Far Flung Proposal

Broadband via TV

This is a proposal to fund the research, development and deployment of a national low-speed broadband network using the broadcast television infrastructure.

The Australian National University has identified the upcoming VHF and UHF spectrum plan could be coupled with recent research activities to build a wireless broadband access network that brings internet access to long-distance connections.

The enclosed technical report details the results of recent trials, yielding the opportunity to use this technology for some of the 2% of Australians that will not be connected by the National Broadband Network.

The *Far Flung* "self adjusting" technology would enable stationary broadband connections in the 1-2 Mbps range, and also much lower speeds to more remote locations.

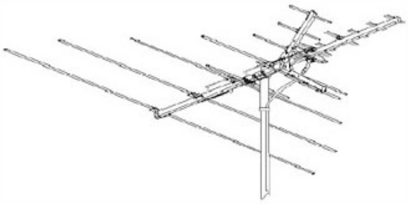
Investigations with Broadcast Australia reveal no technical impediments to ongoing trials and eventual national deployment.

This project should be assessed in the areas of the National Broadband Network, the ACMA Spectrum Review and the DBCDE Remote Broadband Services enquiry. It should be considered for inclusion into further specification and funding readiness tasks.

far-flung (adj.)
extending over a great distance
widely disbursed or distributed.

Far Flung Project Milestones

- Complete R&D for optimal modem and tower equipment.
- Conduct comprehensive spectrum testing in a variety of scenarios.
- Fast-track manufacturing of customer premises equipment to agreed specification.
- Equip Australia's 600 broadcast television towers with a fibre connection to the NBN.
- Equip an aggregator to commercialise the operation of a retail network.



Designed to work with existing TV antenna. Low power modem negotiates the best connection considering your antenna, interference, power allowances and geography.

Careful spectrum planning and long-term investment could see more Australians receive the benefits of broadband.

The *Far Flung* network would enable widespread weather monitoring and water management applications.

The Australian National University's research can now be implemented in a national deployment that supplements the NBN participation coverage.

The intellectual property of the resulting "cognitive" radio sensing technology would be applicable in world markets and represents an export opportunity.

HOW IT WORKS - TWO-WAY BROADBAND INTERNET VIA TV

TV Modem

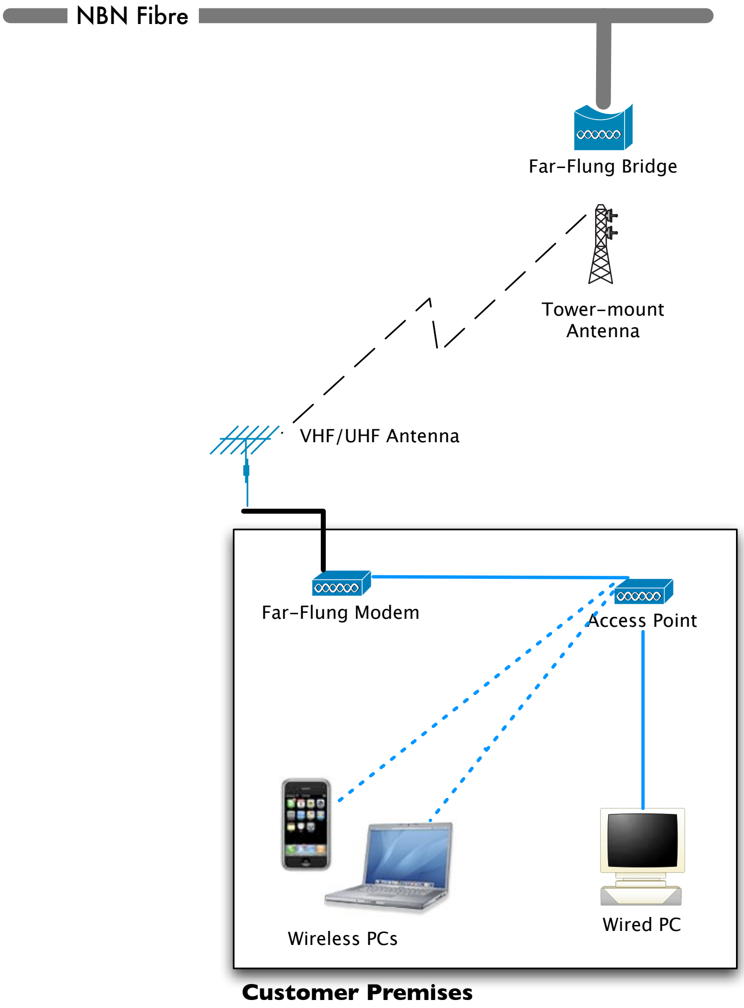
The speed of a *Far Flung* connection to the internet depends on the location with respect to the nearest TV transmission tower.

The *Far Flung* modem at the consumer's home determines the best frequency and power in the current conditions. Thereafter, the connection is monitored and optimised according to nearby spectrum usage and weather conditions.

The broadband connection can be reticulated within the premises using ordinary WiFi technology.

Far Flung can also be used for independent mesh networks in isolated or emergency situations.

The low frequencies of VHF communication allow the service to travel further distances, while the higher frequencies of UHF allow higher speed services at shorter "line of sight" distances.



KEY POINTS

Implementation of the *Far Flung* network extends the reach of the NBN by 600 locations, each able to deliver low-speed broadband connectivity throughout a TV reception area.

In many cases, the customer's antenna will already be in a position to receive IP services. Precise aiming and a clean electrical installation will ensure better performance.

A key goal of the ANU's future research and development is evolving the radio negotiation intelligence we have today into devices that also take account of local tower capabilities.

Low speed and long range services can evolve for unattended weather monitoring and water management operations. The number of potential online telemetry applications increases dramatically with a national VHF/UHF IP network in place.

Using the *Far Flung* network to connect remote and regional users would be more cost effective per-installation when compared to satellite-based two-way services.

Far Flung

Ingenious internet connectivity for regional and remote Australia

BUILDS ON AUSTRALIAN RESEARCH

The *Far Flung* network leverages Australia's expertise in radio communications research to build a wide-area network specifically for Australian long-range conditions. Collaborations with CSIRO would be welcome for antenna design and propagation measurement technology.

ALWAYS ON AT ANY SPEED

Those living in regional and remote areas without access to any internet services will embrace a full-time connection, even if the conditions warrant only a minimal connection speed.

USING SCARCE SPECTRUM EFFICIENTLY

By using the VHF/UHF spectrum and ANU's methods for efficient radio negotiation the *Far Flung* network automatically makes best use of spectrum for the users' connections.

COMPLEMENTING THE NBN

Conducting the design and implementation phases alongside the NBN rollout would allow *Far Flung's* coverage to be tested and mapped as an extension to the NBN.

INNOVATIVE INFRASTRUCTURE

By investing in the innovations already pioneered at ANU it is possible to equip Australia with more ubiquitous connectivity services. *Far Flung* is an enabling infrastructure for "web and email" users at the homestead. It can also be used for remote monitoring, measurement and control of distant, independently powered equipment.

NEW SERVICES IN NEW MARKETS

By applying our expertise in small-scale solar design we suggest a market for inexpensive remote sensing devices will evolve to operate on the network.

AGRICULTURAL ADVANTAGES

Enormous potential exists for independent devices to monitor and control appliances for farming applications. From weather interpretation and dam level monitoring to gate-opening, the *Far Flung* network could provide internet connectivity to increase our access to remote areas in mining and agricultural endeavours.

THE LAST TWO PER-CENT

Far Flung is a network aiming to reach a large proportion of those living and working too far from the FTTN network. It operates at less than the 12 Mbps mandated by the NBN and provides a "best effort" connection for the location and conditions.

The *Far Flung* network is a two-way IP service and could complement or replace existing rural broadband delivery efforts.

GLOBAL SCOPE

Some nations are planning the redeployment of their analogue spectrum now. Australia has a unique opportunity to implement a *radio etiquette* for both long (VHF) and short (UHF) range applications, and compatible with emerging standards. The resulting product and national experience would then be applicable to other nations seeking long-distance IP solutions.

LONG TERM PROJECT

Far Flung is expected to be a multi-year project to commercialise ANU's BushLAN research and deploy a national access network using the analogue TV spectrum due to be available from 2013. It encompasses taking our basic research, testing it in real-world scenarios, optimising the equipment, manufacturing the equipment and engineering the transmission tower network to provide a near ubiquitous low-speed broadband internet service.

Australian National University **Far Flung Proposal**		
Dr. Gerard Borg Research School of Physical Sciences and Engineering Department of Engineering	gerard.borg@anu.edu.au Ph. (02) 6125 8567 (DoE) Ph. (02) 6125 4055 (RSPhysSE) Ph. 0409 924 662	**Australian National University** Attn: Dr. Gerard Borg Plasma Research Laboratory Research School of Physical Sciences and Engineering College of Science Australian National University Canberra 0200 ACT
Mr. Andrew Howard Advanced Communications Research	andrew.howard@anu.edu.au Ph. (02) 6125 9495	
Mr. George Bray Digital Resource Services	george.bray@anu.edu.au Ph. 0411 111 606	

An Australia-wide Broadband Wireless Network based on TV Spectrum

Dr Gerard Borg
Department of Engineering,
College of Engineering and Computer Science.
Research School of Physical Sciences and Engineering,
College of Science.
Australian National University
Canberra 0200 ACT.
26 June 2008

Executive Summary

The provision of broadband services to regional and remote areas of Australia continues to be a vexing national issue because of the repeated failure of existing technologies to meet the challenge at a reasonable cost.

According to the ABS, 2.3 % of Australians live in remote areas. This class of the population could number around 400,000 individuals who mostly dwell in isolated and blackspot areas. These citizens could benefit from on-line educational, health, banking services and e-commerce if only they had access to an Internet connection at 1 – 2 Mbps.

Unfortunately, there are misconceptions about the capabilities of wireless. So far only the most conventional technology alternatives such as satellite and microwave wireless access have been canvassed. This problem is not confined to Australia and few alternative solutions appear on the horizon.

In this report we propose an R&D effort to investigate and develop new technologies that exploit the TV bands: particularly the band I TV channels (45-70 MHz). We propose that a service of at least 1-2 Mbps can be provided to the 2.3% of Australian in remote areas. We also propose that better throughput can be obtained by the judicious application of higher frequency TV spectrum (such as UHF spectrum) in some circumstances.

This solution would have the minimum cost of any technology and no doubt several orders of magnitude lower than the cost of an Australia-wide Fibre to the node network.

This is a world first solution to the remote last mile problem. Early adoption will not only provide a low cost and effective solution to the current service provision problem in regional and remote Australia, but will almost certainly become an export opportunity.

1. The Problem

It remains clear that wireless networks hold the key to truly ubiquitous, low cost broadband services. Although speeds have been improving, the achievement of truly ubiquitous coverage has lagged. The main limiting factor has simply been the meaning of coverage. In cellular and WLAN networks coverage usually refers to the ability of wireless signals to penetrate and propagate between buildings in built up areas. Such "non-line-of-sight" wireless links are popular because they obviate the need for external roof mounted antennas for premises in close proximity to an access point (AP) or base station (BS).

Coverage and non-line-of-sight propagation should also describe the ability of wireless links to propagate around large terrain objects such as hills and mountains over terrains spanning 3 – 100 kms. Investigations have been made of the use of wireless to serve sparsely populated regional and remote areas. Lack of awareness of this work and a continued worldwide R&D trend toward high throughput short-range wireless networks has meant that future wireless technologies are unlikely to provide a connectivity solution for regional and remote areas. Evidence of this can be seen in the fact that world-wide roll-outs of wireless networks have been exclusively in the frequency range above 470 MHz and more usually above 1 GHz. Wireless signals at these frequencies cannot be used to economically service regional and remote areas.

1.1 Why is it so difficult to access Remote Areas with Current Technologies?

Numerous wireless technologies are currently available in the market. All of these operate in the upper UHF range from 800 – 5000 MHz. In the context of providing long range 20 – 50 kms in average Australian terrain, they all require a **visual line-of-sight** between the transmitter and receiver because their wavelengths are so short that the hills and mountains **completely** shadow them.

The predicted range for a smooth earth is severely reduced if hills or mountains are in the path.

This is not the case at the low VHF frequencies in TV band 1 (45 – 70 Mhz) as these can diffract over most of the hills and mountains that are typical of the Australian landscape.

1.2 An Experimental Study of Diffraction and Coverage in TV Band I

To investigate low frequency coverage, an experiment was performed on channel 1 of the band I TV channels using an ACMA emission license. A 2.5 meter (half wavelength) dipole transmitting antenna at 59.5 Mhz was erected with vertical polarization on a building of height 20 meters (approx.) at the Australian National University (Australian Capital Territory). A half-wave dipole antenna is omni-directional and has the lowest gain (2.15 dBi) of all antennas. The antenna was driven by a signal of 40 Watt CW power. An identical receiving antenna was erected with a 20 meter height at the Molonglo Radio Telescope near Hoskinstown, Queanbeyan (New South Wales) and connected to a receiver with baseband bandwidth 500 kHz. The telescope is situated at about 32 kms from ANU. Figure 1 shows a map of the region.

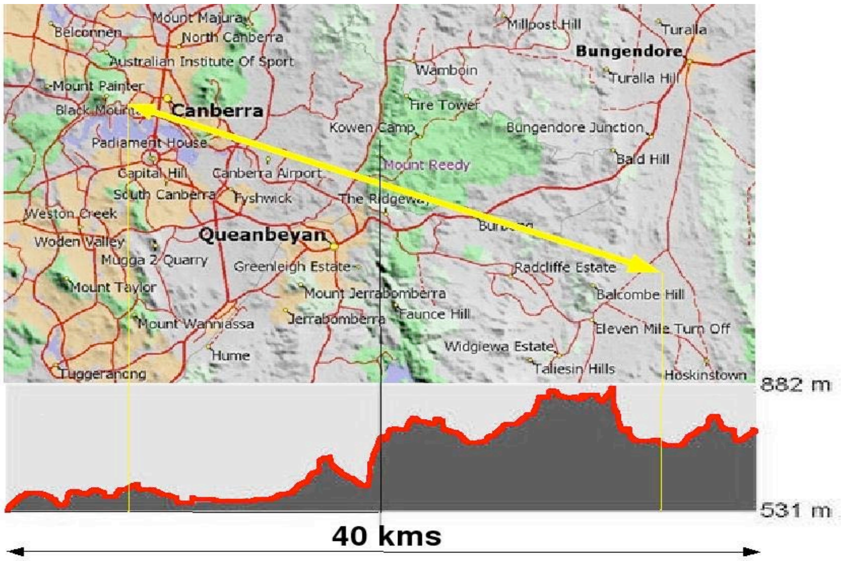


Figure 1. Map of the ANU – Molonglo telescope propagation experiment

A relief topography along an east-west line is also shown. Note that the link is not on a visual line-of-sight. In order for signal to arrive at the receiver, it must first diffract over an escarpment of relative altitude 200 m at a distance of about 5 kms from the receiving antenna.

The received signal had a measured signal to noise ratio (SNR) of 20 dB. Based on the theoretical capacity that one can calculate for this SNR and 500 kHz of base band bandwidth, one can draw the following equivalent conclusions.

(i) **For an RF power of 40 Watts and a pair of dipoles each having a gain of 2.15 dBi at each end of the link (as used in the experiment), the SNR and baseband bandwidth of 500 kHz are sufficient for communications at about 3 Mbps on this link.**

(ii) **A baseband bandwidth of 5 Mhz would support 30 Mbps for the same dipole antennas but would require a transmit power of 400 Watts to maintain the same SNR.**

(iii) **A baseband bandwidth of 5 Mhz would support 30 Mbps for a transmit power of 40 Watt if a pair of 7.15 dBi antennas were used in order to maintain the same SNR.**

Each of the above scenarios is achievable in practice and the approach one adopted would depend on the requirements of the service.

1.3 A Computational Study of Diffraction and Coverage as a Function of Frequency

Without an emission license for each frequency of operation, we could not repeat this experiment for frequencies higher than 59.5 MHz. We use a conventional path loss calculation model to compare the link budgets for a number of frequencies in which the escarpment is modeled by a smooth hill / diffracting object of height 200 m and width 1500m located at 5 kms from the receiver. The ITU terrain model (ignoring antenna gains) predicts a path loss that is slightly more pessimistic than the path loss for the model of the 1500m radius, 200 m high diffracting object. The total range is 32 kms. We assume that the transmitted power is 10 Watts (10 dBW) and that the antennas are half wave dipoles. We assume that the noise at the receiver is determined by both thermal and an ambient or environmental component due to atmospheric effects.

The left three columns give the frequency, wavelength and baseband bandwidth (either 1 MHz or 22 MHz, depending on the technology). The received signal to noise ratio (SNR) depends on the received signal strength which is mostly limited by receiver noise and diffraction over the escarpment. The ambient noise figure is in dB above thermal noise. At 50 and 175 MHz, the noise is predominantly atmospheric and is much greater than at higher frequencies. Beyond 400 MHz the only noise is the thermal noise of the receiver itself, hence the frequency independence of noise power. The final column presents some representative technologies that are currently used in these bands.

As can be seen, the negative SNRs point to a link severely shadowed by the escarpment for all frequencies except 50 MHz. **Communications above 50 MHz is impossible on this link.**

Freq MHz	Wavel (m)	Base band BW (MHz)	TX to escarpment (kms)	RX to escarpment (kms)	Path Loss ITU Terrain model	Path Loss Circular object of radius 1500m	Ambient Noise Figure dB	Total Noise Power 300K (dBm)	**SNR (dB) Circular object of radius 1500m**	Typ. Technol.
50	6	1	27	5	129.2	124.0	20	-94	**10.3**	Analog TV
175	1.71	1	27	5	159.8	152.0	5	-109	**-2.97**	Analog TV
403	0.74	1	27	5	189.0	176.3	0	-114	**-22.4**	Fixed Links
751	0.40	1	27	5	217.8	198.8	0	-114	**-45.0**	WRAN
915	0.33	1	27	5	228.7	207.0	0	-114	**-53.2**	900 ISM WLAN
2300	0.13	1	27	5	293.4	254.0	0	-114	**-100.2**	WLAN
2500	0.12	1	27	5	300.7	259.2	0	-114	**-105.4**	Slow WiFi (1 MHz)
3500	0.086	1	27	5	333.0	281.7	0	-114	**-127.9**	WiMAX
2500	0.12	22	27	5	300.7	259.2	0	-100	**-118.8**	Fast WiFi (22MHz)
5300	0.057	22	27	5	380.3	314.1	0	-100	**-173.7**	WiFi 802.11a

We conclude that the choice of carrier frequency and not the technology is the fundamental limitation to long-range non-line-of-sight terrestrial wireless communications. In order to significantly improve coverage in regional and remote areas, one must choose frequencies in the spectrum of the band I TV channels (45 – 70 MHz).

It should be stressed that this a relative result. Although coverage at UHF (above 500 MHz) is much worse than at low VHF (45 – 70 MHz), this range is nonetheless much better than at microwave frequencies (above 2.5 GHz). If deployed from a TV tower, UHF can have quite good coverage for some applications. For deployment from antennas at ground level however, we are forced to use the low VHF spectrum in order to provide data services suitable for remote and regional Australia.

It should also be stressed that the above scenario is a particularly adverse terrain example among possible terrain scenarios. Nonetheless it is a typical situation in ground level to ground level links.

In the next section we take a closer look at how to choose spectrum for different applications.

1.4 On the Suitability of Different Frequency Bands For Different Kinds of Services

The above calculations can be repeated for the case where the antenna at ANU is moved to black mountain tower (which is right near ANU) at an elevation of 150 m above the terrain and with a transmit power of 30 dBW (1 kWatt) and otherwise exactly the same link conditions. At 50 MHz, we have a path loss of 121.5 dB and an SNR of 32.8 dB: a 20 dB improvement achieved at greater financial and implementation cost. For 750 MHz we have a path loss of 191.6 dB and SNR at the receiver of –17.8 dB. At 750 MHz, the link is still shadowed. However if in addition, we use a pair of 15 dBi (high gain) antennas at each end of the link then we obtain 165.9 dB and 7.9 dB respectively. Thus even for this difficult link it becomes possible to consider 750 MHz as an operating frequency. Since the wavelength at 750 MHz (0.40 m) is much lower than that at 50 MHz (6 m), it is not a difficult matter to manufacture high gain antennas for 750 MHz. High gain antennas however have directional radiation patterns, whereas the antennas in the scenario of the above table are omni-directional.

Another important point to consider is that ranges of over a hundred kilometers at both VHF and UHF can be obtained from towers, depending on the terrain. Thus site testing to determine the best choice of operating frequency will be a feature of all TV band Internet service installations.

We conclude that in some circumstances where terrain conditions are not too adverse and towers are available, it is wise to consider the use of UHF frequencies where more spectrum is available to provide a better service. An obvious example would be the provision of data services to a community near a TV tower. One would service the high population density of customers nearer to the tower using several UHF channels with ample spectrum and adequate throughput and the lower population density of remote users on band I VHF channels.

1.5 How to Achieve Higher Data Rates than 1-2 Mbps

From the above discussion we can assume that with the SNR observed experimentally for a 500 kHz bandwidth, we obtain a theoretical maximum capacity of over 3 Mbps on the link. Thus 1-2 Mbps should be achievable on average per 500 kHz of spectrum bandwidth in the band I VHF. Since there is 21 MHz of bandwidth in the three band I TV channels we can say that 1 – 2 Mbps is available on 42 separate channels giving a total of 42 – 84 Mbps. If more spectrum were made available at UHF in situations of high SNR one could consider using all of the 7 MHz channel bandwidth to provide higher data rates in the range 14 – 28 Mbps. One could go further and even consider channel bonding, wherein adjacent TV channels are combined into larger spectrum blocks.

When SNR is high enough one can adapt the modulation scheme to use higher order coding. The 1 Mbps rate requires QPSK with 2 bits per symbol. 16-QAM, having 4 bits per symbol, would produce 2 Mbps. 64-QAM, having 6 bits per symbol would produce 3 Mbps. Frequency reuse using high gain antennas at high VHF and UHF also allows improved overall throughputs. We discuss these and other methods further when considering a case study.

2. Networking Solutions for Regional and Remote Areas

In this report we present an argument for the redeployment of band I TV spectrum for the provision of telecommunications infrastructure and broadband services in regional and remote Australia. In the USA, the development of a TV band whitespace technology based on cognitive radio is well advanced. This latest wireless technology is known as **Wireless Regional Area Networks (WRAN, IEEE 802.22)**. Cognitive radios are radios that are environmentally sensitive. They are capable of sensing and avoiding TV spectrum that is used for broadcast in local areas. Recently spectrum in the UHF TV bands around 700 MHz has been sold for the deployment of this technology, although the technology itself is still in the specification phase. It is important to note that there does not appear to be any plans to develop this technology for the band I TV channels as we are proposing here. In the USA, IEEE 802.22 only appears to be for deployments above about 470 MHz.

In Australia, work on the characteristics and the suitability of the TV band I signals for broadband applications in regional and remote areas has been the main goal of the BushLAN project at the Australian National University. The use of Band I TV spectrum as proposed here is unique. However the wireless coverage problems due to terrain are issues the world over. Australia has a unique window of opportunity to be the first to develop the technology.

The first step is to obtain funding to properly scope out the research, development and application space for the use of TV spectrum for broadband wireless networks. The next is to carry out the R&D. A summary of this R&D process is provided in section 3 together with some important case studies that can be performed.

In the remainder of this section we describe four possible scenarios for the redeployment of TV spectrum for wireless data networking.

2.1 A Regional Access Network

There are many regions of Australia that could be connected to broadband if a TV band wireless service were installed on existing TV broadcast towers. Many of these towers are located in remote areas and contain much of the infrastructure already required. There are about 600 Broadcast Australia TV towers in Australia. **This opportunity has enormous potential to enhance Australia's network infrastructure.**

To make use of this resource, two things need to be done.

(i) A high speed backhaul network has to be provided in the form of a fibre optic backbone to the TV broadcast towers.

(ii) A long range broadband wireless access network consisting of access points (APs) has to be installed on the towers. Subscribers gain access through a customer premises equipment (CPE).

Figure 2 shows a pictorial representation of the RAN. It is a multiple access network, that could operate on several TV channels. Coverage would be enhanced by the elevation of the TV towers. Areas nearer to the tower and with the highest population density can be serviced by radios operating on UHF TV spectrum. The most remote and sparsely populated areas would need to be serviced by the lower VHF frequencies. The tower antennas would have reasonable gain and would be sectorised to cover different equatorial angles from the tower. Depending on the frequency of operation it should even be possible to reuse existing TV aerials at the customer premises.

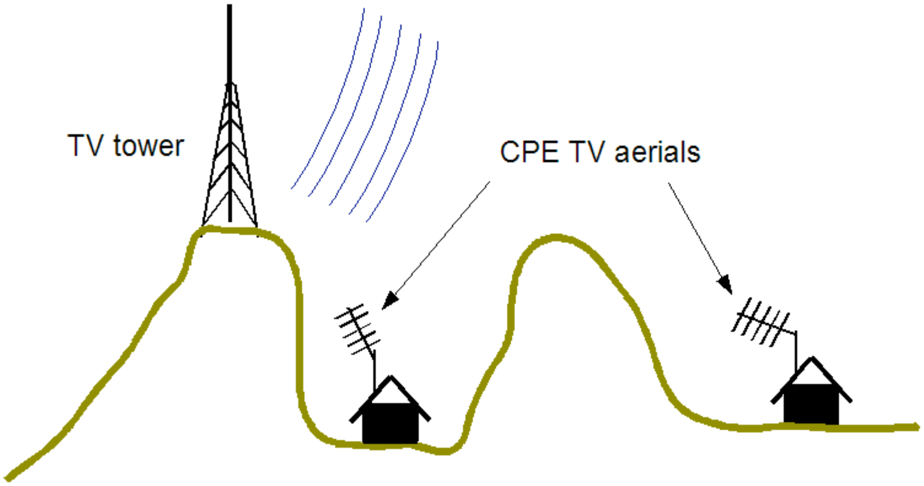


Figure 2. The Regional Access Network.

2.2 A Remote Mesh Network

A network topology relevant to areas where there is no access to a tower is the **Remote Mesh Network (RMN)**. Figure 3 shows a pictorial representation of the RMN. The green circles represent the range of an access point node on the network. According to the ACT results these circles would have a radius of about 32 kms in average terrain for 20 m elevated aerials. An access point (AP) at the nodes (black points) provides an access network for users inside the green circles. Each node also has a radio that operates on the mesh backbone network. These radios run the links shown in blue lines, channeling wireless traffic from the access networks to the Internet gateway. Notice that in order to maximise throughput, there may be many paths back to the gateway. In mesh networks it is important to design the routing protocols to avoid bottlenecks on the mesh.

RMNs are infrastructure free. Without access to towers and the facilities they provide, power, shelter and backhaul have to be a part of the solution.

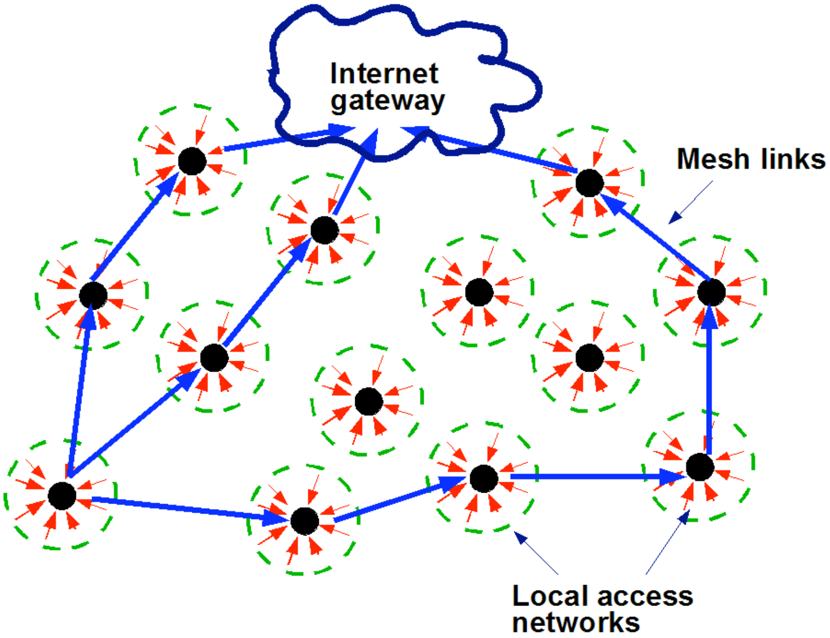


Figure 3. The Remote Mesh Network.

2.3 Other VHF Network Applications

Access to low frequency VHF spectrum, whether supplied from TV towers as in the case of the RAN or in a mesh networking fashion as in the case of the RMN, is not confined to Internet services. Telemetry and other communications infrastructure projects that rely on long range communications now become possible.

2.3.1 A Remote Telemetry Network

There are many situations in the mining industry and in scientific research where low bandwidth sensor networks relay information over long distances. Such a network is similar to an RMN. A scattered array of access networks feed data to aggregating nodes that relay the data to a backbone. Such networks would have greater coverage and lower cost than the short range mobile phone networks currently in use.

2.3.2 Coastal Broadband Network

Ocean swell and earth curvature prevent the use of microwave frequencies for coastal communications. Access to low frequency VHF spectrum could provide long range networking solutions for coastal surveillance purposes and the extension of telephone and broadband networks to off-shore locations, such as coastal islands, oil rigs and ships. As a concrete example consider a wireless relay network across Bass Strait in which a long range VHF network provides broadband services to oil rigs and vessels for scientific purposes.

3. Operational Plan

In this section we describe in broad terms the steps required to bring a national TV band wireless network to fruition. We discuss the various research and development stages. We also propose case studies of the solutions presented in section 2.

There will be four stages in the development of the VHF wireless system for each of the proposed networking solutions.

1) Wireless channel research and case studies.
2) Design review of the underlying wireless technology.
3) The implementation of a working concept demonstrator base and CPE modem (RAN) and a wireless mesh network (RMN).
4) Network trials.

3.1 Regional Access Network

The regional access network benefits from the existing network of TV broadcast towers. The aim of this TV band wireless network is to capitalise on this existing infrastructure to improve communications services.

3.1.1 Wireless channel and signal research

The **regional access network (RAN)** will require access to a TV tower with a nominal height of 150 meters (for example Black Mountain Tower). We envisage four phases of research:

1) Coverage and channel response,
2) Atmospheric and impulse noise investigations, signal quality and data throughput,
3) Telephony and video conferencing tests,
4) Case studies.

Phase 1. Coverage and channel response. The first set of trials will investigate coverage performance and channel dynamics. Because the towers are elevated over the surrounding terrain the signal range with 7 MHz bandwidth could be over 100 kms even at UHF. Therefore there is the possibility of investigating and developing systems to operate over the whole TV band from 45 – 820 MHz. The trials will be performed around 50, 175 and 750 MHz to cover the range of available frequencies for the low VHF band and a typical UHF frequency relevant to 802.22.

In many circumstances it would be advantageous to exploit spectrum at higher frequencies, in order to maximise available bandwidth to subscribers nearer to the towers. The VHF spectrum would be reserved for the long range subscribers. Depending on spectrum availability, it may be necessary to operate the long range links at the highest frequency possible where spectrum is available.

These trials will be used to assess coverage and verify terrain field mapping software that will become a necessary tool for future network design.

Phase 2. Atmospheric and impulse noise investigations, signal quality and data throughput. Site surveys of interference and noise will reveal the existence of TV band communications system impairments. Impulse and power line noise are especially significant at low frequencies and have been known to deleteriously affect DTV reception. It addition there will be co-channel interference from TV emissions (especially inter-state vision carriers). We also have to learn how to design networks free of co-channel interference. We know that anomalous propagation such as troposcatter and space wave at low VHF could be present. Troposcatter may even be exploited for very long range communications (1000 kms).

Previous experiments have been performed using channel sounding techniques to investigate the effects of multi-path (channel induced echoes) which leads to inter-symbol interference (ISI). We do not anticipate significant ISI at 50 MHz but ISI could be worse at UHF frequencies. ISI will be handled by standard signal processing techniques such as equalisation and (if useful) OFDM[1].

Raw base band signals will be recorded using instrumentation transceivers for off-line analysis. They can be used for receiver design and simulations to predict network throughputs.

Phase 3. Telephony and video conferencing tests. Future IP networks will need to supply voice and video. Optimisation of the network to provide a high quality service can be performed using the **phase 2** data. Experimental tests can also be performed using off-the-shelf equipment.

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[1] Orthogonal Frequency Division Multiplexing: a data multiplexing technique used in nearly all modern wireless standards.

Phase 4. Case studies. We will perform case studies of such a system to predict system performance.

3.1.2 Design Review.

A design review of wireless hardware and software will follow. This should be a rapid process as much work has already been done. The aim is to write the detailed specification for the RAN.

Information on coverage and channel impairments will directly influence the design of the antenna (the required antenna gain will affect the size of the antenna with the largest antennas being at the lowest frequencies) and the power amplifier (certain modulation schemes need linear class A or AB amplifiers). The physical layer processing will be directly influenced by impulse noise and cochannel interference.

Power line and impulse noise and co-channel interference from inter-state TV vision carriers has generally been a problem in experiments performed in the ACT. These effects are not so severe at UHF frequencies. Thus even at 50 MHz with 10 Watts of power, a sophisticated receiver will still be required for communications.

Conversely we will have to assess possible interference produced on existing broadcast services. In the USA the 802.22 radios are planned to be cognitive radios capable of sensing broadcast signals and setting their carriers to avoid interference. We will need to decide whether BushLAN has to be cognitive.

The RAN requires a MAC protocol to control access among many users. We have analysed a couple of MAC protocols in BushLAN that may be applicable. Because the same technology will be operational at both ends of a link some form of in-line compression may be used for uncompressed web traffic in order to enhance throughput.

3.1.3 Development of Concept Demonstrators

Following the design review, the next step is to build concept demonstrators satisfying the requirements. Some properties of these demonstrators are already clear but need further investigation.

The tower base station or **access point (AP)**

- Capable of instantaneous tuning over the TV band,
- The addition of Software Defined Radio capability for future proofing. For example, if the 802.22 standard is made mandatory in future years then the existing BushLAN radios can be reprogrammed to suit.
- Present 802.22 specs appear to suggest OFDM (Orthogonal Frequency Division Multiplexing) in the PHY layer. If we adopt this scheme then all power amplifiers will have to be class A linear (expensive). In addition, with OFDM, impulse noise

may be a problem. Thus whether we follow the 802.22 specification here is not yet clear.

- The antenna will allow a degree of sectorised pattern shaping.
- If there is a need for full duplex operation at the base then a filter diplexer must be implemented. This is an expensive and difficult option to implement for closely spaced frequency channels.

The consumer premises equipment (CPE)

- Must operate at lower power than the AP.
- Will support less bandwidth for the same range as the AP. This is convenient because a number of CPEs will be sharing the downlink with uplink-downlink load matching.

The CPE must also operate at low power if commercial grade TV aerials are to be used. In this case the CPE and a TV set could share the same aerial. UHF RF power is less likely to heat the aerial baluns than VHF RF power. This matter will need investigation.

3.1.4 Network Trials

This is the final phase of development in which the radio concept demonstrators are tested in the field.

3.2 Remote Mesh Network

The procedure for the development of the **remote mesh network (RMN)** will be similar to that for the **RAN**. The RMN is a user access network in which traffic is transported from one network node to another toward an aggregation point where high speed backhaul to the Internet is provided. User access to the mesh would be similar to that in the RAN. Since there is no shelter, power or backhaul, the environmental conditions and network requirements are tougher.

The RMN wireless coverage and signal experiments will be performed in terrain that is more intractable than the norm. These experiments must be less restrictive than those reported so far in the ACT. The main difference compared to the **RAN** is that antennas will not be elevated. Elevations as low as 5 meters (house roof height) to 25 meters (building roof height) will pose a major challenge to long range communications. Coverage experiments and validation of terrain mapping software will allow us to plan future networks. The mesh network will most often operate at low frequency VHF.

The other development phases and their issues are similar to those of the RAN. The poor coverage of non-elevated aerials driven at UHF compared to the coverage at 50 MHz (low VHF) implies a lower access to spectrum and hence much lower bounds on attainable throughput. On short-range links in the access networks, bandwidth might be enhanced if transmission is possible at UHF or microwave frequencies. In a case study below we show that this may even be the case in the indigenous communities of the remote Northern Territory.

3.3 Case Study: A Remote Mesh Network for the Northern Territory.

Figure 4 shows one embodiment of an RMN. Each access network region (azure dashed circle) is serviced by an AP. There are three circles each exploiting two adjacent 1.167 MHz channels in a 7 MHz TV channel. The AP radiation patterns are circular. The red, blue and brown ellipses depict the radiation patterns of the VHF mesh links that form the network backbone. In this example the mesh has a string of pearls topology, however other topologies such as that in figure 3 will sometimes be more appropriate and efficient. In this example, the mesh links operate on the same spectrum as the APs. This is only necessary if only one VHF TV channel is available and the access network is also a long range network using antennas of low elevation. Notice how the frequencies are chosen so that the same frequency is not reused in the same location. The radiation patterns of the mesh antennas have twice the gain in order to support twice the bandwidth for the same range.

The reuse of frequencies can be maximised if the radii of the access network regions is sufficiently small. In this case UHF TV bands involving multiple bonded 7 MHz channels could lead to much higher network efficiencies provided that sufficient VHF spectrum is dedicated to the mesh links.

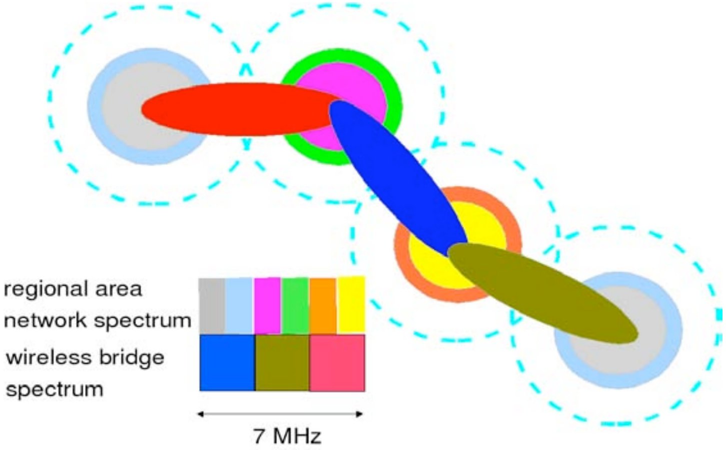

Figure 4. An RMN topology using one 7 MHz Band I TV band

Let us consider a difficult case in which Internet services are currently very poor. We will use the 7 MHz spectrum block of Band I TV Ch 0 to serve the indigenous communities surrounding Alice Springs in the Northern Territory (Figure 5). For an RMN without towers we can expect about 32 kms for antennas on 20 meter masts at each end of a link. Given similar terrain conditions to that in the ACT experiment described above, we can expect there to be few black spots at carrier frequencies in the range 45 - 52 MHz and RF powers ~100 Watts (20 dBW). We may therefore assume the range contours to be circular.

The indigenous colonies are shown in the map of Figure 5 below with the populations of 500 – 3000 (green), 50-500 (blue), 20-50 (red), 10-20 (yellow) and 0-10 (mauve): a total population upper limit of about 46,800 individuals. Each circle in the figure has a radius of 32 kms. An access point (AP) located at the centre of each circle is equipped with an omni directional antenna (similar to the above ACT experimental measurements) and serves the access network. Backhaul can be supplied either by satellite if necessary (worst case and most expensive option) or by mesh networking between circles (no ongoing costs) as described above. In the case of the mesh network, the mesh is assumed to terminate at an Internet gateway with a broadband backbone. For clarity the VHF mesh links are not shown in the figure.

A data rate of 2.33 Mbps is available per 1.167 Mhz RF spectrum bandwidth based on error free transmission using QPSK. Since there will be two such channels per circle in the above network model, we can supply 4.67 Mbps to the communities within a circle.

As one can see from the figure, a population of up to 46,800 could be serviced by 47 nodes in a mesh network covering an area of about 1000kms x 1000kms. The above data rate could be further increased by a number of techniques. If SNR is sufficiently high, a higher level modulation scheme such as 16-QAM would give 9.33 Mbps or 64-QAM, 14 Mbps. In-line compression would increase throughput by perhaps a factor of ten for uncompressed web traffic (as opposed to compressed voice, video and downloads which would be unaffected). Greater data rates can easily be achieved by sectorisation of beam patterns to allow frequency reuse within each access region (azure blue circles).

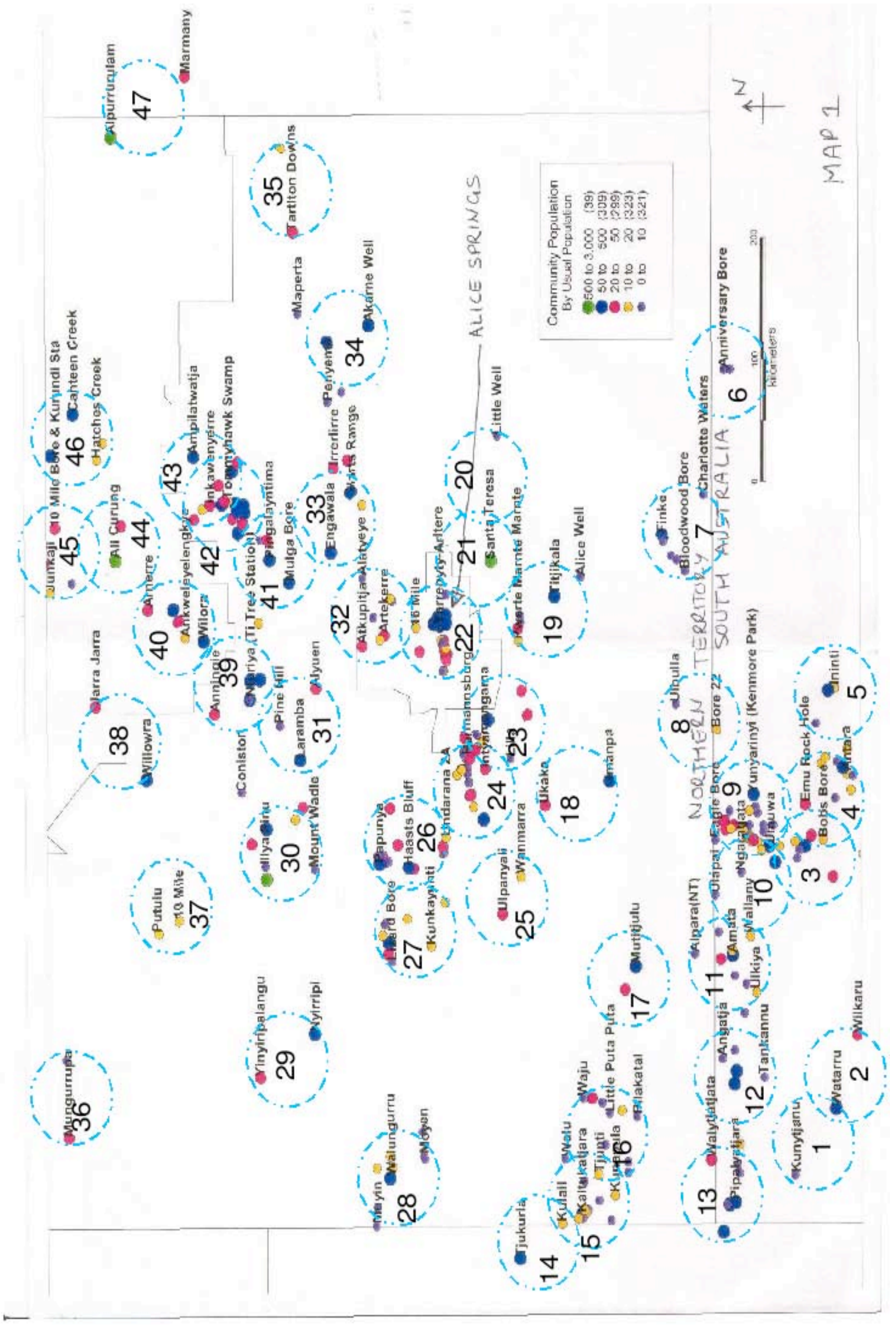

Figure 5 Map of the southern Northern Territory and northern South Australia. Coloured spots show the population centers. The azure blue circles show the range of the access networks of the RMN.

The following table summarises the demographic data in the map. The indigenous communities form population clusters. There are about 1-3 clusters per circle and the population of the entire circle is heavily concentrated in these clusters. The populations of the clusters are labelled by N_c. Since these clusters are themselves highly localized, UHF or microwave spectrum could be exploited to provide higher throughput.

Network	Min pop.	Max pop.	50< Nc < 500	Nc >= 500
1	50	510	1	0
2	70	550	1	0
3	160	1180	2	0
4	130	730	1	0
5	60	530	1	0
6	0	20	0	0
7	50	550	1	0
8	10	30	0	0
9	740	4390	2	1
10	60	520	2	0
11	100	650	1	0
12	100	1030	2	0
13	180	1600	3	0
14	60	520	1	0
15	110	580	0	0
16	40	140	0	0
17	70	550	1	0
18	70	550	1	0
19	80	590	1	0
20	0	10	0	0
21	500	3000	0	0
22	380	2840	1	1
23	120	690	1	0
24	170	880	1	0
25	30	70	0	0

Network	Min pop.	Max pop.	50< Nc < 500	Nc >= 500
26	210	1300	2	0
27	110	600	1	0
28	80	590	1	0
29	70	550	1	0
30	600	3640	1	1
31	70	560	1	0
32	60	160	0	0
33	150	1120	2	0
34	110	1010	2	0
35	30	70	0	0
36	20	60	0	0
37	20	40	0	0
38	70	550	1	0
39	170	1550	3	0
40	150	1120	2	0
41	460	3390	6	0
43	50	500	1	0
44	520	3050	0	1
45	50	130	0	0
46	120	1040	2	0
47	520	3050	0	1

3.4 Remote Telemetry Network

The **RTN** investigation program is similar to that of the **RMN**. Telemetry is a very common application of low bandwidth wireless. Often however range is a problem. Consider the following figure which shows the locations of soil moisture, temperature and rainfall measurement equipment in the Goulburn River catchment near Newcastle (NSW). This information is gathered as a part of the SASMAS project[2].

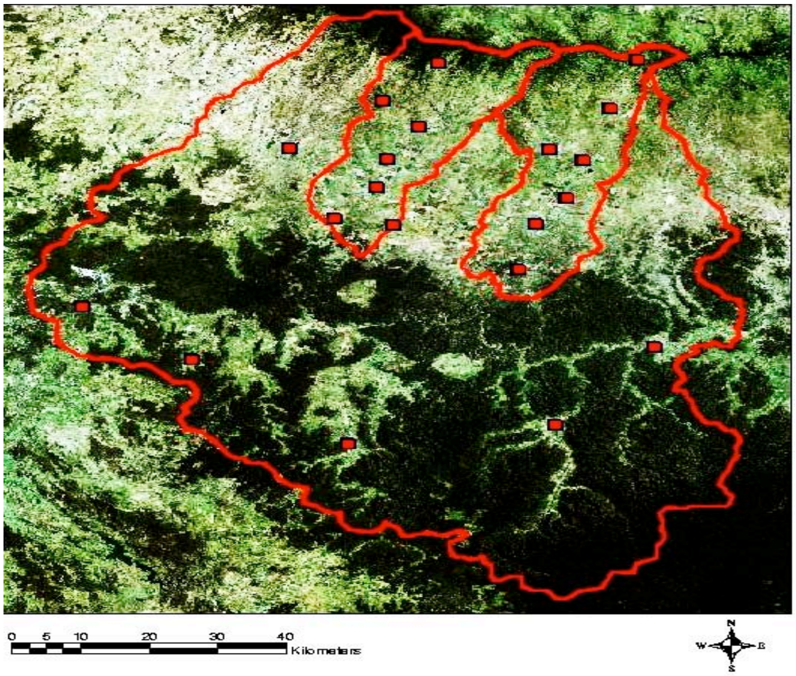

Figure 6. The SASMAS project in the Hunter Valley NSW. The red spots show the locations of hydrology diagnostic stations. Currently these are serviced in most cases by GSM modems but the five most southern diagnostic stations are inaccessible.

In this telemetric application data has to be retrieved from some fairly isolated locations typically separated from each other by about 40 kms. The mesh network concept presented above could be applied here and to many similar telemetric applications to pipe low bandwidth data from site to site back to an aggregation point.

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[2] (http://www.eng.newcastle.edu.au/sasmas/SASMAS/sasmas.htm)

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