, has track access, available power and the potential for wireless backhaul from Vodafone's planned Porangahau tower. In fact it is the same site that Pourerere's telephones are currently connected to. It appears to be an ideal tower for coverage of Pourerere.

TV White Space Availability

The nearest television towers to Pourerere are Wharite, near Palmerston North; Mt. Erin, near Hastings; and Otahoua, near Masterton. Wharite transmits using even-numbered channels, while Mt. Erin and Otahoua transmit using odd-numbered channels. The following three studies show significant physical obstructions between each of the broadcast towers and the radio site at French Hill.

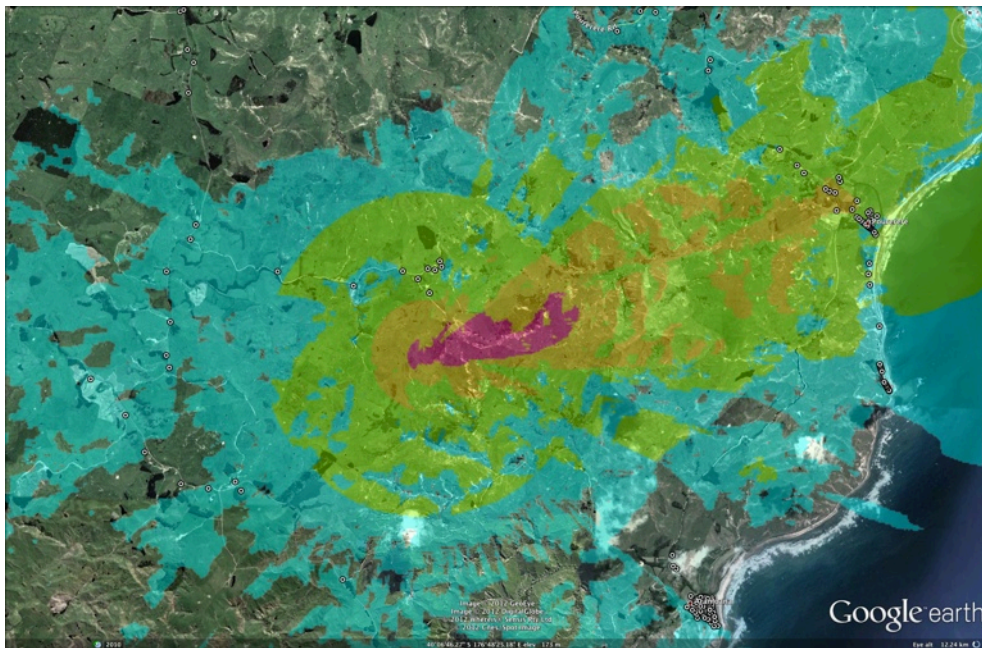**Mt. Erin**   **Otahoua**   **Wharite**

Due to the obstructions and the distance between the TV transmitters and the selected tower site, no television signals are received at French Hill or the Pourerere coverage area. The entire range of channels is free as illustrated below.

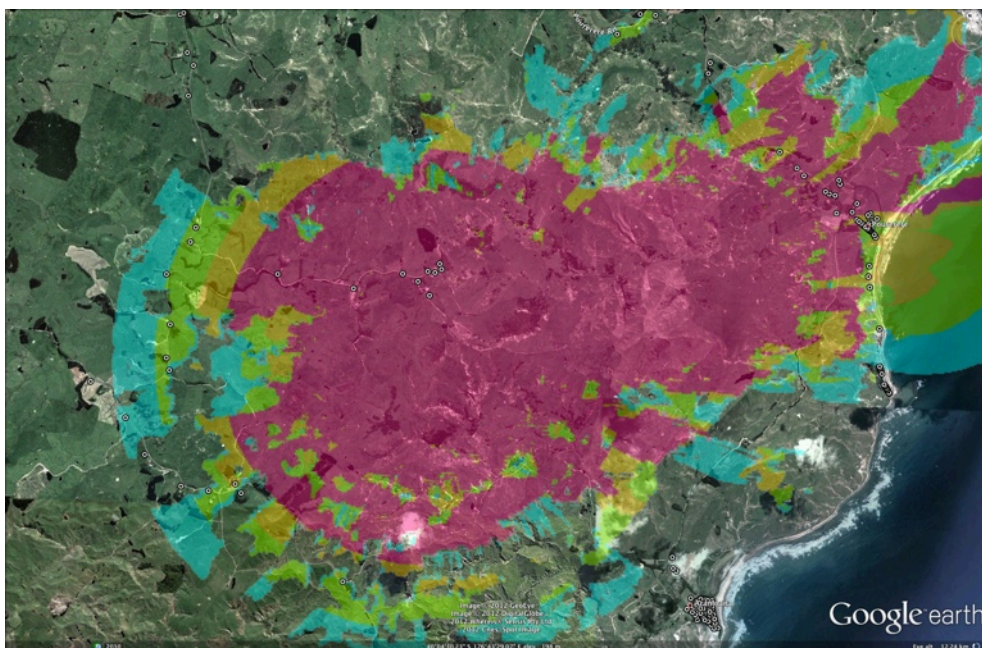|	Mt. Erin	Wharite	Otahoua	French Hill
534 - 542			green	blue
542 - 550		orange		blue
550 - 558	orange			blue
558 - 566		orange		blue
566 - 574	green			blue
574 - 582		green		blue
582 - 590	orange			blue
590 - 598		orange		blue
598 - 606	orange			blue
606 - 614				blue
614 - 622				blue
622 - 630		green		blue
630 - 638				blue
638 - 646				blue
646 - 654				blue
654 - 662				blue
662 - 670	green		green	blue
670 - 678		green		blue
678 - 686				blue

Broadband Coverage Predictions

The maps below shows a prediction of the effective coverage of Wi-Fi and TVWS from the tower site at French Hill, with good service achievable (from highest to lowest signal levels) in magenta, orange, and green areas, and a potential for weak service in turquoise areas. Service definitions and color level steps for each technology are defined in Appendix C.

Wi-Fi Results

TVWS Results

Wi-Fi Technology vs. TVWS

The table below details the number of households in each of several scenarios that could receive an acceptable wireless broadband service using traditional Wi-Fi or using TVWS broadband. The numbers take into account position of houses, but not whether individual houses have trees between them and the tower. If a house in the "good signal if unobstructed" category has trees around it, it probably won't be able to get service. If it's in a "good with trees" category, Wi-Fi subscribers will likely lose service when it rains due to reflections of waves off wet leaves, while TVWS users will not suffer any service degradation.

Likely coverage is an estimate that assumes availability for 10% of weak if unobstructed, 20% of good if unobstructed, and 100% of good with tree obstructions.

Pourere	Wi-Fi	TVWS
Weak Signal if Unobstructed	48	7
Good Signal if Unobstructed	30	24
Good Signal with 10m Trees	5	10
Good Signal with 20m Trees	0	19
Likely Coverage	15.8	34.5

TVWS broadband has a significant advantage in likely coverage for the community of Pourerere.

All of the households in the targeted community could be serviced by a single TVWS transmitter, and some households in other communities could achieve coverage. Additional directional antennas at the French Hill site would likely achieve a similar coverage result for the communities of Aramoana and Blackhead further south down the coast from Pourerere.

For Pourerere it is likely that TVWS would be an excellent solution for providing broadband, and far better than using an existing fixed wireless broadband technology.

Conclusion

TVWS is a disruptive technology in a number of ways. It can be technically and commercially effective for providing broadband to areas of extremely low population densities. The equipment is an order of magnitude less expensive than traditional cellular base stations. It operates at low power levels, orders of magnitude less than typical cell towers. Finally it achieves its coverage through the use of idle spectrum that may be licensed to a commercial broadcaster.

The three communities evaluated are different in location, terrain, climate, and people. Each has a long history of both Māori and European settlement. Each has a well developed network of roads, electricity, and telephone service via copper cables. None has access to Vodafone or 2Degrees Cellular, and only one has access to Telecom's XT. None has access to fast broadband, and none will benefit from the government's rural broadband initiative.

Adding 700MHz Digital Dividend spectrum to existing or planned cellular towers will do nothing to help these communities. As the maps throughout the paper show, even by the end of the RBI there will still be huge gaps in cellular coverage. In areas of such low population density the cost of fibre optic cables, ADSL2+, or traditional cellular or fixed wireless coverage would never be recovered by a telecommunications provider. Barring future government subsidies or a new method of broadband delivery like TVWS, these communities may never have fast broadband.

In the three communities reviewed, TV White Space spectrum is abundant today. In Parikino, spectrum will become even more abundant when the last analog television transmissions are halted in 2013. In the Hawkes Bay and Whanganui River Valley examples, TVWS is likely to be a very good solution for providing broadband power levels equivalent to those used by Wi-Fi equipment. In the Marlborough Sounds case, allowing TVWS equipment to operate at higher power levels (but still an order of magnitude lower than cellular transmissions) would very likely make it a good solution for providing broadband.

Wireless ISPs have built businesses selling broadband to rural New Zealand, but none have been tremendously successful. One of the greatest problems these operators have is access to suitable radio spectrum. The radio spectrum used by most wireless operators is not well suited to rural use. The three studies in this paper show that for the same amount of emitted power and similar sized subscriber antennas, TV white space spectrum provides better coverage than 2.4GHz Wi-Fi, in a band that unlike 2.4GHz is impervious to most vegetation and weather conditions.

The rural communities discussed in this paper could benefit significantly from TVWS, and the investigation of its place in New Zealand's wireless ecosystem should be a priority for policy makers, telecommunications providers, and concerned communities.

Appendix A: Rural Fixed Line Telecommunications Technologies

Broadband Enabled Exchange Connectivity

The default rural configuration consists of an uninterrupted copper pair between a customer property and a fibre connected Exchange. Both telephone service and broadband can be provided from the exchange, with ADSL limited to households within the first four kilometres of copper cabling. The broadband service could be ADSL1 or a newer service like ADSL2+ or VDSL. In most cases the ADSL service will be provided by Chorus. In some towns third parties like Vodafone or Airnet have installed equipment in the exchange through Local Loop Unbundling.

Illustration 1: Supports Telephony and Broadband

Subscribers in towns like Picton, Waipawa, and Whanganui have this type of connectivity. When exchanges have fibre backhaul, this is the most cost effective method of providing broadband, as exchange buildings typically have ample space, security, and protected power supplies.

Modern Cabinetized Connectivity

The latest and most technologically advanced configuration consists of a copper pair between a house and the Exchange that passes through a modern cabinet mounted on a concrete plinth. In almost all cases, Chorus will be the only provider available in the cabinet. Broadband service will be backhauled to the exchange over fibre at 1gbps. Telephone service will run over copper pairs that pass through the cabinet back to the exchange where they will connect to traditional telephone switches. Cabinetization is done to shorten the distance an ADSL signal needs to travel over copper. End users at the median cabinet distance of 1.8km will receive download speeds up to 10mbps.

Illustration 2: Supports Telephony and Upgraded Broadband

Along with their RBI fibre build, Chorus will be installing around a thousand new rural cabinets by July of 2017.

Time Division Multiplexing (TDM) Cabinet or Exchange: Terrestrial

Copper pairs from a neighborhood can be aggregated into a time division multiplexing cabinet or exchange and backhauled to the nearest fibre-fed exchange over fibre or copper with a TDM technology such as PDH. In the case of PDH, a pair of copper wires carries a stream of 2mbps,

and sometimes multiple pairs of copper are used. This arrangement allows for voice and standard dial-up connectivity but does not typically offer broadband connectivity. In some cases, especially around schools that received broadband via Project Probe in 2004, "Conklin Intracom mini-DSLAMs", or "Conklins" are installed, allowing ADSL1 with very limited backhaul speeds.

Illustration 3: Supports Telephony, Fax, and Dial-Up Internet

Around 36% of all cabinets in New Zealand are TDM based, and will remain so even after RBI upgrades.

Time Division Multiplexing Cabinet: Microwave

Copper pairs from a neighborhood can be aggregated into a time division multiplexing cabinet and backhauled to the exchange over microwave - either in a single hop or in multiple hops. To date all microwave backhaul has been based on TDM technologies. This arrangement allows for connectivity as described in the Terrestrial TDM section above, and microwave links typically replace four to eight pairs of backhaul copper.
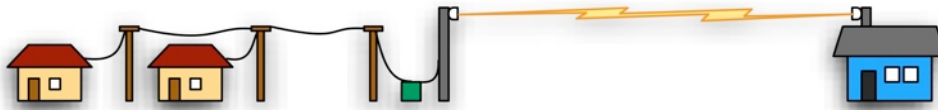

Illustration 4: Supports Telephony, Fax, and Dial-Up Internet

Customer Multi Access Radio (CMAR)

CMAR is a narrow-band wireless technology for distributing voice in remote areas. Copper pairs from a neighborhood can be connected to CMAR outstations and backhauled with radio to an intermediate CMAR switch, then backhauled again to an exchange using microwave or radio. This arrangement allows for voice and low-speed data connectivity including fax. Both last mile broadband and fast regional backhaul connectivity are lacking, and there is no possibility for broadband at all.
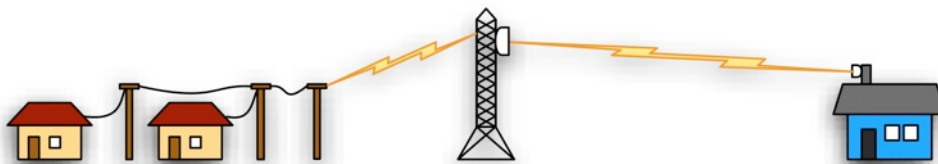

Illustration 5: Supports Telephony, Fax, and Low-Speed Dial-Up Internet

Appendix B: Rural Wireless Telecommunications Technologies

Cellular Connectivity: Voice and Data

Rural cellular coverage for both voice and data exists on both the Telecom XT and Vodafone networks. The 3G cellular technologies available today support voice and data natively, and concurrently in the same spectrum. Vodafone's voice and data coverage will be significantly improved by tower upgrades funded by the RBI. In remote areas however, coverage is typically restricted to hilltops, and comes via cell sites tens of kilometres away. Of the three communities, only the Marlborough Sounds bays has average cell phone coverage, and then only from the Telecom network.

Data speeds over current generation rural cellular can reach 5mbps, but due to the technology and spectrum in use only very low committed data rates and monthly caps are available to end users. Low usage plans are typically 50% more expensive than fixed line plans, and high usage plans are not available at all.

Satellite Connectivity: Data + VoIP

New Zealand is covered by a number of satellites that provide broadband but only Timaru-based Farmside offers mass-market plans. Their services use Thaicom 4 (IPStar) and Eutelsat 172A. Specialist services are also available from global companies on the Iridium and Inmarsat networks.

Download speeds on satellite plans can match those of rural ADSL, and can exceed those of cellular broadband, allowing the smooth streaming of media. Latency introduced during the long round-trip to space and back means that everyday web surfing will be affected by a lag of half a second or more between a mouse-click on a web page and an action. Voice over IP is supported by satellite, but a half-second delay in conversations is enough to prevent many people from using it. The limited amount of satellite capacity dedicated to New Zealand also means that low usage plans can be 100% more expensive than equivalent fixed line plans, and high usage plans are not available at all.

Wireless Connectivity: Data + VoIP

Fixed wireless differs from cellular connectivity in that it assumes end users that never move, and typically have directional roof-mounted antennas connected to indoor terminals. Services can be offered using both public and licensed radio spectrum, and can range in speed in capacity from slower than satellite to faster than ADSL2+. Data caps are typically a fraction of those available on fixed line plans. Using licensed spectrum radio, Voice over IP performance can match or exceed that available on rural copper phone lines.

Almost every region of New Zealand has a local or regional wireless Wireless Internet Service Provider (WISP). Many regions have several, ranging in size from a guy and his dog to teams of dozens of employees. The following is a list of the largest WISP in each region, from North to South.

- Northland: Uber Net
- Auckland: Bush Wireless
- Waikato: No8 Wireless (nee Ruralink)
- Bay of Plenty: NetSmart
- Gisborne: Gisborne.Net
- Hawke's Bay: Now (nee Airnet)
- Taranaki: Primo Wireless
- Manawatu-Whanganui: Inspire Net
- Wellington/Wairarapa: Wiz Wireless
- Tasman/Marlborough: NetSolutionz (nee ThePacific.Net)
- West Coast: Zelan Wireless
- Canterbury: Amuri Net
- Otago: WIC (Wireless Internet Connections)
- Southland: Woosh Wireless

Radio Spectrum for WISPs

Fixed wireless services can be run in licensed and public bands, typically between 2-6GHz. Many of the fixed wireless providers listed above utilize public spectrum in the 2.4 or 5.8GHz bands for their networks. Lower frequencies provide better performance in situations where direct line of sight may not be available due to hills or trees, but due to congestion in the 2.4GHz band, many providers who use public spectrum prefer 5.8GHz.

2.4GHz is modeled in this paper as it provides the most optimistic coverage predictions for an unlicensed band, and is close in properties to the 2.5GHz "Managed Park" band used by providers such as NetSmart and Gisborne.Net and the 2.3GHz spectrum owned by Woosh, Kordia, and Te Haurahi Tika Trust. The table below shows the 2.4GHz band in context with surrounding licensed bands.
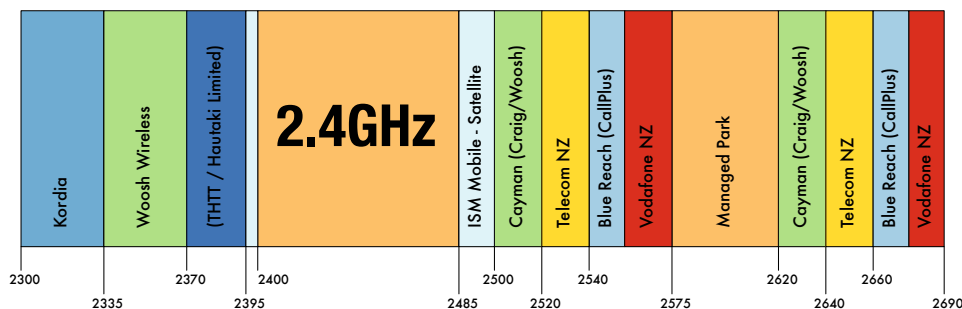
2.4GHz Radio Properties

2.4GHz provides a good balance between availability, cost, antenna size, and radio propagation performance in remote areas. 84MHz of spectrum is available for use, and is typically broken in to three or four 20mHz channels.

At the 2.4GHz channel selected for this paper, 2411MHz, emitted radio waves are 124mm long. While these waves are too large to be affected by rain, the attenuation of signal through vegetation at 2.4GHz is problematic. As discussed in Appendix D, 2.4GHz will lose roughly .5dB of signal per meter of trees it passes through. This is in addition to any losses or gains achieved through wave reflections. Assuming a pair of small trees in the path, received signal levels could be 10dB lower than predicted. On a windy day, random reflections from vegetation could increase or decrease signal levels significantly. On a rainy day, wet leaves can become more reflective, typically decreasing signal levels significantly.

2.4GHz Radio Equipment

More than a billion Wi-Fi chipsets capable of operating in the 2.4GHz band have been manufactured, and any recent smart phone, broadband router, laptop, or peripheral is likely to have one. The same chipsets have been utilized by countless manufacturers of outdoor wireless broadband equipment, as they're fast, robust, and inexpensive.

The equipment modeled in this study is the Ubiquiti Nanostation M2 Access Point, and the Ubiquiti AirGrid M2 subscriber unit. While it is designed with software extensions to optimize its outdoor performance, at its heart is a Wi-Fi chipset. A number of regional wireless providers use this equipment in Northland, Taranaki, the Wairarapa, Canterbury, and Otago. Both the access point and the subscriber unit are meant to be mounted outside, on a mast or on a rooftop.

Appendix C: Settings used in constructing the ProMan models

- Awe Communication's Rural Dominant Path Model is used to determine radio coverage, as described below

The DPM determines the dominant path between transmitter and each receiver pixel. The computation of the path loss is based on the following equation:

$$L = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(l) + \sum_{i=0}^{n} f(\varphi,i) + g_t$$

L is the path loss computed for a specific receiver location. The following parameters are considered by the model:

- Distance from transmitter to receiver (*l*)
- Path loss exponent (*p*)
- Wave length (*lambda*)
- Individual interaction losses due to diffractions (*f*)
- Gain of transmitting antenna (*gt*)

As described above, *l* is length of the path between transmitter and current receiver location. *p* is the path loss exponent. The value of *p* depends on the current propagation situation. In areas with vegetation (which is not modeled in the project) *p* = 2.4 is suggested, whereas in open areas *p* = 2.0 is reasonable. In addition *p* depends on the breakpoint distance. After the breakpoint, increased path loss exponents are common due to distortions of the propagating wave. The function *f* yields the loss (in dB) which is caused by diffractions. The diffraction losses are accumulated along one propagation path. The directional gain of the antenna (in direction of the propagation path) is also considered.

- Exact coordinates across the predicted grid are used instead of a vertical plane approximation
- The curvature of the earth's surface is not taken into account as the area involved is too small for it to be significant
- Frequency dependent attenuation of land use is considered for the dominant class along each ray predicted, with a constant weight factor regardless of the distance from the base station. The clutter classes taken in to account are:
  - Undefined (includes Salt Water)
  - Commercial
  - Residential
  - Open Space
  - Fresh Water
  - Wetland
  - Pasture grass
  - Orchards
  - Scrub
  - Native Forest
  - Exotic Forest (i.e. pine plantations)
  - Permanent Snow
- The base station is assumed to be 13M above ground level (utility pole height) and the receivers are assumed to be 6M above ground level (roof of a 1-story house on a nominal 1M tall mast)
- Base stations are assumed to have a 16dBi gain antenna. At 602MHz the antenna will be larger than at 2411MHz
- 300mm antennas are considered for both subscribers at 602 and 2411MHz. At 602MHz the gain is 8dBi, and at 2411MHz the gain is 16dBi. The higher gain of 2411MHz gives 2.4GHz an advantage in open territory

- Colors on prediction maps, from highest to lowest signal amounts, are magenta, orange, green, turquoise
- Green shows the minimum signal required for the radio to operate in its highest order modulation with the chosen antenna and no excess path loss due to vegetation
- Wi-Fi radios have a spectral efficiency of 2.7 bits/Hz. With a 20mHz channel, the data rate is 54mbps
- Carlson TVWS radios have a spectral efficiency of 2.66 bits/Hz. With a 6MHz channel, the data rate is 16mbps
- Each color step indicates the ability to operate the radio with up to 20m of trees in the path. Signal attenuation due to trees is discussed in Appendix C.
- At 2411MHz considering a 16dBi gain antenna at 6M high, color steps are: -92, -82, -72, -62
  - Acceptable service without obstruction is achieved at -82dBm or lower
  - Weak service may be available down to -92dBm
- At 602MHz considering an 8dBi gain antenna at 6M high, color steps are: -90, -87.6, -85.2, -83
  - Acceptable service without obstruction is achieved at -87.6 dBm or lower
  - Weak service may be available down to -90dBm

Appendix D: Attenuation of Radio through Trees

As per ITU-R P.833-7 Attenuation in vegetation:

- A_m is the maximum attenuation for a terminal within a specific type and depth of vegetation
- Based on calculations of woodland in Mulhouse, France, $A_m = A_1 f^a$ where:
    - $A_1 = 1.15dB$
    - $a = 0.43$
    - f = Frequency in Megahertz

This results in the following figures used in the paper:

- For 602MHz, $A_m = 18.03$
- For 2411MHz, $A_m = 32.74$
- Y is the specific attenuation in dB/m due to woodland

Based on the table provided in figure 2 of ITU-R P.833-7, given horizontal polarization

- For 602MHz, y = 0.12 dB loss per meter
- For 2411MHz, y = 0.5 dB loss per meter

Appendix E: General User Radio License & Power Limits

Radiocommunications Regulations (General User Radio License for Short Range Devices), Notice 2012 is used to define the operating conditions of 2.4GHz Wi-Fi. This license, ID 233717, came into force 8 March 2012. It allows for up to 4W EIRP allowed in 2.4GHz. In this model, we assume transmit power of 22dBm, cable & connector losses of 2dB, and antenna gain of 16dBi, resulting in EIRP 36dBm, or 4 watts.

As no New Zealand regulations exist for the use of TV White Space, a 4W EIRP is assumed at the 602MHz base station with identical transmit power and antenna gain settings to 2.4GHz. The Carlson equipment modeled is capable of transmitting at 30dBm, so higher emitted powers are available if allowed.

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