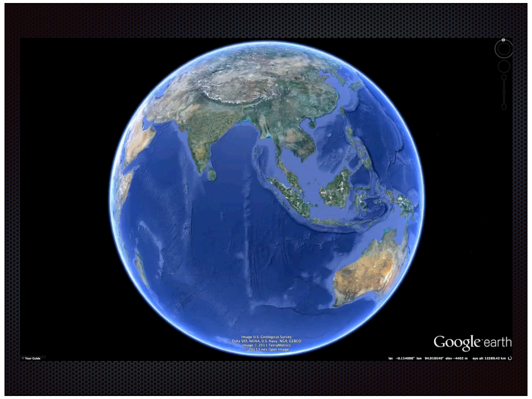
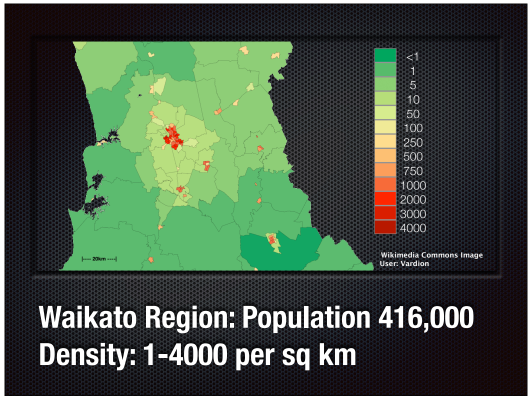
Good Afternoon: My name is Jon Brewer and for many years I ran a microwave network in New Zealand. Since 2011 I've been a freelance telecommunications consultant, mainly advising businesses on rural and remote communications. I've also engaged in some research, including some in to cognitive radio.

I'd like to acknowledge that the work presented here was funded in part by a grant from Internet New Zealand.

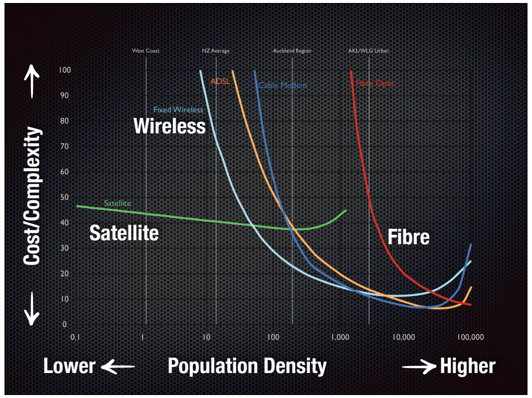


We're going to start this off by talking about a part of New Zealand called the Waikato, one of the country's most fertile and productive agricultural regions.



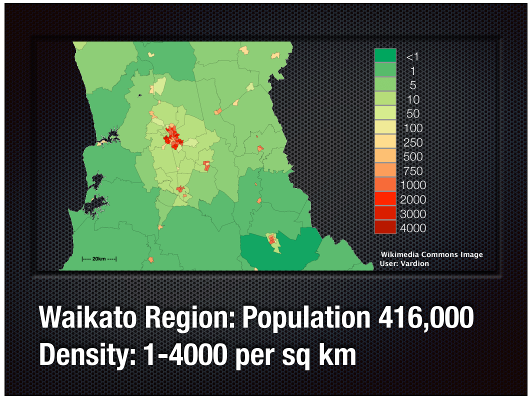
The Waikato region has a problem shared by most of New Zealand. The majority of people live in a few towns, while the countryside is given over mainly to farming. Dairy in the flatlands, sheep and beef cattle in the hills, and forestry in the remote regions.

Population density over the majority of the region is under fifty people per square kilometer.



This chart, adapted from a Communications Research Canada submission to the 802.22 working group, shows the relative cost and complexity of delivering broadband via several technologies as population density changes.

The X Axis shows population density, ranging from fewer than one person per square kilometer on the left to 100,000 people per square kilometer on the right.

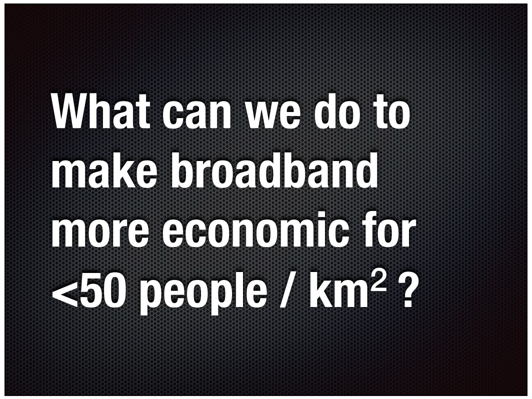


And back to our density map. A large part of the Waikato region, and New Zealand in general, has fifty or fewer people per square kilometer, meaning satellite is the only economic way for delivering broadband.

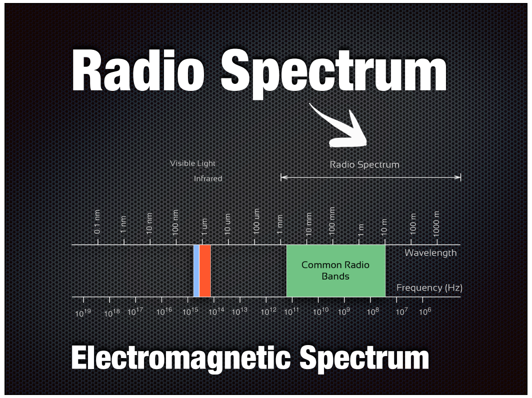
Summary:
Terrestrial broadband only economic when >50 people / km^2

To help bring broadband to uneconomic areas, like Whitianga in the eastern Waikato region, in 2011 New Zealand's government embarked on a five year program to build infrastructure to its rural communities, which will see thousands of kilometers of new fibre, a thousand new DSLAMs, and new 3G broadband on hundreds of towers. But it's still not enough.

At the end of that program of fibre and fixed wireless build, at least 45,000 households will still have no options but satellite – a service which in New Zealand brings high latencies and extraordinary costs.

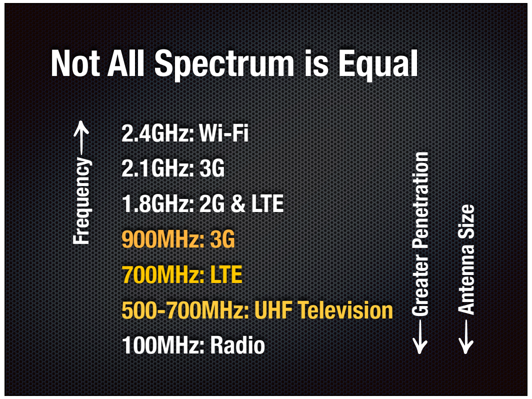


Let's talk briefly about wireless as it's used to deliver broadband today.



The chart on the screen describes the electromagnetic spectrum. All the energy that flows through space from gamma rays to x-rays, visible light, infrared, millimeter wave and microwave, down to low frequency radio is made of the same stuff.

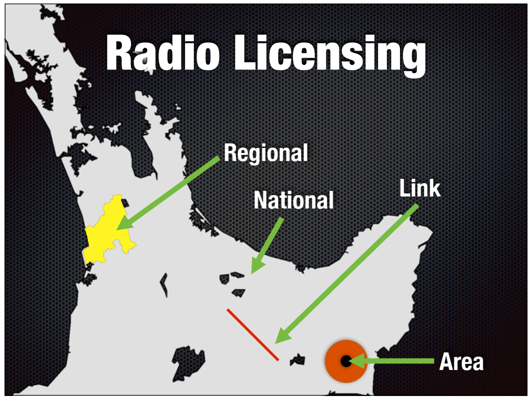
The part we call radio spectrum is waves larger than 1mm, and the part we typically use in communications is made up of waves from around 10 millimeters to ten meters in length.



Not all radio spectrum is created equal: there's a sweet spot for digital communications where frequencies penetrate walls and trees well, yet don't have antennas so big they cause logistical problems.

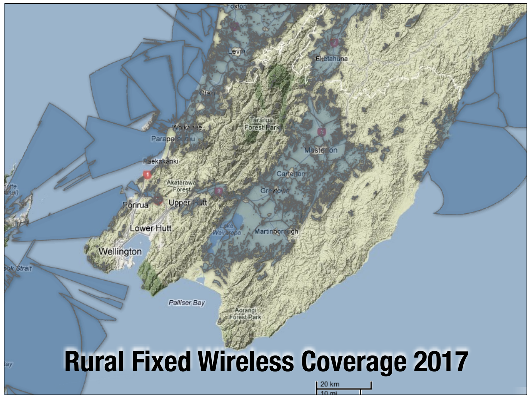
Wireless broadband tends to be restricted to 2GHz and above, which isn't great when it comes to signal that penetrates trees.

900MHz, 700MHz, and broadcast television frequencies on the other hand, are amongst the best available in this respect.



Traditional Spectrum Licensing allows a party exclusive rights to transmit on specific frequencies in a geographic area – a link allowing a narrow corridor of use between two points. An area around a transmitter. A region of the country – as displayed on the image on the screen now, or the entire country.

In fact New Zealand is about to sell of rights to more of its radio spectrum to what'll likely be three parties – who will gain property rights over the entire country in the range of radio spectrum they



Unfortunately this is what happens when you give a company a national spectrum license.

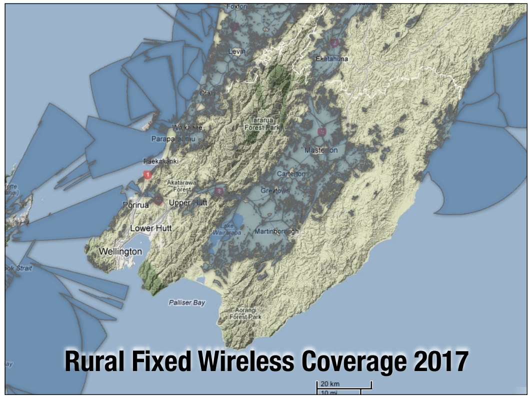
Technical, Geographic, & Economic Factors Prevent License Holders from Fully Utilizing Spectrum in Area Allocations

As you can in the diagram on the screen, in hilly terrain radio waves are often blocked. Flat areas like the ocean are easy to cover, but not so useful to people. Land areas of rough terrain and low population

In New Zealand, the government's purpose is to provide the greatest possible economic benefit to the country with the spectrum. They thought they could get the greatest benefit by auctioning off each frequency to a different company, and that companies would pay what the spectrum is worth.

What happened was that companies paid money so they could use spectrum in the dense populated cities, and didn't care to use it in the rural areas.

Radio waves aren't a blanket you can neatly spread over uneven terrain. So let's talk about how they actually work.



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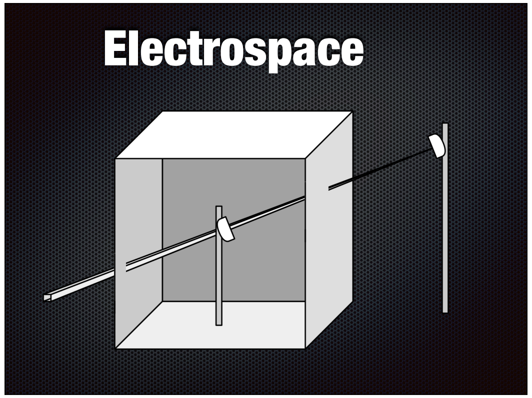
Mountains.
Remote Valleys.
What can we do?

We need to find a new way to think about radio spectrum!

The Electrospace Model* of Radio Spectrum Reflects The Reality of Modern Radio Applications.

See Matheson (2011)
"The Technical Basis for Spectrum Rights: Policies to Enhance Market Efficiency"

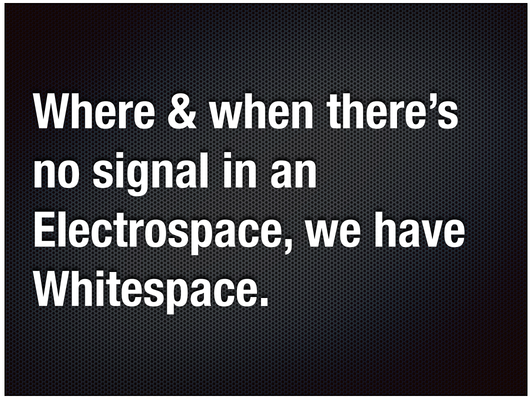
Robert Matheson's Electrospace model is a great way to think about radio waves and spectrum licensing, so I'll quickly take you through the idea.

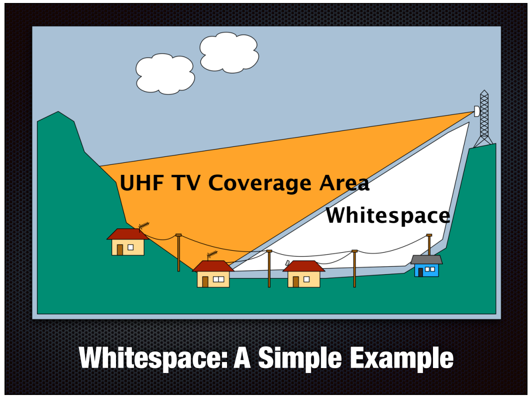


Radio waves exist in an n-dimensional hyperspace that can be called electrospace. Just like a spotlight, all radio waves have:

Latitude: x, Longitude: y, Altitude: z, Bearing: b, Inclination: i, Frequency: f, Polarization: p, Time: t

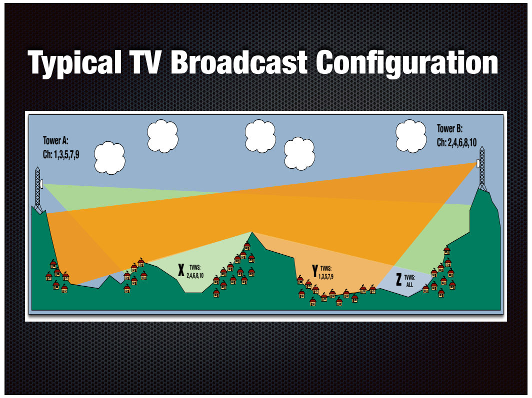
Not all radio waves are equal though. While very high frequency waves behave much in the way a spotlight would, lower frequency waves – especially those used for television and radio broadcast –





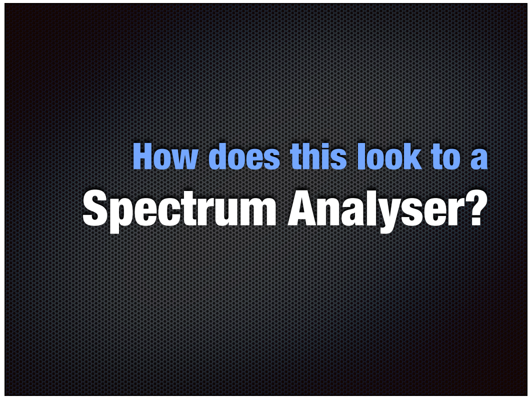
Here's an example. A broadcast tv antenna concentrates its signal to provide the greatest coverage with a set amount of power. Here we have two houses receiving broadcast TV, and a third house outside the coverage area.

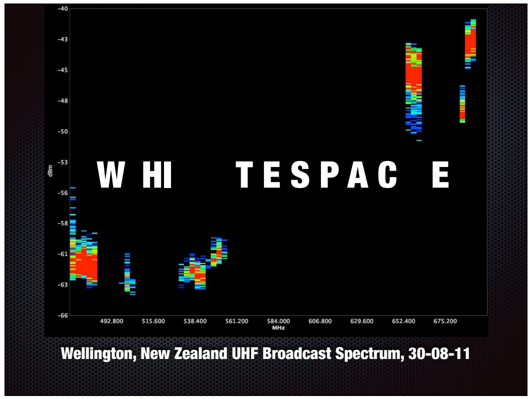
The next slide shows a more realistic scenario.



In this TV broadcast application, we have two adjacent towers using different sets of frequencies to prevent interference in areas where they overlap. A is using channels 1,3,5,7, & 9, B is using channels 2,4,6,8, & 10.

Some areas receive only waves from one of the two towers – for example X only receives signals from Tower A, and Y only receives signals from tower B.

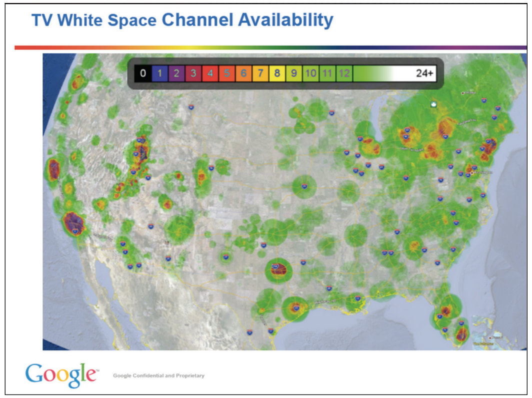




This measurement from My flat in Mt. Vic, Wellington (-41.301°, 174.785° at 40M AGL), bearing due north with an inclination of zero degrees, and a horizontally polarized antenna.

In the heart of New Zealand's second biggest city, more than half of the radio spectrum given over to TV broadcasting is whitespace.

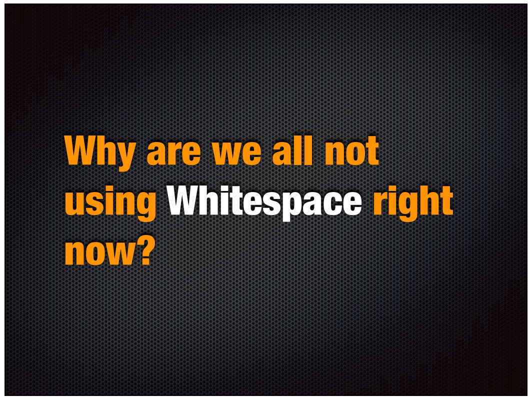
And it's not just TV spectrum.
Spectrum occupancy studies around the world have found that across the most valuable radio spectrum, actual use in any given place and time is extremely low.
Measuring all spectrum from 30MHz --> 3GHz
Chicago achieves 17% spectrum occupancy
New York City achieves 13% occupancy
The USA as a whole averages 5.2%



This study of TV Whitespace suitable for broadband was done by Google by analyzing television transmitter licenses and their propagation over land. The majority of rural areas in the US have spectrum available to them.

White and green areas have at least a dozen free channels available – a lot of capacity as we'll discuss later in the talk.

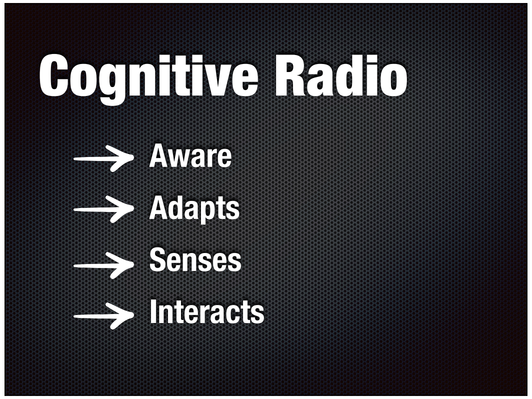
New Zealand's government recently released a similar study showing



Uncontrolled use of whitespace would break things. People can't be trusted to do the right thing with radio transmitters. If television broadcasts were as unreliable as Wi-Fi can be, people would stop watching broadcast tv.

Even at low power, a device capable of using TV whitespace spectrum could cause all kinds of harm to existing systems, which were never designed to be exposed to unlicensed equipment. Many older systems can be affected by transmissions above or below the

Two part slide here.



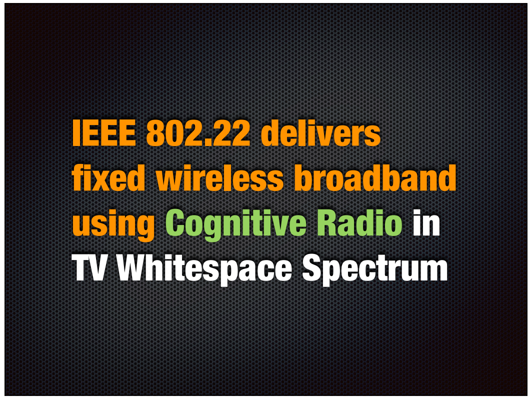
Cognitive radio allows new systems to operate in whitespace without compromising the operation of old systems. It is:

Smart, intelligent, and aware of its environment
Learns from history to adapt itself
Can sense, detect, act, feedback, and adapt to promote good communications and prevent interference. and it
Can interact with other nodes or nets adaptively

When I planned this talk, Texas Instruments was making a DSP "System on a Chip" that could in software implement IEEE's 802.22 standard for providing broadband via cognitive radio in TV whitespace.

Three weeks ago Japan's NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY upped the game by announcing the first silicon implementation of 802.22. I understand we have someone from that institute here today – Jin Yong, if you're here your

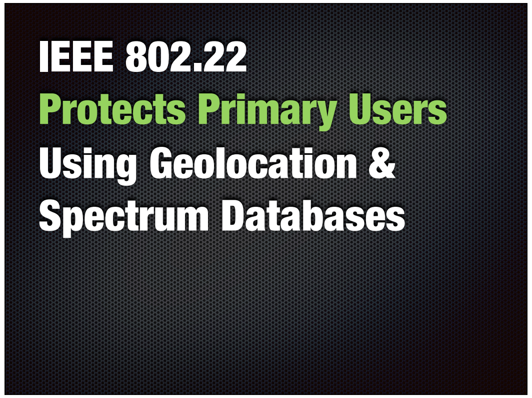
You may know 802.15 – or bluetooth – which provides Wireless Personal Area Networks
You certainly know 802.11: by 2011 more than a billion wi-fi chipsets were shipping every year.
802.16: Wireless Metropolitan Area Networks
802.22: Wireless Regional Area Networks



The number one goal of 802.22 systems is the protection of primary users.

Primary users are those who have a license or property right over the radio spectrum or channels adjacent to it.

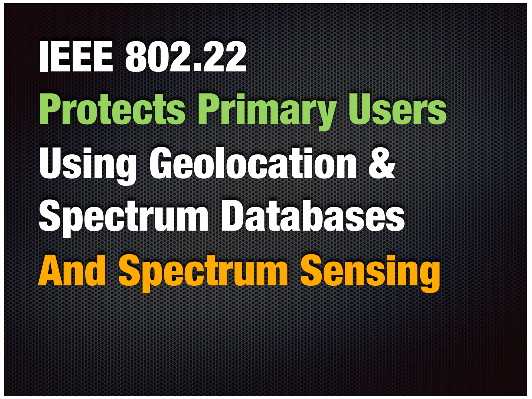
An 802.22 system will never operate in a manner that could compromise existing services.



The geolocation techniques used by 802.22 are enabled via in-built GPS

Base Stations connect to a database of transmitters and exclude licensed channels based on location
Sense channel use & only use clear channels

Multiple companies now offer whitespace databases in the US including Spectrumbridge and Telcordia.

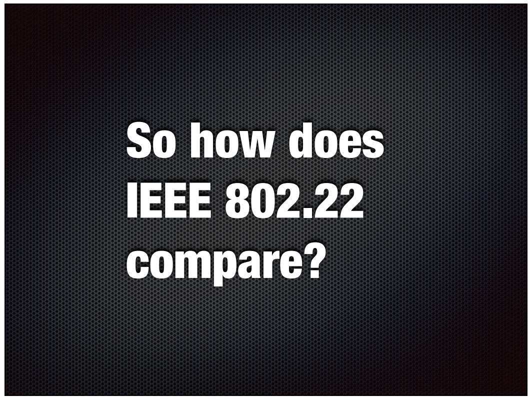


Spectrum sensing is the most advanced of 802.22's technologies

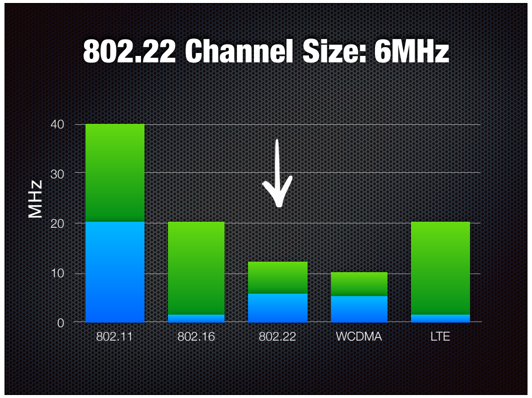
BS & CPE have separate antennas for sensing & comms

In their communications they insert frequent short & periodic long quiet periods for sampling the activity in the radio spectrum.

Both the base stations and the CPEs take measurements, and the clients send samples back to BS for distributed sensing



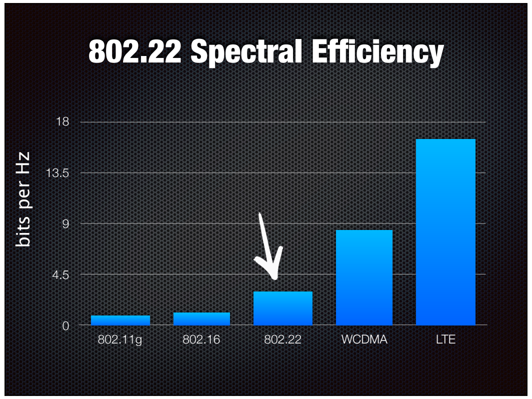
How does 802.22 compare to Wi-Fi, WiMax, 3G, and LTE?



Channel sizes are much smaller than in typical wifi systems.

Sizes are, on a sector by sector basis, on par with what's typically used in 3G and WiMAX systems, but less than wifi.

But channel bonding is planned for, eventually allowing stacks of carriers to work together to increase system throughput as we see in modern cellular systems.



Efficiency is double that of typical wifi or WiMAX systems

But still not nearly has high as with 3G systems

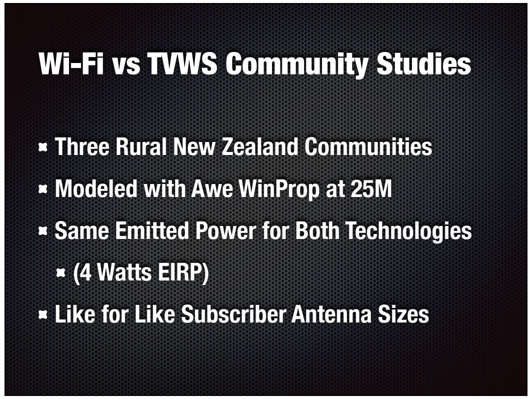
Spectrum availability is where TV Whitespace shines.

Even in New Zealand's second largest city, there's more TV whitespace spectrum available than in the 700MHz frequency block will be auctioned later this year for hundreds of millions of dollars.

Whitespace is more than 802.22!

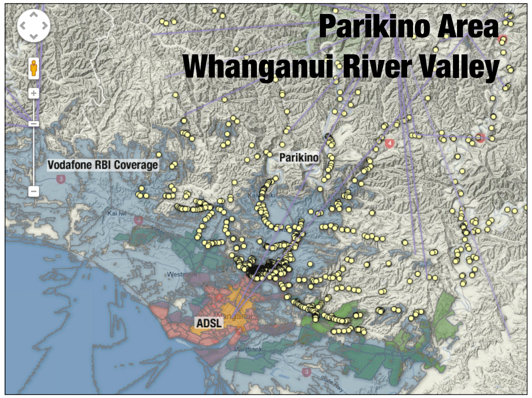
IEEE 802.11af is a proposal to use TV Whitespace for Wi-Fi Wireless Local Area Networks.

GSM Whitespaces is an adaptation of GSM protocol to allow small networks to use free GSM channels for cellular



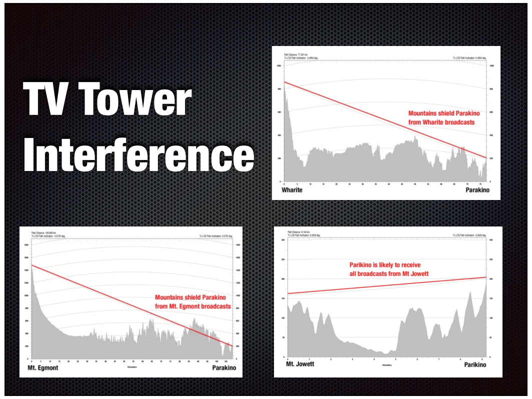
- and now I'll take you through the results of one of those studies.

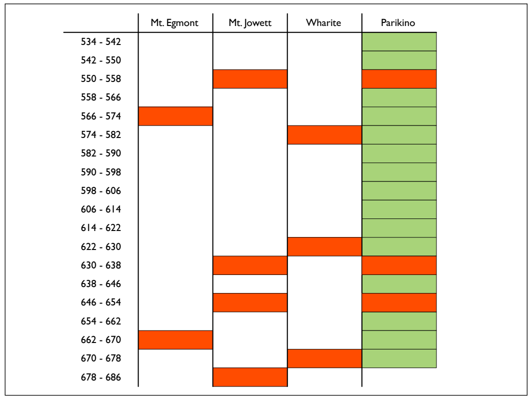
Parikino is a special area for many of New Zealand's Maori people, with a high concentration of Marae, in which people gather to worship and celebrate. It's just 20km outside of the region's largest city, and it has electricity and telephones, but no broadband.

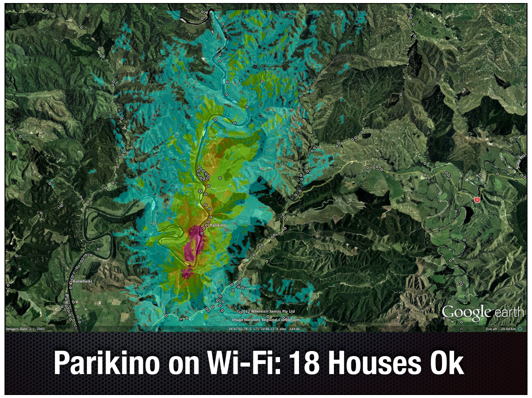


This map shows wireless and adsl coverage across the area, and each yellow dot represents a house.The area of Parikino has copper and Radio-Fed local telephone loops, but No ADSL or 3G

It receives a little TV coverage from one of three nearby towers, but 15 of its 19 TV Channels Unoccupied - leaving around 90MHZ of Free Spectrum for use with TV Whitespace - about the same amount as is available in the 2.4GHz Wi-Fi band.

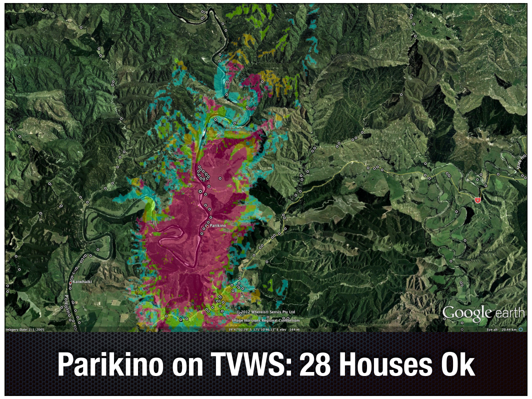




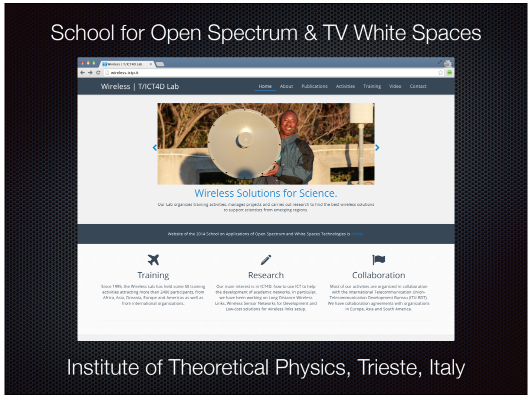


In my model I placed a single Wi-Fi hotspot using the highest legal power settings and a sectorial antenna on a tower site with a good view of the valley, nearby road and power access, and potential for backhaul to a major city.

Red, orange, green, and blue on the page show different received signal levels. Only in the red area will a house receive service if there are trees obscuring the tower. In every other area, service will only work with direct, unobstructed line of sight.

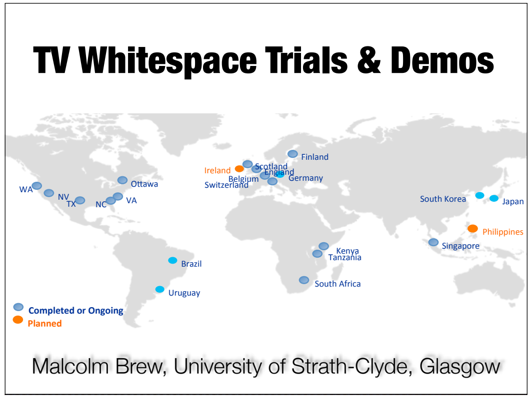


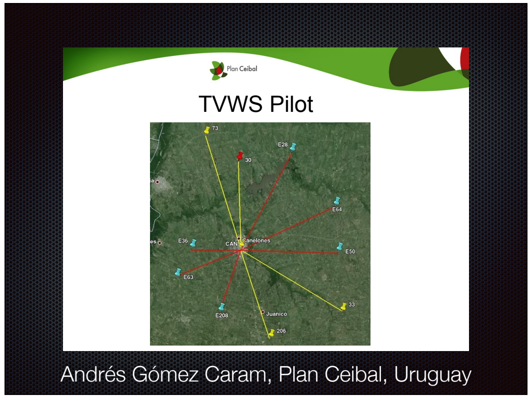
Using TV Whitespace Spectrum, but no more power than Wi-Fi and similar sized antennas, that number jumps to 28 houses. The useful coverage area shown in red is an order of magnitude higher than when using Wi-Fi, resulting in a significant increase in covered houses.

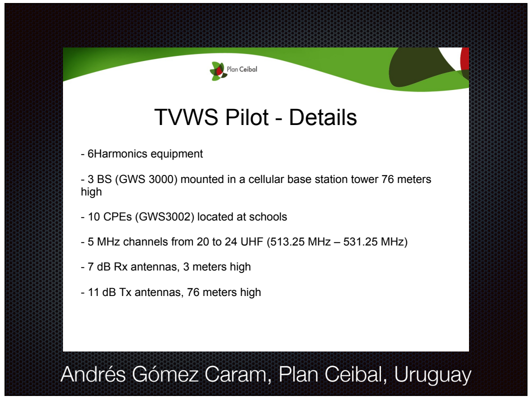


The following case studies were presented at the School for Open Spectrum & TV White Spaces at the Institute of Theoretical Physics, Trieste, Italy, in March 2014.

Slides owners are credited.

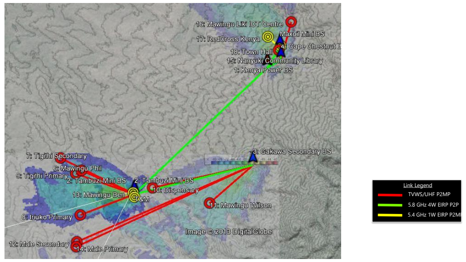



Plan Ceibal
TVWS Pilot
Andrés Gómez Caram, Plan Ceibal, Uruguay


Plan Ceibal
TVWS Pilot - Details
- 6Harmonics equipment
- 3 BS (GWS 3000) mounted in a cellular base station tower 76 meters high
- 10 CPEs (GWS3002) located at schools
- 5 MHz channels from 20 to 24 UHF (513.25 MHz – 531.25 MHz)
- 7 dB Rx antennas, 3 meters high
- 11 dB Tx antennas, 76 meters high
Andrés Gómez Caram, Plan Ceibal, Uruguay


Mawingu Project
Collaboration between Kenya's telecom regulator, Ministry of Information and Communications, Microsoft and Mawingu Networks.
Pilot delivering low-cost wireless broadband access to previously unserved locations near Nanyuki and Kalema.
First deployment of solar-powered based stations together with TVWS to deliver high-speed Internet access to areas currently lacking even basic electricity. Base stations allow end-users to charge devices.
To maximize coverage and bandwidth, while keeping costs to a minimum, the Mawingu network relies on a combination of "license-exempt" wireless technologies, including Wi-Fi and TVWS.
Sid Roberts, Microsoft

Mawingu Network in Nanyuki, Kenya

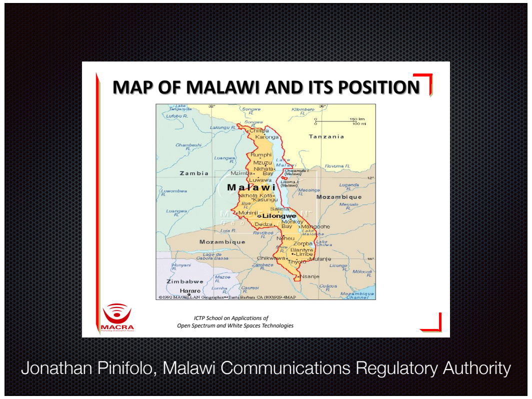


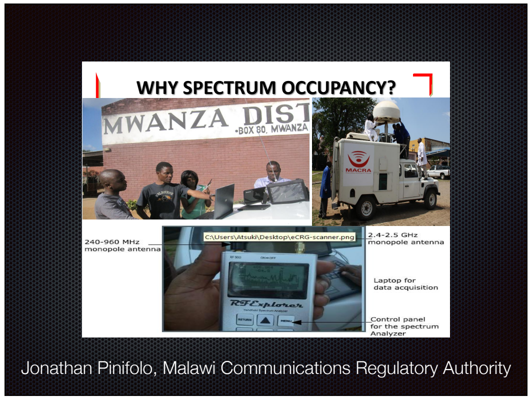
Sid Roberts, Microsoft

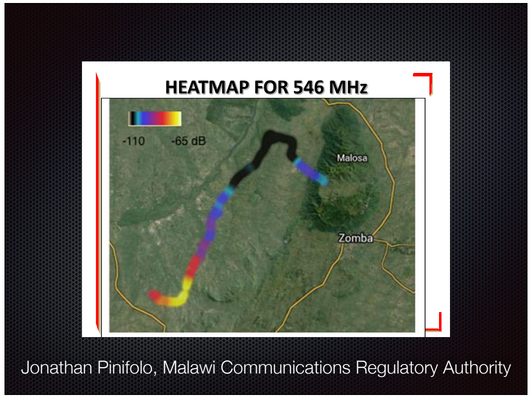
Malcolm Brew, University of Strath-Clyde, Glasgow

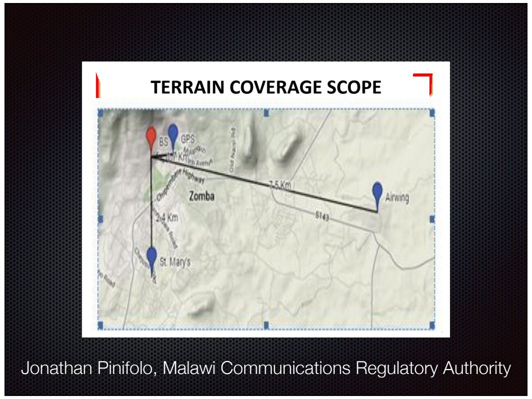
Malcolm Brew, University of Strath-Clyde, Glasgow


AFRIKA
Microsoft
Malcolm Brew, University of Strath-Clyde, Glasgow

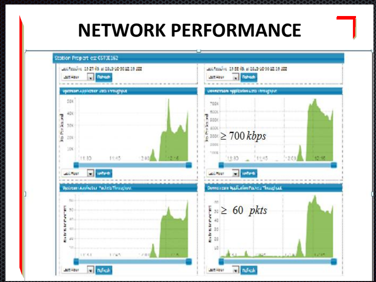

MAP OF MALAWI AND ITS POSITION
Tanzania
Zambia
Malawi
Lilongwe
Mozambique
Zimbabwe
Harare
MACRA
ICTP School on Applications of
Open Spectrum and White Spaces Technologies
Jonathan Pinifolo, Malawi Communications Regulatory Authority


WHY SPECTRUM OCCUPANCY?
MWANZA DIST
BOX 80, MWANZA
MACRA
240-960 MHz
monopole antenna
2.4-2.5 GHz
monopole antenna
Laptop for
data acquisition
Control panel
for the spectrum
Analyzer
Jonathan Pinifolo, Malawi Communications Regulatory Authority


HEATMAP FOR 546 MHz
-110
-65 dB
Malosa
Zomba
Jonathan Pinifolo, Malawi Communications Regulatory Authority

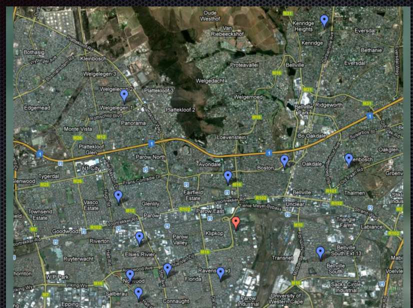

TERRAIN COVERAGE SCOPE
BS
GPS
Zomba
7.5 Km
Airwing
2.4 Km
St Mary's
Jonathan Pinifolo, Malawi Communications Regulatory Authority


BS INSTALLATION WORK
Jonathan Pinifolo, Malawi Communications Regulatory Authority



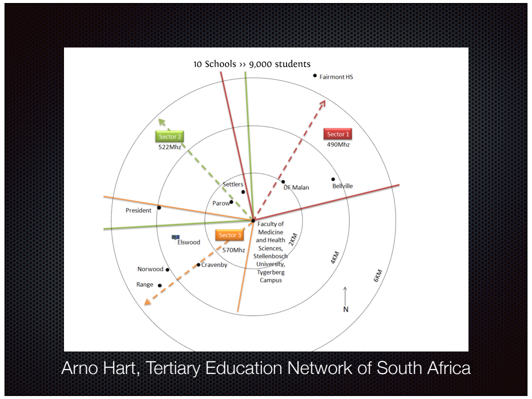
Jonathan Pinifolo, Malawi Communications Regulatory Authority

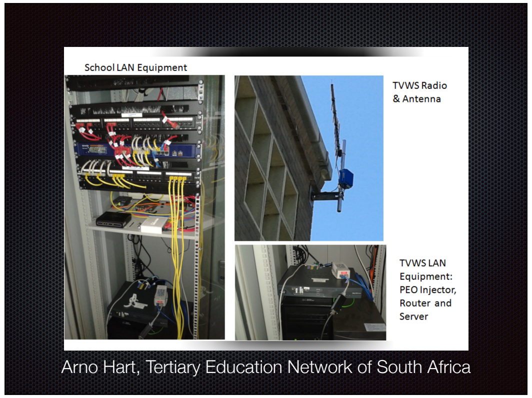
Arno Hart, Tertiary Education Network of South Africa

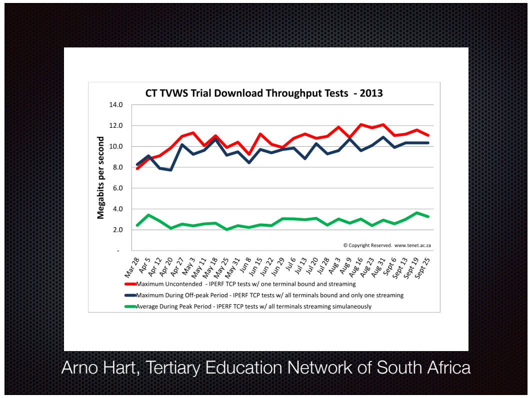


Arno Hart, Tertiary Education Network of South Africa

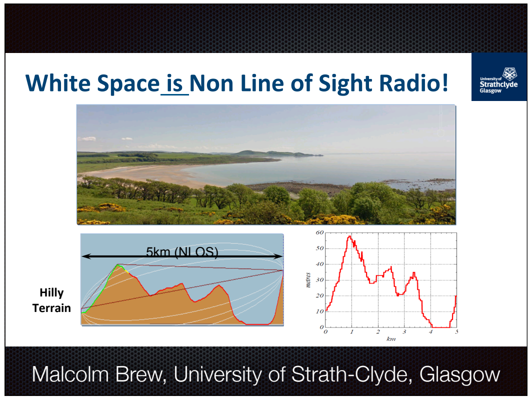

Base Station Equipment at the High Site
ENCLOSURE
ANTENNA 1 & 3
ANTENNA 2
3 Base Stations
Back-haul Equipment
Arno Hart, Tertiary Education Network of South Africa

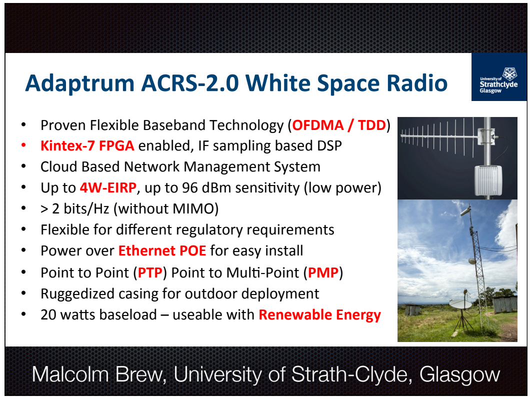

10 Schools ›› 9,000 students
Fairmont HS
Sector 2
522Mhz
Sector 1
490Mhz
Settlers
DF Malan
Bellville
Parow
President
Faculty of Medicine and Health Sciences, Stellenbosch University, Tygerberg Campus
Sector 3
570Mhz
Elswood
Cravenby
Norwood
Range
2KM
4KM
6KM
N
Arno Hart, Tertiary Education Network of South Africa


School LAN Equipment
TVWS Radio & Antenna
TVWS LAN Equipment: PEO Injector, Router and Server
Arno Hart, Tertiary Education Network of South Africa

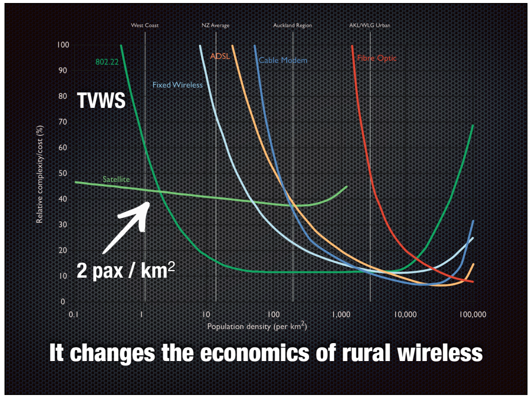

CT TVWS Trial Download Throughput Tests - 2013
Megabits per second
© Copyright Reserved. www.tenet.ac.za
Maximum Uncontended - IPERF TCP tests w/ one terminal bound and streaming
Maximum During Off-peak Period - IPERF TCP tests w/ all terminals bound and only one streaming
Average During Peak Period - IPERF TCP tests w/ all terminals streaming simulaneously
Arno Hart, Tertiary Education Network of South Africa


Isle of Bute TVWS Radio Setup
Telephone Exchange
Trialists' premises
Malcolm Brew, University of Strath-Clyde, Glasgow


White Space is Non Line of Sight Radio!
5km (NLOS)
Hilly Terrain
Malcolm Brew, University of Strath-Clyde, Glasgow



Cognitive Radio in TV whitespace opens up a new set of radio spectrum that has great propagation characteristics making it exceptionally suitable for rural use.



Back to this graph again – also from Canada's Communications Research Centre. The goal of the 802.22 working group was to shift the wireless broadband cost/complexity curve to allow for economic deployment in low population densities. From the radio modeling of New Zealand's terrain, it looks like it achieves this goal.

The paper I discussed is available online via the links on this page.

Thanks, and are there any questions? If you don't want to speak up now, please catch me at afternoon tea or tomorrow.