DESERT KNOWLEDGE CRC

Sparse ad hoc networks for the desert

Mehran Abolhasan
Tony Eyers

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University of Wollongong
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Abbreviations/Acronyms

2.5G	Generation 2.5
3G	3rd generation
ACA	Australian Communications Authority
ADSL	Asymmetrical digital subscriber line
AODV	Ad-hoc on-demand distance vector
ATM	Asynchronous transfer mode
ATSIC	Aboriginal and Torres Strait Islander Commission
CBR	Constant bit rate
CDMA	Code division multiple access
DCF	Distributed coordination function
DRCS	Digital radio concentrator scheme
DSSS	Direct sequence spread spectrum
GPRS	General packet radio service
GSM	Global system for mobile communications
HCRC	High capacity radio concentrator
HMAN	High-powered multi-radio ad hoc node
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet protocol
ISDN	Integrated services digital network
ISM	Industrial, scientific and medical
LAN	Local area network
LMDS	Local multipoint distribution service
LOS	Line of sight
MAC	Media access control
MANET	Mobile ad hoc network
MMDS	Multichannel multipoint distribution service
OLSR	Optimised link state routing
P2P	Point-to-point
PBX	Private branch exchange
PDA	Personal digital assistant
PDR	Packet delivery ratio
ping	Packet InterNet Groper
PSC	Partially serviced settlement
PSTN	Public switched telephone network
QoS	Quality of service
RF	Radio frequency
SAND	Sparse Ad hoc Networks for Desert
STD	Subscriber trunk dialling
SOPHI	Sparsenet's outback phone and Internet
TAPRIC	Telecommunications and Action Plan for Remote Indigenous Communities
TCP	Transmission control protocol
TITR	Telecommunications and IT Research Institute at the University of Wollongong
UDP	User datagram protocol
UHF	Ultra high frequency
URAC	University Recreation & Aquatic Centre
VoIP	Voice over IP
WAN	Wide area network
WCDMA	Wideband CDMA
WLAN	Wireless local area network

1. Executive summary

Providing telecommunication services to remote communities of Australia has proven to be a challenging task both for the Australian Government and the telecommunications industry. Large distances and sparsely populated settlements have limited the deployment of current broadband technologies because of the cost and the insufficient return on investment to recover and maintain the advanced networking infrastructures. In early 2000, a number of different inquiries identified that the gap between the service provision in remote and metropolitan areas has increased and there is a real need for technologies that can provide broadband-type services to remote regions with low initial deployment and maintenance costs.

The Sparse Ad hoc Network for Desert (SAND) project is an initiative of the Desert Knowledge CRC and the University of Wollongong. It started in July 2004. The aim of the project is to develop and provide cost-effective and innovative telecommunications technologies for the remote and rural settlements of Australia. In this document, we provide a summary of the achievements and activities of the project to September 2006.

The initial focus of the project was based on developing cost-effective voice and data services for remote Aboriginal settlements. This included a major field study based on the telecommunications requirements of the Ngaanyatjarra settlements in Western Australia. From this, and an extensive desktop study based on a number of regional telecommunication inquiries, we identified a number of service requirements such as access to cost-effective and higher capacity data networks.

We then studied the types of technologies that could be used to address the identified service requirements. This included a desktop study of a number of emerging networking technologies such as ad hoc networks and the 802.11 radio technology, and a number of simulation studies to predict their performance in sparse desert conditions. The studies showed that ad hoc networking technologies based on the 802.11 radio could be combined to design new telecommunications hardware to address a number of the service requirements identified.

To further investigate this new concept, we developed a prototype networking device called Sparsenet's Outback Phone and Internet (SOPHI). SOPHI provides residential voice and data service, which allows users to make direct voice calls without connecting to a base station. The voice service is based on the popular Voice over IP technology which is commonly used to make cheap long distance calls. SOPHI also provides a broadband data port, which can be used to connect end-user nodes to the Internet.

We also developed a number of other prototypes to provide long-range network connectivity. An example is the High-powered Multi-radio Ad hoc Node, which combines the idea of ad hoc networking with high-powered radio devices to create a backbone network.

In Chapter 2 of this report, we present the project background and a summary of our achievements to September 2006. In Chapter 3, we present the findings of a case study on Ngaanyatjarra settlements; the case study identifies a number of key telecommunication requirements in that region. In Chapter 4, we summarise the telecommunication service requirements based on our desktop and field studies. In Chapter 5, we describe candidate technologies for addressing the telecommunication service requirements identified. We present a theoretical study of the candidate ad hoc networking technology in Chapter 6. We illustrate the application of the candidate ad hoc network technology over various types of networking scenarios in Chapter 7. And in Chapters 8 and 9, we describe the performance of the ad hoc networking prototypes developed in this project.

2. Background and summary of achievements

2.1 Background

Ad hoc networking is a relatively new area of telecommunications research. It allows the creation of telecommunication networks in an unplanned fashion. An ad hoc network aims to provide services over a network that is created by the ad hoc placement of networking devices. It consists of unreliable (due to power supply or movement) network devices, and may consist of moving network devices. Much of the existing research in the area aims to make these networks more reliable and cope automatically with movement or failure of networking equipment. This makes these networks particularly suitable for remote desert settlements, where installation of fixed infrastructure is expensive, maintenance is difficult, and the harsh environmental conditions can cause frequent equipment failures. Ad hoc networks are designed to be used where no infrastructure exists or to extend the reach of existing infrastructure.

Recently, there have also been several significant advances in the capabilities and capacities of digital wireless links. This has been driven by the need for broadband wireless access and fourth generation mobile Internet access services. These new wireless technologies are likely to follow the lead of the current generation of digital wireless (802.11) and become cheap (<$10 for a radio) due to the large market and mass-production manufacturing techniques.

This project intends to use experience in both of these emerging telecommunications areas and apply them to solving telecommunications problems in remote desert settlements in Australia – areas where cost-effective installation, low maintenance, and fault tolerance are important characteristics of telecommunications equipment.

2.2 Research team

Table 2.2.1: Research team

Name	Affiliation
Dr Mehran Abolhasan (Project Leader)	University of Wollongong
Ms Alyson Wright	Centre for Appropriate Technology
Dr Tony Eyers	University of Wollongong
Mr Daniel Franklin	University of Wollongong

Dr Mehran Abolhasan from the University of Wollongong is leading the Sparse Ad hoc Network for Desert (SAND) project. The project team consists of researchers from the University of Wollongong and the Centre for Appropriate Technology in Alice Springs. The research team in Wollongong has significant expertise in wireless and ad hoc networking. Their research and development in this area is internationally recognised through high quality publications, they have industry experience, and strong collaborative links with other universities and with industry. The researchers from the Centre for Appropriate Technology have significant experience in developing systems and devices suitable for remote and desert conditions. The centre also has close relationships with a number of remote Aboriginal settlements. This enabled the SAND project team to perform on-field studies and gather useful data to develop new telecommunications devices for remote settlements.

2.3 Project summary and achievements

In its first two years starting in July 2004, the SAND project had four phases (see Table 2.2.1). The project is now in Phase 3.

Table 2.3.1: Objectives for the first two years of the SAND project

Phase	Objectives
1	Report on the characteristics of unserviced settlements. Provide initial specifications of one or more remote settlement communication services suitable for these areas. Describe candidate technologies for future study. Propose a minimum level of service/performance to effectively provide the remote settlement with communication services.
2	Compare candidate technologies (using simulation/analytical and practical techniques where appropriate) – concentrate on capabilities/cost/performance. Describe network architectures based on candidate technologies that will meet the minimum level of performance for the services described in Phase 1. Identify research gaps and issues. Make a statement of feasibility: 'Is it feasible to meet the minimum levels of service identified in Phase 1?'
3	Document the performance of a test-bed (trial) implementation of the service and infrastructures described in Phase 2. Report on infrastructure costs for candidate network architectures.
4	Describe outcomes of comparative studies and test-bed experiences and make recommendations. Plan for deployment of a pilot study in desert settlements.

In Phase 1, we documented in detail the characteristics of unserviced remote Aboriginal settlements and we described a number of emerging technologies that would address the telecommunications requirements of these settlements. To identify the specific needs of a remote Aboriginal settlement in need of service upgrades, we did a case study on the Ngaanyatjarra settlements in Western Australia. As part of the case study, the SAND project team travelled to Ngaanyatjarra to get a clear understanding of the requirements. We identified a number of services that may provide improvements over the existing forms of communications infrastructure and services, in and between the Aboriginal settlements of Ngaanyatjarra. These include:

- digital voice services (Voice over IP) that would improve capacities of existing inter-settlement infrastructure
- ad hoc style voice networks in settlements, which would reduce major capital infrastructure requirements in the settlements and allow houses or other buildings to be connected quickly to a phone network using emerging wireless networking and physical layer techniques
- improved services similar to the popular UHF repeater service in the Ngaanyatjarra; the improved service aims to allow wider deployment of the service and reduce congestion on the shared communication channel by providing means to restrict the broadcast.

In Phase 2, we described the types of technologies that could be used to develop new telecommunications infrastructure for the remote Aboriginal settlements. We developed a new technology, referred to as an 'ad hoc node', which aims to provide both residential voice and data access. We described a number of different ad hoc node architectures, which were candidates for use in our Phase 3 test-bed study.

In Phase 3, we compared the proposed ad hoc networking technology with a number of existing telecommunications strategies. We focused on the cost benefits, and the availability and the capability of each technology. As an initial study of the performance of ad hoc networks, we simulated the behaviour of an ad hoc network under strict conditions. Our simulation results indicated that ad hoc networks should provide sufficient level of performance to handle the bandwidth requirements of proposed services, such as Voice over IP (VoIP). In this report, we present a number of network architectures based on our proposed candidate technologies. These architectures may provide the telecommunications infrastructure required for the services proposed in Phase 1. We outlined a number of research areas and issues which may be addressed over the course of this project. We also provided a statement of feasibility based on our Phase 2 studies. We summarised the ability of our proposed ad hoc network models, as described in this report, to meet the service requirement outlined in Phase 1.

To achieve the major milestones of Phase 2, we took on extra initiatives to increase the capacity and awareness of the SAND project. These included submitting two applications to the University of Wollongong for infrastructure grants, to increase the capacity of the project to investigate the technologies that will underpin our prototype network. We proposed using these grants to develop a wireless ad hoc network laboratory and ad hoc network emulation cluster. The wireless ad hoc network grant application was successful, and we received $53 000. The equipment will significantly broaden our experimental capacity in the SAND project.

In February 2005, we presented the objectives and the achievements of the project at the Desert Knowledge CRC conference, and submitted our simulation and analytical studies to two international conferences and a journal. Our work on our visits to Ngaanyatjarra has been published as a case study in a book called *Indigenous People and Information Technology* (Abolhasan & Boustead 2007). We have presented the project to the Telecommunications and IT Research (TITR) Institute at the University of Wollongong. We also issued a media release in June 2005, which resulted in articles in newspapers such as The Sydney Morning Herald, and interviews with several ABC radio stations.

In Phase 3, we developed the first prototype ad hoc networking device – the Sparsenet's Outback Phone and Internet (SOPHI). We have successfully trialled the current version of SOPHI – SOPHIv1 – at the TITR labs. To investigate its performance, we developed three different nodes. These nodes can interconnect to analogue telephones to provide real-time voice calls. They also have a data port which can be used to access the Internet. We designed SOPHIv1 to operate using 12-volt DV power, which requires up to a maximum of 12 watts to operate. We have successfully trialled the SOPHI nodes using DC power supply and rechargeable batteries. In Phase 3 we also developed weatherproof and durable cases for the nodes; we investigated the benefits of various wireless technologies and devices such as different programmable wireless routers and radios as a development platform for SOPHI; we investigated various ad hoc multi-hop routing protocols; we developed and bought various types of antenna technologies; and we tested SOPHIv1 using 5-dBi omni-directional antennas. We plan to investigate the performance of the ad hoc nodes using higher-gain antennas, particularly those designed in the TITR labs.

We issued another media release from the University of Wollongong. This resulted in coverage in various newspapers (such as the *Illawarra Mercury* and *The Australian*) and an interview on Illawarra's i98 FM radio station. We also received interest from other organisations such as Centrelink in South Australia which may collaborate with the SAND project in the near future. We were invited to submit an article to *The Mining Chronicles* magazine (Abolhasan 2005), describing the potential benefits of ad hoc networks for mining; the article appeared in the November 2005 edition.

In Phase 4 we developed a backbone node called the High-Powered Multi-radio Ad hoc Node (HMAN). This device provides point-to-point long-range data connectivity over multiple hops. It can also become part of a mesh network, which could consist of multiple HMANs and other 802.11-based networks. The key benefit of its mesh networking capability is its ability to provide wireless coverage beyond the range of a typical wireless access point. The nodes also automatically determine routes within their network. This means they can be deployed or installed in buildings, and users can instantly connect to any existing mesh network. Other benefits of this device include broadband network connectivity. The current implementation of the HMAN can provide data links of up to 54 megabits per second, which is enough to drive real-time voice, video applications and other Internet type applications.

We performed a field study based on the remote desert settlements located along the Plenty Highway in Central Australia. From this study, we identified links between the service requirements in our previous study (in Ngaanyatjarra) and the requirements of the Plenty Highway settlements. Further studies may be undertaken during the second stage of the SAND project to plan for a pilot study of prototype devices in these settlements.

3. Remote settlement telecommunications case study

3.1 Background

In this chapter, we describe a case study of telecommunications issues in the Ngaanyatjarra lands. The insights we gained from this study underpin our definitions of serviced (and unserviced) remote settlements, which we describe in Chapter 4.

The 2002 Regional Telecommunications Enquiry attracted a large number of submissions from settlements, telecommunications service providers, and other interest groups. A particularly strong submission was prepared by Ngaanyatjarra Council, which outlined clearly the history and current problems with telecommunications service in its region, and proposals for addressing identified problems. The Ngaanyatjarra Council successfully applied for Networking the Nation funding for a settlement UHF network which is widely used.

The relatively well organised telecommunications infrastructure at Ngaanyatjarra, and in particular, the UHF network experience, made Ngaanyatjarra a strong candidate for a productive case study. We particularly anticipated that learning of the success (and failures) of specific telecommunications projects would help to form the new initiatives arising from this project.

3.2 Information collection strategies (Phase 1)

One of our main objectives in Phase 1 of this project was to understand the telecommunication service requirements of Aboriginal settlements, and to suggest different types of services that would improve the telecommunication and information flow in and between each settlement. To achieve this goal, we required the following information:

- types of telecommunications services now in use
- telecommunication technology now in place
- flaws in the current telecommunication technology
- types of telecommunications services that are experiencing heavy usage
- types of information being shared
- population density of the settlements
- distance between the settlements
- coverage of current telecommunications services
- the uptake of current technologies in the settlements
- future plans and rollouts of new technologies and services.

Our study focussed on the Ngaanyatjarra settlements, as they represent a remote Aboriginal region of Australia that contains a number of small settlements with various telecommunications service requirement and issues.

To gather the required information, we used the following strategies:

- On-site study: We travelled to the Ngaanyatjarra settlements to investigate the current telecommunication infrastructure.
- Review documentation: We reviewed the publications and documentation on related work performed by government organisations and private industry.
- Interviews: We interviewed operational personnel in the Ngaanyatjarra settlements.

Figure 3.2.1 illustrates the strategies we used to determine the telecommunications requirements of remote Aboriginal settlements of Ngaanyatjarra.

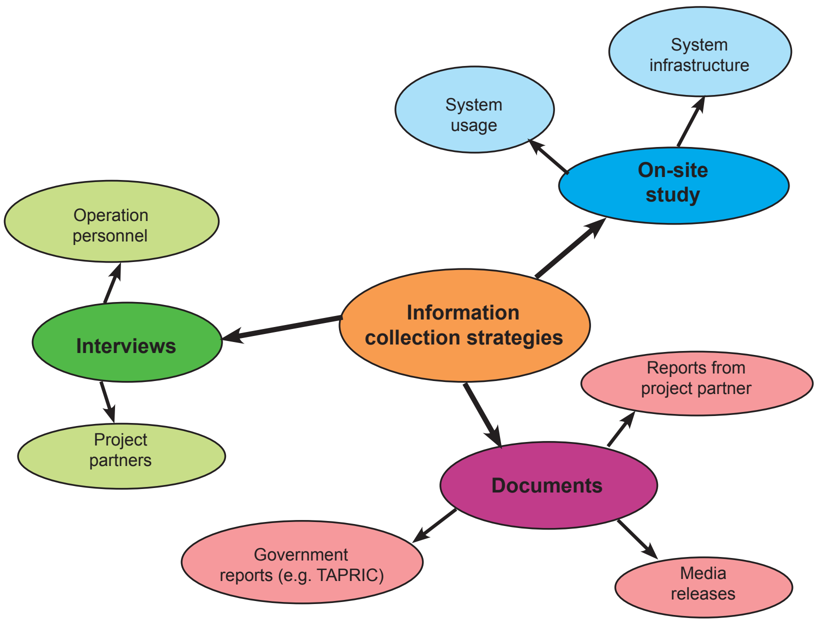

Figure 3.2.1: Information collection strategies

3.3 Case study: Ngaanyatjarra settlements

The Ngaanyatjarra land is located in the Gibson Desert in the state of Western Australia (see Figure 3.3.1). It is home to 12 major Aboriginal settlements. These settlements are spread over 250 000 square kilometres and their populations range from 75 to 450.

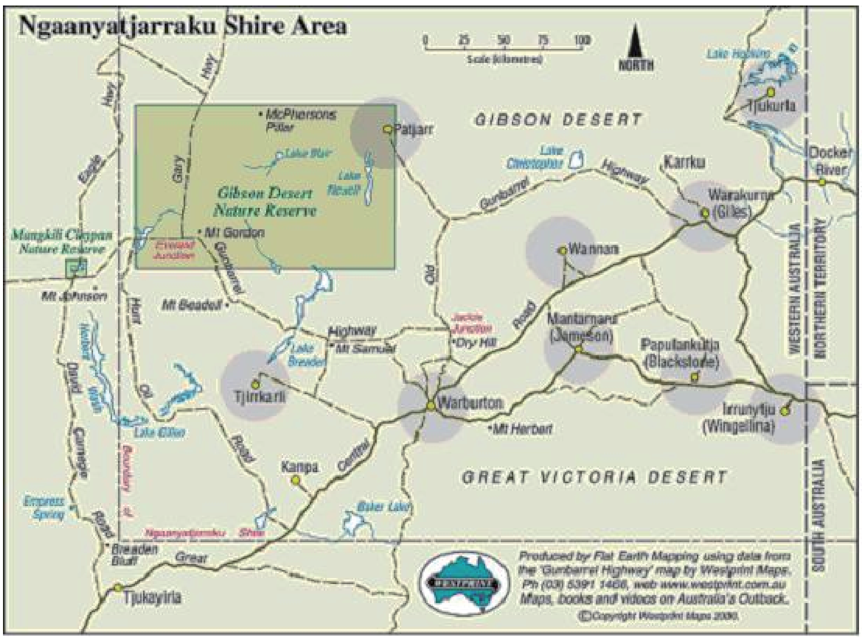

Figure 3.3.1: Location of the Ngaanyatjarra lands and settlements

The remote location of these settlements from major rural areas has limited the rollout of advanced communication technologies. This has been due mainly to the high costs associated with providing and maintaining new types of telecommunications infrastructure over a large geographical area with sparse population densities. The following section lists the infrastructures which have been implemented in the region to date:

3.3.1 Digital Radio Concentrator Scheme system

Until the late 1980s, the main telecommunications in Ngaanyatjarra were a Telstra radio telephone and a high frequency (HF) radio used by the Flying Doctors. A solar-powered Digital Radio Concentrator Scheme (DRCS) system was introduced in the late 1980s to carry voice and low-speed data (2.4 kilobits per second) for the Ngaanyatjarra settlement. The DRCS system was designed to provide 127 lines, with a maximum of 13 repeaters per line. Repeater stations were placed every 40–50 kilometres, covering a distance of 600 kilometres between end users and the exchange. The Ngaanyatjarra settlements were connected to four different exchanges. The Wingellina, Blackstone, Jameson, Warburton, Kanpa and Tjirrkarli settlements were serviced by an exchange in the Pitjantjatjara lands. Warakurna, Tjukurla and Wanarn were connected to an exchange in Uluṟu. The Cosmo Newberry settlement was serviced by the Laverton exchange and the Kiwirrkurra settlement was serviced by the DRCS exchange at Papunya in the Northern Territory.

The system failed to provide efficient communications in the Ngaanyatjarra lands. This was evident from the date the system was configured. By the mid-1990s, the problems became worse as usage increased.

The Shire of Ngaanyatjarraku and Ngaanyatjarra Council (Aboriginal Corporation) described a number of shortcomings in a submission to a regional telecommunications inquiry (2002):

- The system had to cover more distance than it was supposed to according to its design specification.
- The system did not provide enough telephone lines throughout the Ngaanyatjarra settlements.
- Solar power for the system was constrained by the availability of sunlight. In overcast conditions, the solar-powered batteries ran out of power after two or three days of use.
- The system lacked reliability. The DRCS frequently broke down or experienced failed connections.
- The system suffered from clicks, echoes and drop-outs.
- The system could not handle Internet-type application and data exchange. Even low bandwidth intensive applications such as facsimile struggled to operate efficiently.

To address some of the shortcomings, Telstra proposed providing optic fibre connections to Wingellina and Blackstone. They also removed the Warburton settlement from the DRCS network and provided them with a Rapid Switching Stage exchange connected to a satellite station. The satellite system was promoted as a temporary solution for Warburton and it was to be replaced with a fibre optic cable extended from Blackstone. However, this upgrade did not occur.

3.3.2 High Capacity Radio Concentrator system

Similar to the DRCS system, the High Capacity Radio Concentrator (HCRC) system is a microwave radio technology which transmits radio signals using chains of radio towers, equipped with point-to-point and/or point-to-multi-point antennas in a relay system. It provides high-capacity voice services, and facsimile and dial-up data services of up to 19.2 kilobits per second. It also provides advanced call handling functionalities such as call return, caller ID display and three-way chat.

The HCRC system provides higher capacity (8–10 times greater) than the older DRCS system. It also reduces congestion during busy times and has higher service availability. During the construction of the HCRC, two different types of HCRC system were rolled out in the extended zones. The main HCRC technology is referred to as the HCRC Swing. The system availability, or uptime, of the HCRC Swing is 99.5% (Australian Communications Authority 2002).

3.3.3 Settlement UHF-based voice communication system

The UHF network, a project initiative of the Networking the Nation fund, was established in 1997 to provide an alternative networking strategy to the existing HF radio. The HF radios were unreliable and not very mobile due to the bulky transceivers. This restricted their use to vehicles and stations. The UHF radios brought better mobility and flexibility through smaller handheld devices. These devices have proven to be very popular as they provide a cost-effective and easy to use personal communication solution.

The settlement UHF network operates over 18 repeater towers (see Figure 3.3.3.1) and provides coverage to all Ngaanyatjarra settlements except for Kanpa and Tjukurla. The UHF towers increase the area of coverage of the network, allowing people to communicate in ranges of up to 50 kilometres.

Figure 3.3.3.1: UHF repeater tower at Warakurna settlement

Each Ngaanyatjarra settlement now has a dedicated UHF channel which people use to communicate within their settlement and to other interconnected (via repeater towers) settlements. For example, in Warakurna the UHF channel 1 is used for talking to other settlements.

The UHF network is heavily used by the locals – people in the settlement talk over the top of each other on the same channel. Private communication links between end users are not provided by this system.

3.3.4 Untimed local calls in extended zones

Untimed local calls were agreed to by the Australian Government and Telstra to reduce the cost of phone calls in remote regions of Australia, commonly referred to as extended zones (see the shaded area in Figure 3.3.4.1). Extended zones consist of those regions that fall outside Telstra's standard call charging. Most of Australia's Indigenous settlements, including those in Ngaanyatjarra, are in extended zones.

The untimed local call agreement has reduced the cost of phone calls as follows (TAPRIC 2002):

- Within each extended zone and between adjacent extended zones, the cost of each call is 22c or less.
- Calls between extended zones and their 'settlement service town' and adjacent settlement service towns are reduced to 27.5c per 12 minutes.
- Access to at least one Internet service provider is the same as the cost of an untimed local call.

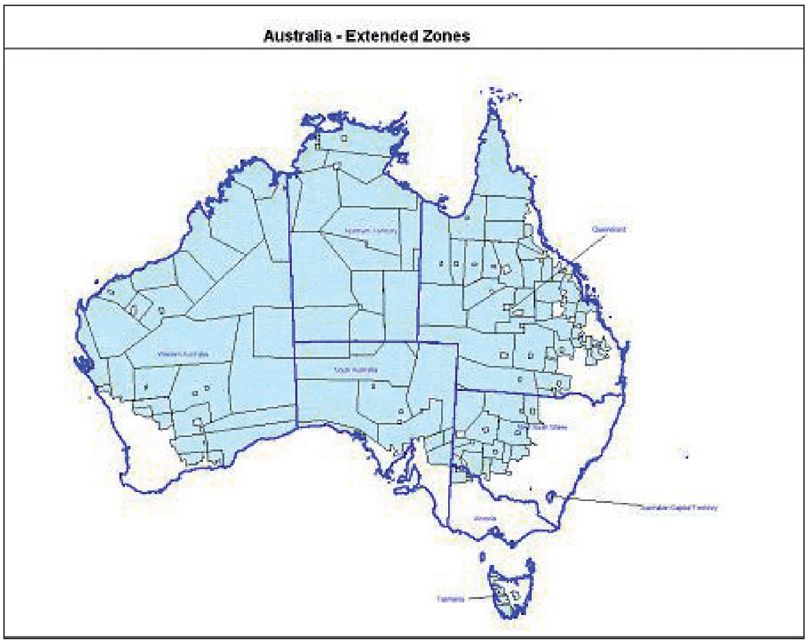

Figure 3.3.4.1: Extended zones of Australia

3.3.5 Two-way satellite Internet service

Under the Universal Services Obligation, Telstra offered (offer has now expired) all customers in the extended zones a two-way satellite system; based on a pricing scheme ranging from $16.95 to $60.50, the data rate ranged between 33.6 and 400 kilobits per second for downloads and between 33.6 and 64 kilobits per second for uploads. Under this scheme, remote Indigenous settlements were provided with free satellite equipment and installation.

The advantage of the satellite system is that it does not have the dial-up call charges and the connection is 'always on' as long the computer is turned on (Australian Communications Authority 2002).

Two-way satellite Internet service was provided to the Ngaanyatjarra settlements (including Warburton and Wingellina) as a temporary solution until other solutions such as the HCRC system and/or fibre optics are provided.

3.3.6 Proposed upgrades

3.3.6.1 The Coordinated Communications Infrastructure Fund

The Coordinated Communications Infrastructure Fund is an Australian Government initiative to fund broadband infrastructure projects that aim to improve the delivery of services such as health, education and other government services in remote Indigenous and regional areas of Australia. The fund supports projects that aim to develop new network infrastructure or enhance the functionalities of existing networking infrastructures.

3.3.6.2 The iConnect project

The iConnect project is a PY Media initiative that subsidises the provision of fixed personal voice communications service for remote Aboriginal settlements. Under the iConnect scheme, customers can buy a telephone handset and a phone card for $25. The advantage of this telephone service is that the phones are card operated, which means that people can monitor and control the amount of money they spend on their calls.

iConnect also arranges and funds the cost of trenching and the delivery of the handsets.

iConnect provides handsets on request. However, applications for new requests are now closed. iConnect is in the process of provisioning services for 945 requests (PY Media 2007).

3.3.6.3 Other upgrades

A number of other upgrades planned for the Ngaanyatjarra settlements include:

- extending the UHF network coverage to the Kanpa and Tjukurla settlements
- providing a fibre optic extension for Warburton, which is still using two-way satellite Internet service; due to the high costs associated with the fibre optic extension, this upgrade is still under consideration.

3.3.7 Desired upgrades

The iConnect project requires upgrades to a number of existing Telstra exchanges to provide more landlines for residential telephones. Telstra has stated that they are holding off on the exchange upgrades until the Coordinated Communications Infrastructure Fund project is completed.

Other desired upgrades include:

- Higher quality voice/video services between settlements

This service would provide better interaction between the settlements. For example, in Ngaanyatjarra the Wingellina settlement could receive help from other settlements with operating the Ngaanyatjarra radio and TV stations.

- Private chat lines for the UHF network

  The UHF network in Ngaanyatjarra is experiencing significant levels of congestion due to the unavailability of this service.

- Extensions to the UHF network to other settlements or regions

  The UHF network is not available to all settlements in Ngaanyatjarra.

- Video conferencing between settlements and to other regions

- User-friendly and simpler hand-held devices for communications in and between settlements

  For example, the operation of the UHF handheld devices used in the Ngaanyatjarra settlements is not well understood by everyone.

3.3.8 Summary of service availability and requirements

Table 3.3.7.1 lists the types of services available now in the Ngaanyatjarra settlements. This data was collected in October 2004.

Table 3.3.7.1: Telecommunications service availability in Ngaanyatjarra settlements

Settlement***	Fixed residential voice *	Fixed residential dial-up Internet	CDMA / GSM mobile	Pay phone	Settlement broadband Internet centre	UHF radio network
Warburton	No	No	No	Yes	Yes **	Yes
Warakurna	No	No	No	Yes	No	Yes
Tjukurla	No	No	No	Yes	No	No
Wingellina	No	No	No	Yes	Yes	Yes
Blackstone	No	No	No	Yes		Yes
Tjirrkarli	No	No	No	Yes	No	Yes
Jameson	No	No	No	Yes	No	Yes
Patjarr	No	No	No	Yes	No	Yes
Wanarn	No	No	No	Yes		Yes
Kanpa	No	No	No	Yes		No
Kiwirrkurra	No	No	No	Yes	No	Yes
Cosmo Newberry	No	No	No	Yes	No	Yes

* The iConnect project is proposing to provide residential telephones. Furthermore, some settlements may already have a limited number of home phones.

** Access to the Internet is provided at the Shire of Ngaanyatjarraku office.

*** As at July 2007, Telstra has won a contract to provide broadband services to Warburton, Jameson, Blackstone, Wingellina, Wanarn and Warakurna. This project is expected to be completed in 2008.

From the table, we see that in the Ngaanyatjarra settlements, lack of access to residential-based telecommunications services such as residential telephone service remains an unresolved issue. The iConnect project is now introducing a number of residential telephone services to these settlements. However, many settlements have missed out on this opportunity as the offer has expired. Furthermore, the telephone exchanges in some of these settlements do not have the capacity (lines) to accommodate all landlines requested by the settlement residents.

The settlement UHF network has been a great success in these settlements as it provides an alternative mode of communications to CDMA and GSM mobile phones used in rural and metropolitan areas. The advantage of the UHF network is that it is free of charge to users, except for the cost of the handset. However, it is experiencing significant levels of traffic as all settlement members talk over the top of each other on the same channel. The current UHF network does not provide private channels for individual users.

Settlement broadband Internet centres attempt to increase interest in information technology and to encourage self-education in remote Aboriginal settlements. In Wingellina, the new settlement Internet centre is very popular. However, Internet centres are not yet available in most of the Ngaanyatjarra settlements. This is due to the high cost of using the two-way satellite systems, which currently is the only broadband Internet option for many of the settlements in Ngaanyatjarra.

4. Communications service requirements and plans for remote Indigenous settlements

4.1 The need for better services

Following a number of different studies performed by the Australian Government in 2002 (TAPRIC 2002; Shire of Ngaanyatjarraku and Ngaanyatjarra Council 2002; ATSIC 2002; Northern Territory Government 2002), it was apparent that the telecommunications infrastructure in most remote Indigenous settlements of Australia was inadequate. In particular, these studies found that a significant number of these settlements do not have basic communication services such as public telephones.

Other services that the studies identified as inefficient or non-existent include:

- private voice services (private home telephones and mobile telephones)
- Internet services
- messaging between settlements; emailing
- video conferencing.

These services improve and/or provide:

- make data such as medical information more accessible
- support distance learning and encourage education
- provide new employment opportunities
- encourage tourism and boost local business
- support law enforcement
- increase people's awareness of 'the outside world', with news and media.

4.2 Definition of serviced and unserviced settlements

We can categorise remote Indigenous settlements into four groups with different levels of service availability:

- fully serviced
- connected
- partially serviced
- unserviced.

We define a serviced settlement to be one that has adequate and reliable voice and Internet services. At a minimum, it can facilitate voice communication to individual users within settlements and can deliver Internet applications such as email and web browsing at dial-up speeds. Serviced settlements can be classified into two different groups: fully serviced and connected settlements.

The fully serviced settlements are those with access to fixed and mobile communications services provided to rural or metropolitan areas with similar or comparable speed and quality.

The connected settlements are those with access to fixed voice and dial-up but not mobile services (such as CDMA). Furthermore, the speed and the quality of the voice and data services may be lower than those provided to fully serviced settlements, i.e. the connected settlements may be using outdated technologies.

Settlements without access to both voice and Internet can be classified as partially serviced settlements and unserviced settlements. A partially serviced settlement has basic communications facilities, which are connected to a major telephone exchange or an infrastructure connected to the Internet. We define a partially serviced settlement as one with at least one payphone.

Unserviced settlements are those that lack basic communication facilities that can link them to a major telecommunications infrastructure (e.g. payphones).

Table 4.2.1 illustrates the types of services which may be available for serviced, connected, partially serviced and unserviced settlements.

Table 4.2.1: Classification of serviced and unserviced settlements

Services	Fully serviced	Connected	Partially serviced	Unserviced
Fixed residential voice services	Yes	Yes	No	No
Residential dial-up Internet	Yes	Yes*	No	No
Broadband residential access	Yes	No	No	No
CDMA / GSM mobile	Yes	No	No	No
Payphone	Yes	Yes	Yes	No
Settlement broadband Internet centre	Yes	Yes	Yes	No
Settlement radio network	N/A**	Yes/No**	Yes	No

* Some settlements may have low-speed dial-up Internet access, such as that provided via the DRCS (Digital Radio Concentrator Scheme).

** These settlements do not necessarily need a UHF network as they have access to residential voice and dial-up; however, the UHF network may help remote settlements keep in touch with other settlements in the region for low cost.

The Ngaanyatjarra settlements are somewhere between partially serviced and connected. There are a small number of residential voice services in some of the settlements; however, this is not widespread and there are many applications with the iConnect program for such services. From our discussions with Ngaanyatjarra settlement members, we learnt that some of these connections will have to wait for increased capacity in the backbone infrastructure that connects the settlements, and for upgrades to telephone exchanges in settlements. In addition, the UHF repeater service would benefit from extensions to more settlements and possibly to surrounding regions.

5. Candidate technologies for providing the proposed services

5.1 Overview

Based on our review of existing remote settlement telecommunications, particularly those in the Ngaanyatjarra settlements, any potential services or infrastructure must address three key problem areas:

1. high cost of installing the service (e.g. trenching)
2. high cost of using the service (i.e. call charges)
3. capacity constraints (ability to facilitate current Internet type applications such as VoIP).

Here we review existing telecommunications technologies and identify candidates for developing new telecommunications services for remote desert settlements.

5.2 Technologies in use in remote settlements

Here we briefly review the telecommunications technologies that are now deployed in remote settlements. We identify key issues to provide context for the candidate technologies we examine in section 5.3.

5.2.1 CDMA

In 1999, the analogue mobile network was replaced by a CDMA network that had greater capacity and service quality. A key advantage of CDMA in rural and remote areas, compared to GSM, is its increased range. More recently, Networking the Nation funding has increased CDMA penetration in regional Australia, with 62 extra settlements to be provided with CDMA service by the end of 2006. These settlements have populations of more than 500. CDMA also provides mobile data capability, with faster data rates than dial-up rates.

Despite the success of the regional CDMA rollout, it is generally not viable for the smaller remote settlements considered in this project (i.e. with populations of 100 or less) due to economies of scale.

5.2.2 DRCS and HCRC

DRCS and the newer HCRC technologies are widely used for circuit-switched telephony and dial-up Internet in remote settlements. The major feature of these systems is the use of microwave links for backhaul, rather than the optic fibre used in urban networks. As outlined earlier in this report, a key problem with the DRCS system is limited capacity. The HCRC upgrade provides significantly higher call capacity and dial-up data rates (19.2 compared to 2.4 kilobits per second). However, the HCRC system is still based on circuit switching. The main disadvantage of circuit-switched voice communications compared to VoIP is its inability to share communication channels, i.e. a route/path is reserved for one user. Therefore, circuit-switched networks do not use the network bandwidth efficiently. In later sections, we discuss the potential cost and capacity improvements arising from VoIP deployment.

5.2.3 Satellite

Satellite underpins three key communication areas: TV broadcast, telephony and broadband service provision. Remote settlement communications using satellite TV is being considered by the companion Desert Knowledge CRC project 'Desert and Interactive Remote Television'.

While satellite telephony has ubiquitous coverage, the call rates, which exceed $1 per minute, preclude widespread use in remote settlements.

Partly due to Networking the Nation funding, there has been extensive rollout of satellite broadband in recent years. In particular, the Electronic Outback Project provided $3.5 million for satellite services for 14 remote Northern Territory settlements, while Optus was involved in a $7 million program for satellite broadband for Northern Territory schools. As a result, many larger remote settlements now have communal centres equipped with satellite broadband, either in educational or administrative facilities, or in public Internet centres. As outlined earlier in this report, some of the Ngaanyatjarra settlements have communal satellite broadband Internet centres.

While satellite is likely to remain the key technology for providing remote settlements with Internet service, there are capacity issues due to their limited monthly quota under the USO. For example, the Ngaanyatjarra settlements often exhaust their monthly download limit in the first few days of the month. So strategies are needed to ensure optimal use of satellite bandwidth. And while satellite broadband provides a data path between a remote settlement and 'the outside world', it can only be accessed via the PCs in the community Internet centre. A key objective of this project is to explore strategies to allow satellite broadband to underpin communications services accessible over a wide area in each remote settlement. In the following section, we describe technologies that may allow this.

5.2.4 UHF radio

As we described earlier, the Ngaanyatjarra settlement UHF radio, arising from Networking the Nation funding, is widely used. A major factor in its success is the low cost and relative simplicity of the handheld terminals. However, the single channel network has obvious capacity restraints and privacy issues. To overcome these problems, a more intelligent wireless system is needed, which retains the low cost and simplicity of the existing UHF one. A candidate technology with these capabilities is 802.11, which we describe below.

5.3 Candidate technologies for new services

The new services proposed in the previous chapters build on existing capabilities, e.g. satellite broadband, but will also require new technologies. Here we outline three candidate technologies, which may potentially underpin these new services. In particular we consider 802.11, a new wireless technology which may reduce substantially the installation cost of new services. The relatively limited range of 802.11 may be enhanced by the use of ad hoc networks, as described below. These technologies provided IP service capability to individual handsets (both fixed and mobile). We outline the capabilities of Voice over IP (VoIP), which can potentially use this IP capability to address the capacity and call cost issues with existing voice services, such as those delivered over DRCS and HCRC systems.

5.3.1 802.11 Wireless local area networks

Wireless local area networks (WLANs or Wi-Fi hotspots) provide broadband connectivity to mobile users within a few hundred metres of an access point; access speed is up to 54 megabits per second (802.11g). Each access point provides an interface between a wired network and mobile Wi-Fi devices.

Typical application of these networks includes:

- extending the connectivity of existing wired networks in an organisation or setting up a network infrastructure in buildings without a pre-existing wired network
- providing broadband network access to mobile users; Wi-Fi services are becoming common in public areas such as airports and cafes.

802.11 WLANs can cost-effectively increase the coverage of existing data networks. For example, in remote settlements such as those in the Ngaanyatjarra region, satellite broadband or fibre optics solutions may connect settlement or government centres to the wider network. Using 802.11, the coverage of these networks can be increased to provide Internet access and potentially voice services to mobile or residential users in the settlements. And 802.11 can be used with directional antennas and amplifiers to provide point-to-point access over tens of kilometres. This is potentially far cheaper than the existing point-to-point microwave links.

802.11 provides a shared capacity radio network located in the Industrial, Scientific and Medical (ISM) bands, which have been set aside for unlicensed wireless equipment. A key feature with 802.11 is that no licence fees apply for the ISM spectrum. A potential downside in urban areas is congestion in these (unregulated) 802.11 channels; however, this problem is not likely in remote settlements.

Unlike many technologies (e.g. ATM), 802.11's capabilities have met market needs, and it has been very successful. A key success factor is its economies of scale; 802.11 equipment is now at commodity prices, and prices are likely to fall further. So 802.11 infrastructure may well fit the limited budgets of remote settlements.

5.3.2 Infrastructureless (ad hoc) networks

Unlike cellular networks, infrastructureless networks (commonly referred to as ad hoc networks) provide connectivity without requiring a base station or centralised controller. In ad hoc networks, each end-user node can transmit, receive and route information to different parts of the network. So ad hoc networks may be deployed in environments where fixed infrastructure does not exist or cannot be installed. Some possible applications of ad hoc networks are:

- coordinating disaster recovery such as search and rescue missions in remote locations that lack telecommunications infrastructure
- for redundancy or as back-up networks; communication links in areas where a disaster has disabled the communications infrastructure
- as temporary infrastructure for exhibitions and conferences
- coordinating government services such as emergency services.

In the context of this project, ad hoc networks may extend existing wired or wireless infrastructure. For example, in remote desert settlements ad hoc networks may be set up to extend the reach of existing infrastructure. In particular, a communal satellite broadband Internet facility may connect to an ad hoc network, thereby reaching a greater range of users in the settlement.

5.3.3 Multi-hop mobile ad hoc networks

Mobile ad hoc networks (commonly referred to as MANETs) add mobility to ad hoc networks. Each user/node in the network is capable of transmitting, receiving and determining routes to different nodes over multiple hops. MANETs have introduced a number of challenging areas of research as the dynamic and wireless nature of these networks demands new and more sophisticated routing techniques compared to wired networks.

A MANET may extend considerably the range of a standard 802.11 network (currently several hundred metres from a fixed access point). In particular, a settlement populated with mobile devices, each having MANET capability, may provide a self-configured network, extending over several kilometres. This is potentially a powerful capability for remote settlements, and, in particular, may extend significantly the range and capability of existing UHF networks.

5.3.4 Ad hoc and wireless metropolitan area networking

The aim of the next generation of ad hoc and wireless networks is to provide connectivity over a metropolitan area and wide area. Two standards are being developed by different IEEE working groups – 802.16 and 802.20.

Within 802.16, two standards are being developed. The first is 802.16a (also known as WiMAX), which aims to provide wireless metropolitan area networking and last-mile broadband access over the 11-gigahertz frequency bands, to connect to businesses, homes and wireless LAN hotspots. The 802.16a networks will comprise devices mounted on top of buildings and roofs. One of their major advantages is the improvement in non-line-of-sight access over technologies such as optical devices and 802.11. They can also provide throughputs of up to 75 megabits per second. 802.16a products are expected to become available in late 2006.

The 802.16e standard is based on 802.16a, the key difference being that it aims to provide network access to mobile users (with slow to moderate mobility) with devices such as laptops and personal digital assistants (PDAs). The 802.20 (also referred to as Mobile Broadband Wireless Access) working group aims to design a networking standard to provide broadband access for high mobility users.

As part of this project, we will closely monitor the evolution of these new IEEE standards. However, equipment costs will greatly exceed those for 802.11, which will remain our focus at this stage of the project.

5.3.5 Voice over IP

Voice over IP (VoIP) standards have been under development for the last decade, and are now mostly in place. Key challenges have been to overcome inherent delay variations in IP networks, and to develop signalling mechanisms suited to IP multimedia services. Another major challenge has been to incorporate VoIP systems into the Public Switched Telephone

Network (PSTN). Initial VoIP products have appeared in enterprise networks to lower the ISDN costs associated with PBX interconnection. More recently, VoIP products such as Engin and Skype appear to be aimed at consumer markets. VoIP is also widely used for international voice calls.

VoIP allows a single IP network to provide both Internet and voice services. In particular, the efficiency of VoIP codecs (the algorithms used to encode and decode the conversation) potentially allows far greater call volumes than equivalent circuit switched systems. There is clearly potential for VoIP deployment in remote settlements, particularly in Ngaanyatjarra settlements, which experience capacity constraints with current circuit switched systems.

Once an IP network is established, the marginal call cost of individual VoIP calls is small and far less than existing PSTN rates. In particular, a VoIP system may underpin an intelligent local voice network, based on either fixed or mobile devices in a settlement (or group of settlements). However, VoIP is less practical over satellite broadband networks, given the inherent satellite delay.

6. A comparison of candidate technologies

6.1 Overview

Providing efficient yet cost-effective communication systems to remote Aboriginal settlements is a challenging task for two major reasons. The first reason is the population size and location, which often isolates these settlements from rural areas. Therefore, extending high-capacity telecommunication infrastructure to these settlements would incur high costs without significant financial returns. The second reason is the inability of most settlements to pay for new telecommunications services. Other factors inhibiting new telecommunications services are maintenance and administration costs.

Here we describe the functionality of these technologies, and discuss how they may be used together to provide a cost-effective and efficient networking solution for these settlements. We then compare the proposed candidate technologies to telecommunications technologies being used now in remote Aboriginal settlements. We also compare the candidate technologies with alternative solutions that provide similar levels of performance and services. We compare the transmission requirements, costs, performance and coverage of the technologies.

6.1.1 Transmission requirements

Table 6.1.1.1 illustrates the transmission requirements of each access technology in terms of the type of medium and the required infrastructure. The technologies in use now in desert settlements such as Ngaanyatjarra mostly comprise HCRC microwave networks, satellite and fibre optics (in a few settlements only). Technologies such as cellular networks, cable and ADSL are usually not available and may not be possible to implement. For example, ADSL requires each user to be close to the PSTN for providing broadband connections. Therefore, wireless technologies such as ad hoc networks and Multichannel Multipoint Distribution Service (MMDS) may be more viable options since they do not require trenching or a wired connection at the user end. Note that 'ad hoc networks' in this context refers to a multi-hop data network built on top of 802.11 radio technology.

Table 6.1.1.1: Candidate technologies: transmission paths and required infrastructure

Technology	Medium	Infrastructure
HCRC	Wireless	Microwave radio network
ADSL	Copper wire	Access through PSTN; close to exchange
Cable	Coaxial cable	Cable rollout to homes
Fibre optics	Fibre optic cables	Fire optic cable, mostly used as backbones
Satellite	one-way (direct to home and return over PSTN) two-way (direct uplink and downlink)	Geostationary satellite; low earth orbiting satellite network
Fixed wireless technologies	Wireless, Terrestrial RF transmission at 2.4–28 GHz + (LMDS, MMDS)	MMDS: 2.5–2.7 GHz RF transmission from a hub to end users LMDS: 28.5–29.5 GHz and 31–31.3 GHz RF transmission from a hub to end users
Ad hoc network	Wireless 2.4 GHz or 5 GHz	RF transmission between 802.11 network infrastructure, connected to a backbone
2.5G/3G Cellular network	Wireless	Cellular networks: GPRS, CDMA1x, WCDMA (3G)

6.1.2 Infrastructure and operations costs

Table 6.1.2.1 illustrates the operational and infrastructure costs that may be associated with each access technology when deploying in remote settlements of Australia.

Table 6.1.2.1: Candidate technologies: equipment and operation costs

Technology	Installation costs	Infrastructure costs	Service access fee
HCRC	End users must get connected to local switch	Infrastructure available in some locations	Voice: 22c for calls in extended (local) zone
ADSL	~ $100–$200 for activation; other costs include modem and filters	Not available in most remote regions; needs to be close to a PSTN exchange	Data: ~ $30–$130 depending on the plan. Excess charges of 15c/MB after quota (Telstra) Voice: VoIP call can be made 2c–10c
Cable	~ $200 installed by the provider	Not available in most remote regions	Data: ~ $30–$99, depending on the plan. Excess charges of 15c/MB after quota (Telstra) Voice: VoIP call can be made 2c–10c
Fibre optics	Professional installation usually used as a backbone by major organisations Very high set up costs	Only available in few settlements; could cost millions to roll out to other settlements	Mainly used to by large businesses and organisations; very high costs
Satellite	Phones: $500 to a few thousand Dish for home: ~ $300 professional installation for dish	Infrastructure available Satellite phone for voice For data and voice in houses, a dish is required	Voice: Sat phone ~ $1–$10/min depending on the network used Data: $17–$60 monthly (subsidised), ~ 27c/MB after quota limit is reached. Normally, $49–$500/month with 15c/MB for exceeding quota May run VoIP calls for 2c–5c
Fixed wireless technologies	Professional installation $100–$300	Higher-gain antenna, access point, costs can be a few thousand; more expensive than 802.11 equipment	Voice: 2c–10c for VoIP international or STD; free calls to other VoIP subscribers in local area Data: Not widely used/provided in Australia Similar types of technologies cost $15–$120/month (www.unwired.com.au)
Ad hoc networks	Can be done by user; professional installation $100–$300	Higher-gain antennas, ad hoc nodes (access points)	Voice: 2c–10c for VoIP international or STD home to home; free to other VoIP subscribers in local area Data: Depends on where services are received (e.g. backbone) Similar technologies cost $15–$120/month
2.5G/3G Cellular network	Mobile handsets can be ~ $500–$2000 each; must be in range of a cellular network	Not available in most remote settlements; very expensive to roll out infrastructure in remote regions	Access: $20–$149 (3 mobile) Voice: ~ 25c–$1/min Data: ~$4/MB Internet usage

From Table 6.1.2.1, we see that most of the high-bandwidth or mobile telecommunications technologies are not available in remote regions of Australia, mainly due to high infrastructure costs and poor return on investment.

The wireless technologies such as MMDS and ad hoc networking are more promising as the infrastructure costs are much less than for wired solutions. The cost of deploying an ad hoc networking infrastructure now would be much lower than using MMDS-type infrastructure. And an ad hoc networking architecture provides a multi-hopping mesh network infrastructure, which allows the network to grow cost-effectively with minimal re-design.

6.1.3 System performance

Table 6.1.3.1: Candidate technologies: performance

Technology	Downstream bandwidth	Upstream bandwidth	Various quality of service offered?
HCRC	19.2 kbit/s	19.2 kbit/s	No; mainly used for voice
ADSL	64 kbit/s–1.5 Mbit/s	10% less than downstream; usually varied from 64 kbit/s to 256 kbit/s	Yes; users can get various speeds and quality depending on the chosen plan
Cable	64 kbit/s–few Mbit/s	64 kbit/s–few Mbit/s	Yes; users can get various speeds and quality depending on the chosen plan
Fibre optics	Up to 40 Gbps	Up to 40 Gbps	Yes; provides highest level of performance; performance levels may be chosen based on an agreed contract between the user and the provider
Satellite	50 kbit/s–2 Mbit/s	64 kbit/s–1 Mbit/s	Yes; varied according to the chosen contract
Fixed wireless technologies	MMDS: Up to 10 Mbit/s LMDS: Up to 155 Mbit/s	MMDS: Up to 10 Mbit/s LMDS: Up to 155 Mbit/s	Yes; LMDS may be affected by various conditions, such as environmental conditions (e.g. rain)
Ad hoc networks	802.11g-based spec: Up to 54 Mbit/s	802.11g-based spec: Up to 54 Mbit/s	Emerging, under research; quality of service guarantees cannot be made yet
2.5G/3G Cellular network	2.5G: up to 144 kbit/s 3G: up to 384 kbit/s (mobile); up to 2 Mbit/s (fixed)	Up to 144 kbit/s; usually 64 kbit/s	No; speeds may vary depending on various circumstances, such as location

Table 6.1.3.1 illustrates the bandwidth capacity provided by each technology and their ability to provide various levels of quality of service. We see that that the performance of the current HCRC system is significantly less than that of other technologies. For example, HCRC bandwidth capacity is 19.2 kilobits per second, which is not sufficient for most Internet applications.

While fibre optic systems provide the highest bandwidth, they are not readily available to most remote Aboriginal settlements. Fibre optic systems are very expensive for remote Aboriginal settlements and generally require government subsidies to sustain them. Subsidies are often needed for satellite services too.

The cellular networks (2.5G/3G) have much lower available bandwidth than MMDS and the ad hoc networks based on the 802.11 radio technology. Both MMDS and ad hoc networks provide an order of magnitude capacity increase over cellular networks. Therefore, these technologies would seem more beneficial for remote settlements than cellular technologies.

6.1.4 Coverage

Table 6.1.4.1 compares performance of candidate technologies in terms of range and coverage provided. We see that the transmission range of ADSL and cellular networks is lower than that of other technologies. Both technologies achieve their best performance when their physical location is less than a few kilometres from the telephone exchange or base station. The range of cable and fibre optics is limited to the physical reach of the cables. These services are mostly available in metropolitan areas and do not provide mobile coverage. Wireless technologies, such as cellular and ad hoc networks, introduce the added flexibility of mobile coverage to a networked environment. This is mainly due to the relatively compact size of their networking equipment and antennas. Note that MMDS is mainly used for fixed wireless connections, due to the need for larger antennas and networking equipment.

Satellite technology clearly provides the best coverage compared to the other technologies outlined in this section. This technology is used in many remote Indigenous settlements in Australia. However, satellite communications may incur heavy usage costs. And the geostationary satellite service may not be suitable for real-time applications such as VoIP. Other alternatives, such as low earth orbiting satellites may be better suited for these applications. However, the access cost of these systems is much higher than the geostationary satellites. Therefore, satellite technology may not be suitable for providing telecommunications services to individuals in a remote Indigenous settlement. Instead, an individual satellite service may be shared by people in a settlement. For example, if a remote settlement organisation had access to a satellite network, it could use ad hoc network technology to cost-effectively extend this service to individual houses.

Table 6.1.4.1: Candidate technologies: transmission capability and coverage

Technology	Transmission range and reach	Availability	Mobile coverage
HCRC	50 km between each tower	Some Indigenous settlements have a HCRC network Not widely available yet	No
ADSL	Maximum wired range of 3–4 km between users and the exchange	Only near local exchanges; not available in remote regions	No
Cable	Physical reach of the cable network	Mostly metropolitan areas; not available in remote regions	No
Fibre optics	Physical reach of the cable	Where fibre cables have been extended or extended by request	No
Satellite	Very high range; requires line of sight (LOS) to the satellite network	Either one-way or two-way; available everywhere	No, except for satellite phones.
Fixed wireless technologies	MMDS: ~ 50 km (requires LOS) LMDS: ~ 3–8 km	Not widely available in Australia	No
Ad hoc networks	Outdoor: up to 60 km (requires LOS)	Not yet available	Yes; vehicles, users with mobile wireless devices
2.5G/3G Cellular network	Up to 10–15 km	Mostly in metropolitan areas	Yes

6.1.5 A summary of the comparative study

In section 6.1, we presented a comparative study of services being used in remote Indigenous settlements, the types of new telecommunications services being used in rural and metropolitan areas, and our proposed HMAN architecture. From this study, we see that existing telecommunications services such as the HCRC microwave radio system will not have enough capacity for Internet services and real-time applications such as VoIP.

Technologies such as fibre optics and satellite may require continual support from the Australian Government to be sustainable in the long term. And direct access to these services is not affordable for most members of remote Indigenous settlements. Instead, sharing these services using emerging wireless technology may be more appropriate due to the relatively low cost of infrastructure and deployment.

Technologies such as ADSL, cable modems and cellular networks are generally not available to remote Indigenous settlements, as the infrastructure requires major investment without significant returns.

Wireless technologies such as MMDS and ad hoc networks may be more beneficial to these settlements as their infrastructure is much cheaper than that of wired technologies. And using the multi-hop ad hoc networking architecture may bring the added flexibility of allowing the existing networks to be extended or shared with minimal interruption.

6.2 Simulation study of ad hoc networks

The ad hoc networks we are proposing in this project must provide adequate performance for the VoIP traffic. To investigate this, we did a simulation study using the GloMoSim network simulation package. We outline the key results of this study below.

6.2.1 Aim

The aim of our simulation study was to investigate the performance of sparse and dense ad hoc networks using 802.11 radio technology, with particular emphasis on whether these networks provide adequate performance for VoIP traffic.

6.2.2 Objectives

The objectives of the simulation study were to:

- determine the proportion of data packets lost for a variety of ad hoc network configurations; packet loss ratio is a key factor affecting VOIP performance
- determine the proportion of network capacity consumed by ad hoc network control traffic
- determine the end-to-end delay for a variety of ad hoc network configurations; delay is a key performance parameter as it directly affects perceived voice network performance.

6.2.3 Simulation model

To simulate the behaviour of ad hoc networks, we chose the GloMoSim simulation package. GloMoSim is an event-driven simulation tool specifically designed to simulate and investigate the performance of wireless ad hoc networks over various types of networking conditions and protocols. Here we outline the simulation model parameters we used in our study.

We performed the simulations for 20-node and 100-node networks, migrating in a 5000 metre by 3000 metre area. To emulate the behaviour of a radio device for ad hoc networks, we used the IEEE 802.11 Direct Sequence Spread Spectrum with maximum transmission power of 15 dBm (the power level in decibels relative to one milliwatt) at a data rate of 11 megabits per second. In the MAC layer, we used IEEE 802.11 in Distributed Coordination Function mode, i.e. the physical and MAC layer model used in Wi-Fi. We also took into account the radio capture effects. A two-ray path loss characteristic was considered as the propagation model. We used an omni-directional antenna model with a height of 1.5 metres, a gain of 15 dBm, and a potential transmission range of 2.1 kilometres. The radio receiver threshold was set to -81 dBm and the receiver sensitivity was set to -91 dBm according to the Lucent Wavelan card. We used the Ad-hoc On-demand Distance Vector (AODV) routing protocol to determine routes between nodes over multiple hops.

We used the random waypoint mobility model to model the mobility and the movement pattern of each node. This model is used to investigate the performance of ad hoc networks under various levels of mobility (e.g. from a highly mobile network to a static network). In the random waypoint model, nodes travel at a constant speed in a particular direction, pause for a specified length of time and then travel in a different direction for a set period of time. In the simulations, the node mobility was set to vary from zero to 20 metres per second and pause time was varied between zero and 200 seconds.

The simulations ran for 200 seconds and each simulation was averaged over four different simulation runs using different seed values. To generate traffic in to the network, we used the constant bit rate (CBR) traffic model to transmit data between nodes. Each CBR packet contained 28 bytes and was transmitted at 0.02 second intervals, which emulates VoIP type traffic.

We ran the simulations for five, 10 and 20 client/server pairs. Each session began at different times and was set to last for the duration of the simulation.

6.2.4 Performance metrics

We used the following performance metrics to investigate the performance of the ad hoc network:

- packet delivery ratio (PDR)
- normalised control overhead
- end-to-end delay.

PDR is the ratio of the number of packets received by the destination to the number of packets sent by the source. The normalised control overhead is the ratio of the number of control packets transmitted for each data packet which was successfully transmitted. The end-to-end delay represents the average delay experienced by each packet when travelling from the source to the destination.

6.2.5 Packet delivery ratio results

Figure 6.2.5.1 illustrates the PDR for the 20- and 100-node scenario. From the 20-node scenario and the 100-node scenario with 10 flows, we see that the single radio ad hoc network achieves a PDR of more than 99%. Therefore, it may be capable of handling VoIP-type traffic in a sparsely populated ad hoc network. However, in a dense network (in this case a 100-node network with 20 flows), the PDR of a single radio ad hoc network degrades significantly. This is because, in this model, only one radio (and one frequency) is used for all communications. So, as the network and traffic becomes denser, the channel contention between all nodes increases, which means that the available bandwidth for each node is lower. In a multi-radio strategy, the extra bandwidth will improve the ad hoc network scalability. In addition, channel contention may also be reduced by using directional antennas.

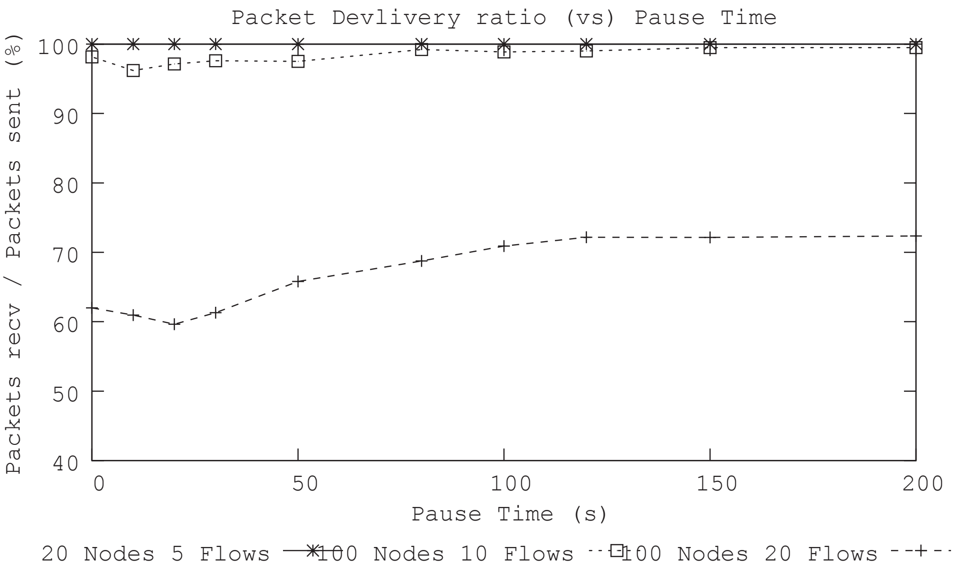

Figure 6.2.5.1: Packet delivery ratio versus pause time

6.2.6 Normalised control overhead results

Figure 6.2.6.1 illustrates the normalised control overhead for the 20- and 100-node scenarios. For the first 20 nodes and 100 nodes with 10 flow scenarios, the amount of traffic due to control packets is less than 7% (i.e. there are less than 7 control packets sent per 100 data packets), leaving the remaining network capacity for applications such as VoIP. However, for the 100-node network with 20 flows, this figure increases to 15.5% (i.e. 0.155 point in the graph), representing a greater burden on the network. Therefore, for higher node densities, more radios using different channels would be required to meet the bandwidth requirements.

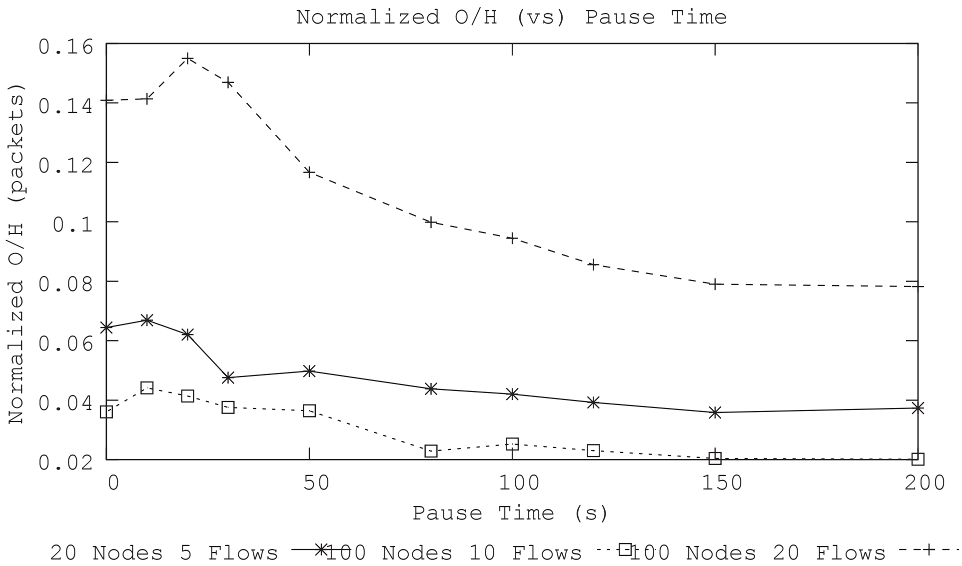

Figure 6.2.6.1: Normalised control overhead versus pause time

6.2.7 End-to-end delay results

Figure 6.2.7.1 illustrates the end-to-end delay for the 20- and 100-node scenario. The average delay produced in the 20-node scenario is mostly lower than 10 milliseconds, which will not significantly affect VoIP performance. However, in the 100-node with 10 flows scenario, the delay is much higher, exceeding 200 milliseconds at times, a level that will noticeably impact VoIP performance. This increased delay is due to higher channel contention (arising from higher node density), compared to the 20-node scenarios. Another factor that increases delay is the increased control overhead associated with higher node densities. The increase in delay becomes more evident in the 100-node with 20-flow scenario when the delay becomes too high to efficiently handle VoIP traffic. Therefore, a single radio model would not provide efficient and low-delay routes as the traffic and node density increase.

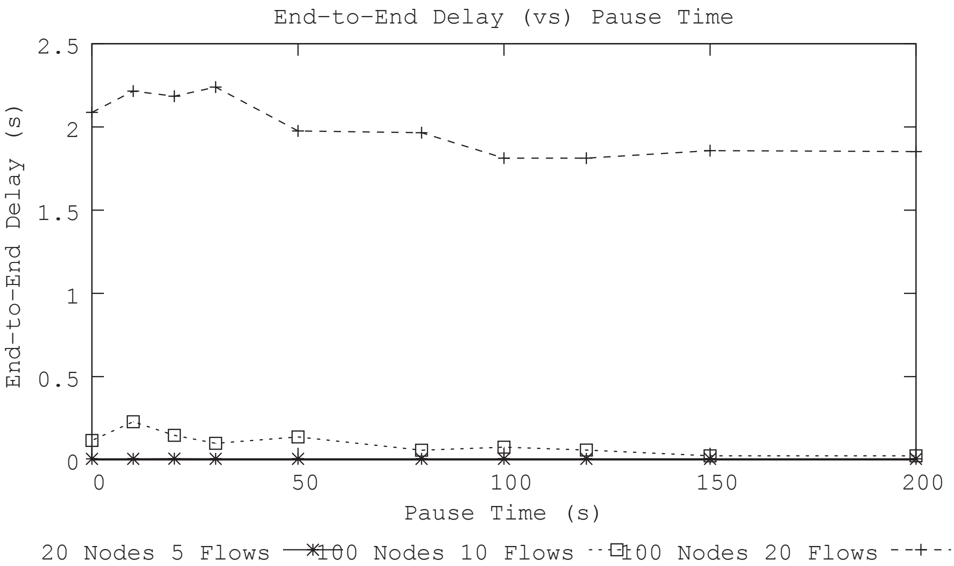

Figure 6.2.7.1: End-to-end delay versus pause time

6.2.8 A summary of the simulation results

In our simulations we investigated the performance of ad hoc networks using worst-case scenarios where channel contention is high. A key aim has been to determine whether the ad hoc networks can satisfy VoIP traffic performance requirements. The results show that single radio ad hoc network performance is adequate for VoIP traffic when node density is relatively low. For higher node concentrations, however, VoIP performance targets are not always met, particularly with regard to end-to-end delay. So, multi-radio schemes may be required to make sure that VoIP performance targets are met.

7. Network architectures based on the candidate technologies

7.1 Overview

In this chapter, we present a number of different network architectures, which illustrate how the proposed candidate technologies could be used to develop new telecommunications infrastructure or improve the capabilities of existing infrastructure in remote desert settlements.

7.2 Extending the existing infrastructure in each settlement

Many remote Aboriginal settlements (with a population of 50 or more), in remote desert regions of Australia, have limited access to telecommunications networks and services. These include pay phones, Internet facilities and other types of centralised telecommunications facilities. Here we demonstrate how ad hoc networks can be deployed to provide access to these services.

Figure 7.2.1 illustrates how ad hoc networks could be integrated with existing telecommunication networks in the remote Aboriginal settlements of Australia.

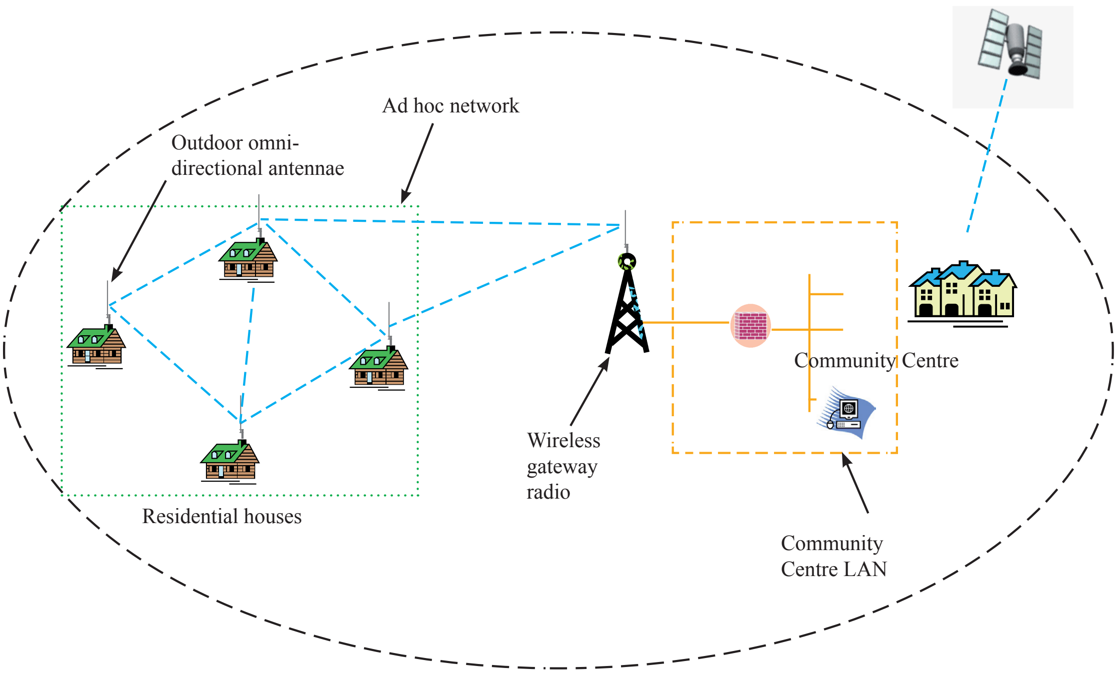

Figure 7.2.1: Extending the existing telecommunications services using ad hoc networks

The houses form an ad hoc mesh network, which connects to a settlement centre with access to a satellite network. Once a communication link is provided to residential homes, it may be possible to extend their coverage to provide access to mobile users. Figure 7.2.2 shows a range of mobile devices interconnected via the residential ad hoc wireless network.

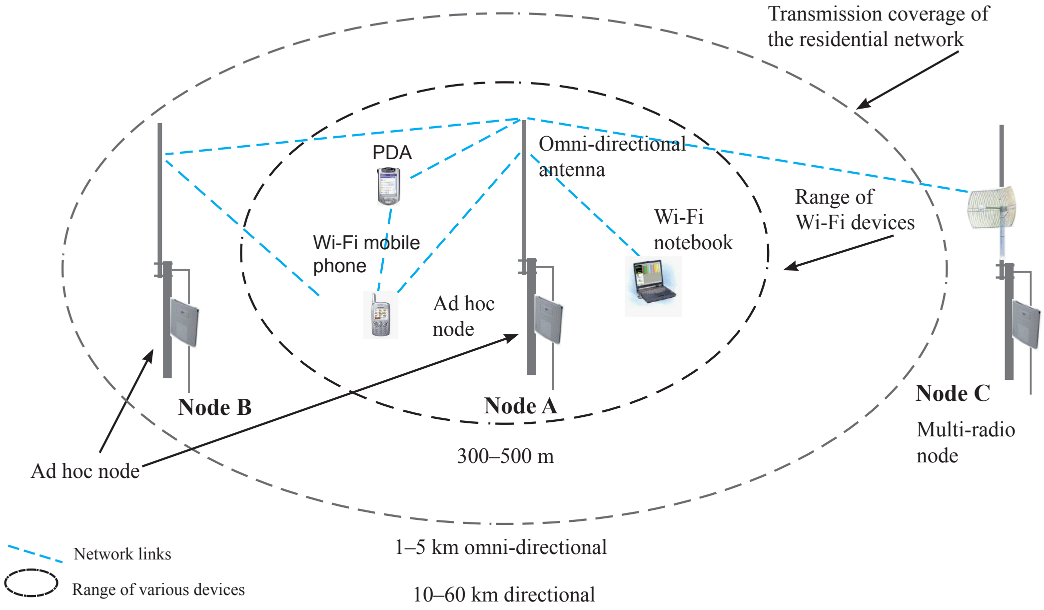

Figure 7.2.2: Extending residential ad hoc networks to mobile users

With ad hoc networks, if links fail, the nodes can re-route their data through other nodes. For example, if the link between the ad hoc nodes in Figure 7.2.2 becomes blocked, the nodes can still communicate via the mobile devices. In this case, the Wi-Fi mobile phone is a gateway between the two ad hoc nodes. The multi-radio node may also communicate with the ad hoc node (node A) using the omni-directional antenna. This is because the directional antenna used in the ad hoc network would amplify both the received and transmitted signal. So, even a weak signal received from node A by node C may still be enough to establish a link.

7.3 Interconnecting an outstation to a connected settlement

The outstations and homelands are among the most disadvantaged in terms of the availability of telecommunication services. This is mainly due to their relatively small populations and their distance from major remote Aboriginal settlements. People in these settlements often travel from one location to another, which means that a permanent networking infrastructure may not always be used.

One strategy to provide a cost-effective networking infrastructure to these settlements is by extending the network infrastructure from nearby hub or non-hub Aboriginal settlements using multi-hop ad hoc networks. These networks can be used to increase the coverage of a network by allowing data to travel over multiple hops. They can be developed to transfer both voice and data traffic at broadband speed. Figure 7.3.1 illustrates interconnecting outstations with larger settlements using multi-hop ad hoc networks.

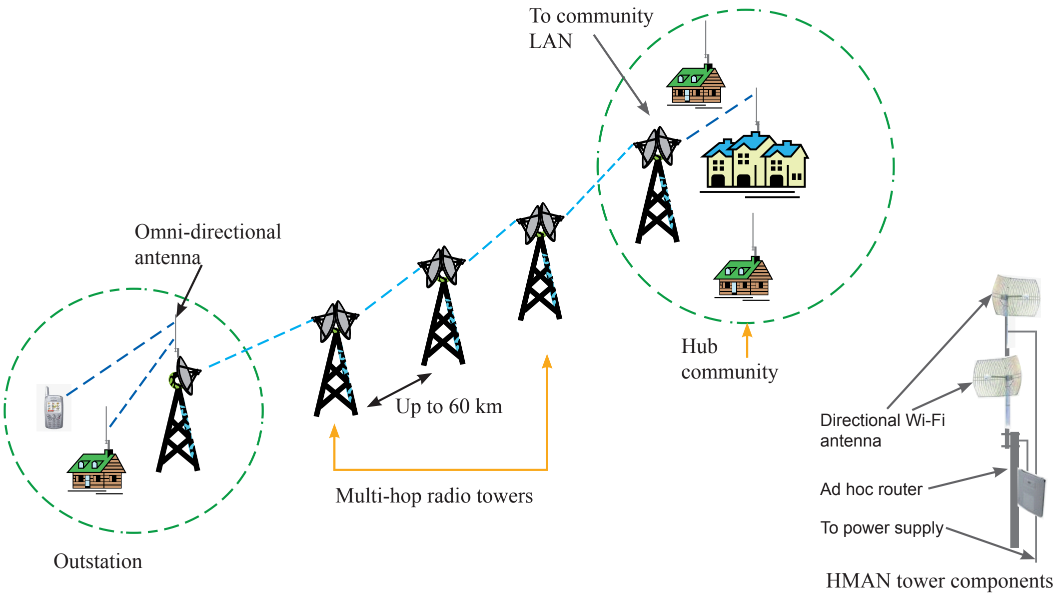

Figure 7.3.1: Interconnecting hub/non-hub settlements to outstations using multi-hop ad hoc networks

7.4 Interconnecting settlements

Ad hoc networks may also comprise a mesh of ad hoc nodes, which could potentially interconnect remote Aboriginal settlements. To do this, a chain of ad hoc nodes would be used to extend transmission range. For example, using 802.11 technology with a higher-gain antenna (e.g. with a gain of more than 20 dB), an ad hoc node may achieve a transmission range of up to 50 kilometres. Figure 7.4.1a and 7.4.1b illustrate two strategies based on how ad hoc networks may be used to interconnect remote Aboriginal settlements.

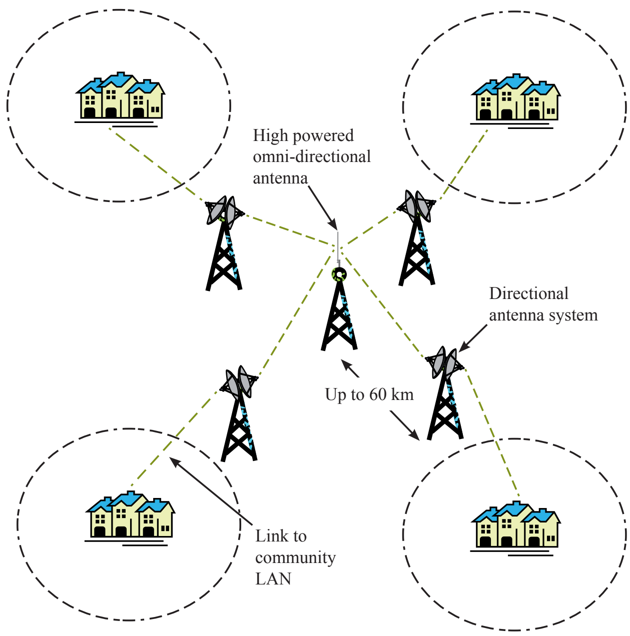

Figure 7.4.1a: Interconnecting settlements using a centralised approach

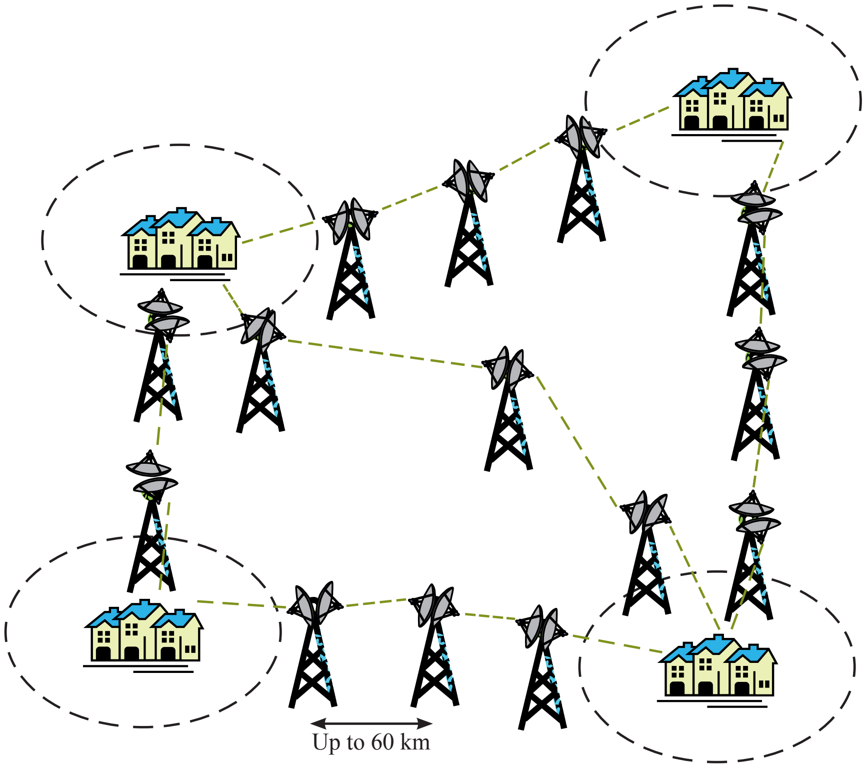

Figure 7.4.1b: Interconnecting settlements using a partial mesh-based approach

To interconnect settlements, a number of different network topologies may be used. Figure 7.4.1a illustrates a centralised approach. In this approach, some nodes may be used to interconnect two or more settlements, either by using omni-directional antennas or a chain of directional antennas connected to ad hoc nodes with multiple radio interfaces. The advantage of this strategy is that fewer towers are needed. The disadvantage is that if towers which serve multiple settlements fail, a significant part of the network may not operate. Furthermore, a centralised approach may create network capacity bottlenecks.

Figure 7.4.1b illustrates a mesh-based approach to interconnecting the settlements. In this strategy, the settlements may be interconnected using a series or mesh of ad hoc nodes. Therefore, each settlement may be able to establish a route to another settlement through multiple paths. The advantage of this strategy is that there is extra redundancy, which may allow settlements to communicate through different paths if equipment fails. Furthermore, network bandwidth may be used more efficiently by establishing communications over routes that have less traffic. While extra ad hoc nodes will be required, these may use existing microwave towers, so that the cost is simply the (relatively) low ad hoc node cost, plus installation.

8. Performance of the wireless ad hoc clients

8.1 Overview

In this chapter, we describe the results of a series of field studies and experiments that we conducted in December 2005. We investigated the performance of a number of wireless client ad hoc nodes, developed by the SAND project team, over various types of scenarios. These included long- and short-range tests, point-to-point and multi-hop. In addition to network tests, we ran some common applications on the network to examine their affect. We used various antennas in these tests.

8.2 Applications used

8.2.1 Transmission Control Protocol

Transmission Control Protocol (TCP) makes sure that all transferred data is received in the correct order with no loss. This is useful with transferring files since any loss could result in corruption of the file.

We wrote a Perl script that scanned the network performance data for each node, and measured the latency, throughput and packet loss. Approximately 50 megabytes of data was sent through the network (which consisted of four nodes) to get the results.

8.2.2 User Datagram Protocol

User Datagram Protocol (UDP) is a simple protocol where only the destination, source, length and checksum are sent. This is the minimum required for a packet to reach its destination without error. Due to the simplicity, this kind of protocol provides the lowest possible latency. However, the source may not receive all the packets, so the protocol is not suitable in scenarios where every byte has to be transferred successfully. The protocol is useful, however, in streaming (such as for VoIP and games), since latency is the crucial factor and packet loss is not of great concern.

The latency, throughput and packet loss was recorded in this test by a Perl script. Approximately 50 megabytes of data was sent through the network to get the results.

8.2.3 VoIP (voice/telephone application)

VoIP calls can be made from wireless ad hoc clients (also referred to as SOPHIv1) through the built-in VOIP card. The card uses UDP to send voice over the network. This is another real world application that is used to evaluate the network.

8.2.4 Xtris (interactive gaming application)

Xtris is a simple multiplayer Tetris® game with a text chat interface. The game communicates using TCP. Network gaming applications put significant levels of overhead on the network. We used Xtris to investigate the performance of the network in the presence of other types of traffic such as voice and data.

8.3 Performance metrics

We used the following metrics to investigate the performance of the test beds:

- Throughput versus offered load: Throughput represents the amount of data packets successfully transferred from a source to a destination. The higher the value of throughput, the higher the available bandwidth. Therefore, throughput versus offered load illustrates the amount of bandwidth still available as the level of traffic in the network increases.
- Packet loss versus offered load: This metric illustrates the level of data packets lost as the amount of traffic in the network increases. This shows the resilience of the network to packet loss as the traffic and other types of network conditions such as power, interference are varied over time.
- Round-trip delay: This metric illustrates the amount of round-trip delay experienced for each packet to travel from the source to the destination. We got the delay results by running a 'ping test' while the network was running. Therefore, during our discussions, we will present the average value of delay experienced for all setups.

8.4 Test-bed configurations and results

8.4.1 Short-range point-to-point

The short-range point-to-point (P2P) test is a test of the network established between two SOPHIv1 boxes across a range of ~200 metres. This test was conducted on Oval 3 at the University of Wollongong. It simulates a situation where two houses with SOPHI nodes communicate with each other and/or where two handheld client nodes communicate in an ad hoc manner.

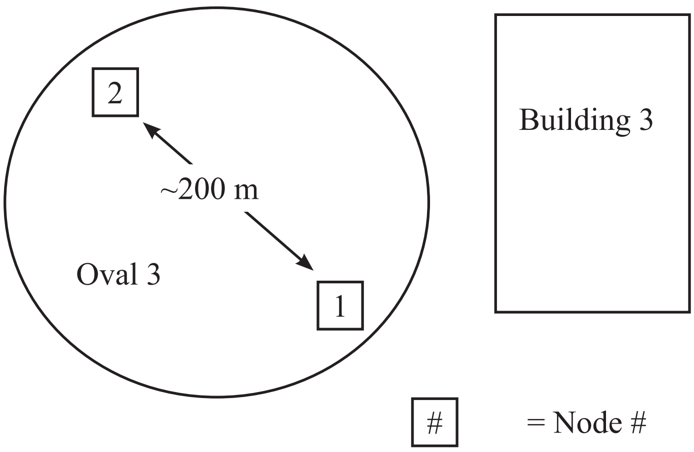

Figure 8.4.1.1: Short-range point-to-point test-bed setup

In this scenario, both node 1 and node 2 are equipped with highly directional dish antennas (see Figure 8.4.1.2). There were no obstacles between the antennas (with the exception of interference caused by people walking in front of the antenna and the possible interference from the university's wireless network). The weather was fine.

Figure 8.4.1.2: A grid directional antenna

To investigate the performance of the point-to-point network connectivity of the SOPHI nodes, the experiments were conducted using various antenna configurations:

• both nodes using high-gain directional antenna (i.e. high-gain setup)

• both nodes using small omni-directional antenna (i.e. low-gain setup).

Note that to investigate the performance of the applications described in section 8.2, we slowly saturated the network with background traffic, and observed their performance as the network became overloaded. The experimental results for the short-range point-to-point study are discussed below.

Throughput versus offered load results

Figures 8.4.1.3 and 8.4.1.4 illustrate the throughput versus offered load results for the low-gain and high-gain antenna setups.

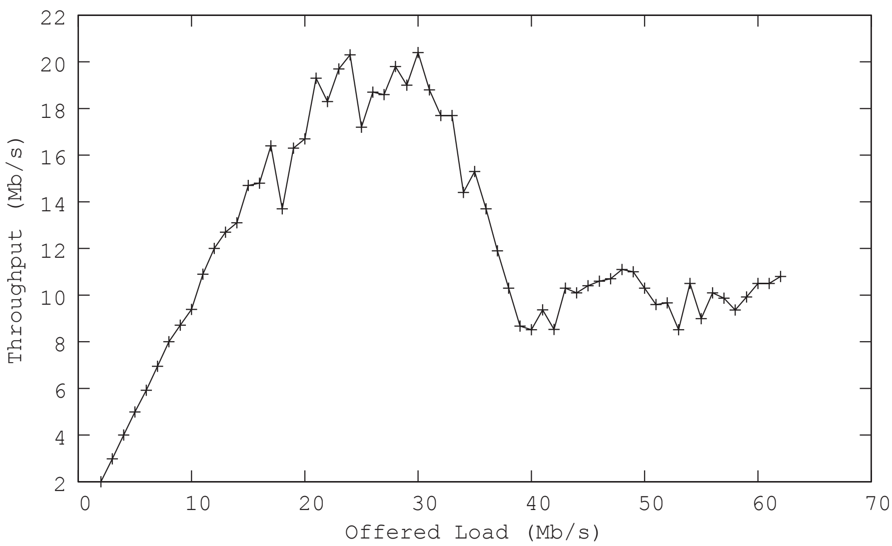

Figure 8.4.1.3: Throughput versus offered load short-range P2P with low-gain antennas

From Figure 8.4.1.3, we can make a number of important observations. Firstly, the throughput continues to rise as the level of traffic is increased to 30 megabits per second. This shows that up to this point the network has enough bandwidth to service the presented load on the network. Secondly, the throughput begins to drop when the network load goes beyond 30 megabits per second. This means that after this point the data packets begin to be dropped as the network's available bandwidth starts to become saturated. However, the network continues to produce a throughput of approximately 10 megabits per second as the load is further increased.

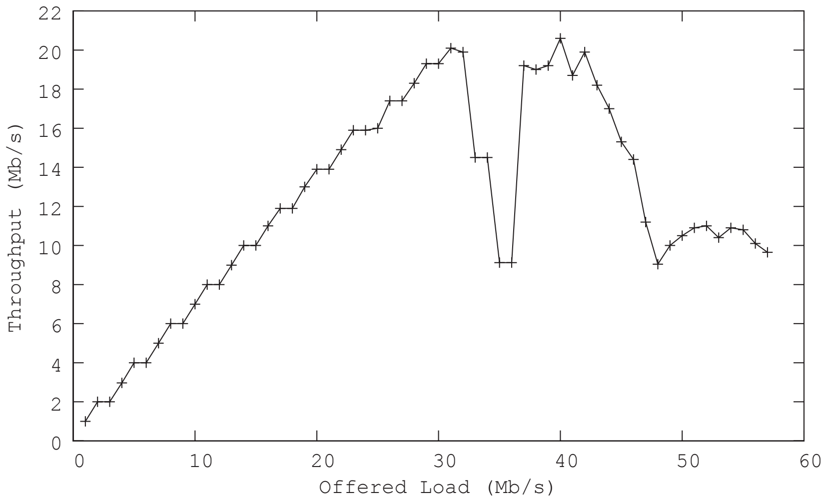

Figure 8.4.1.4: Throughput versus offered load short-range P2P with high-gain antennas

In Figure 8.4.1.4, which represents the high-gain setup, we see that the throughput also climbs up to 20 megabits per second when the offered load is at 30 megabits per second. We then see a sharp fall. This is because at this point we ran a number of different applications on top of the existing traffic being generated through the network. This includes running a multi-player network game. After this point the network continues to achieve a throughput of 20 megabits per second until the load reaches 42 megabits per second, after which the throughput drops to 10 megabits per second.

It is important to note that these results were achieved with the presence of interference from the university's own Wi-Fi network and other surrounding wireless networks. In desert situations, it is unlikely that there will be interference from other wireless networks.

Packet loss versus offered load

Figures 8.4.1.5 and 8.4.1.6 illustrate the packet loss versus offered load results for the low-gain and high-gain antenna setups.

Figure 8.4.1.5 presents the packet loss for the low gain antenna setup. We see that the packet loss remains less than 10% for an offered load of up to 15 megabits per second. The loss then begins to increase after 20 megabits per second when the network's capacity is close to being reached.

In Figure 8.4.1.6, which represents the packet loss for the high-gain setup, we see that the packet loss remains less than 10% for up to 30 megabits per second. This is because the signal strength is higher than in the low-gain setup. So, when single strength is low, two major effects could occur: firstly, packet loss could increase as the low signal may suffer from interference; secondly, the 802.11 radio automatically reduces the available bandwidth, which could also contribute to packet loss when the load is high.

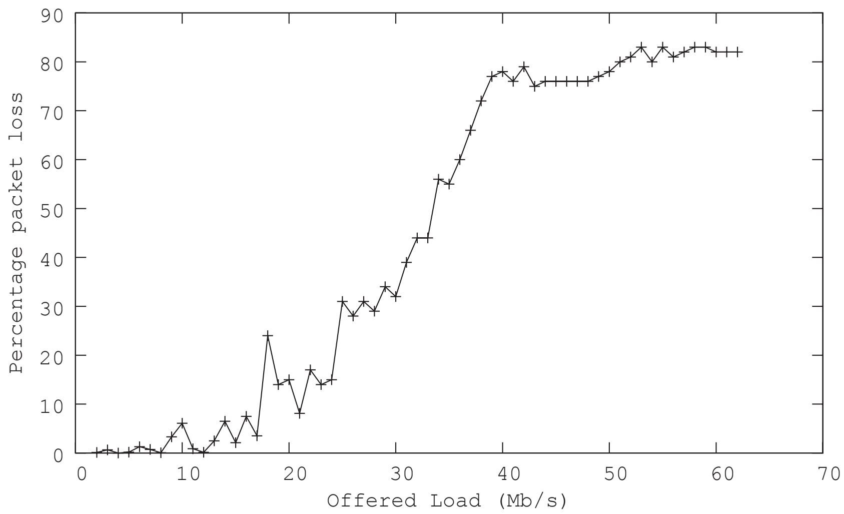

Figure 8.4.1.5: Packet loss versus offered load short-range P2P with low-gain antennas

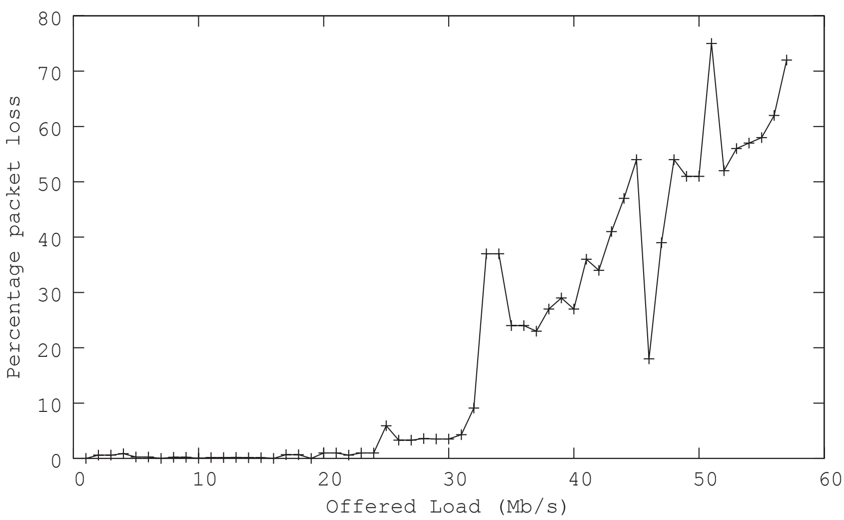

Figure 8.4.1.6: Packet loss versus offered load short-range P2P with high-gain antennas

Delay results

As stated previously, to measure the delays experienced by the data packet in travelling from the source node to the destination, we ran a 'ping' (Packet InterNet Groper) test for each setup. A ping test is generally used to verify the availability of a destination node and also the time it takes for a packet to reach a particular destination. For the short-range point-to-point setup, we observed that the packet delays (based on the ping) were on average less than 2 milliseconds. The delay was slightly increased when the network load was high; however, this was not significantly more. This is because, with the current version of the SOPHI nodes, packets are not queued (stored in a buffer/queue by a routing protocol). Therefore, the packet which successfully reached the destination would experience similar levels of delay.

8.4.2 Short-range multi-hop

The short-range multi-hop test involved two SOPHI boxes communicating with each other via a third SOPHI box. Importantly, the two nodes are unable to communicate without the intermediate node. As a result, all data is required to be routed. This test was conducted in Oval 1 and Oval 3. The total distance amounts to approximately 400 metres.

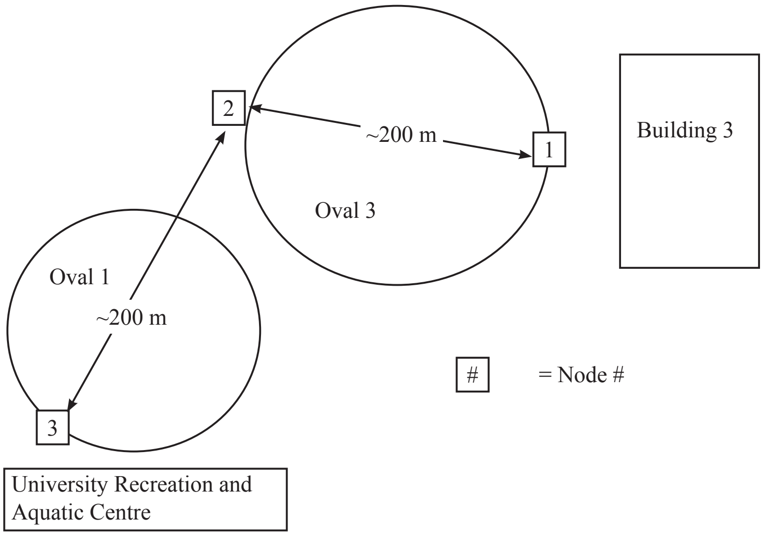

Figure 8.4.2.1: Short-range multi-hop test-bed setup

In this scenario, Node 1 and Node 3 are highly directional dish antennas while Node 2 is a semi-omni-directional wave guide antenna. Therefore, the waveguide acts as the relay point for this network (see Figure 8.4.2.2). We also equipped the replay node with a handset so that we could make voice calls to other nodes. The experimental results for this setup are discussed below.

Figure 8.4.2.2: Relay node for the short-range multi-hop test-bed setup

Throughput versus offered load results

Figure 8.4.2.3 illustrates the throughput versus offered load result for the short-range multi-hop test bed.

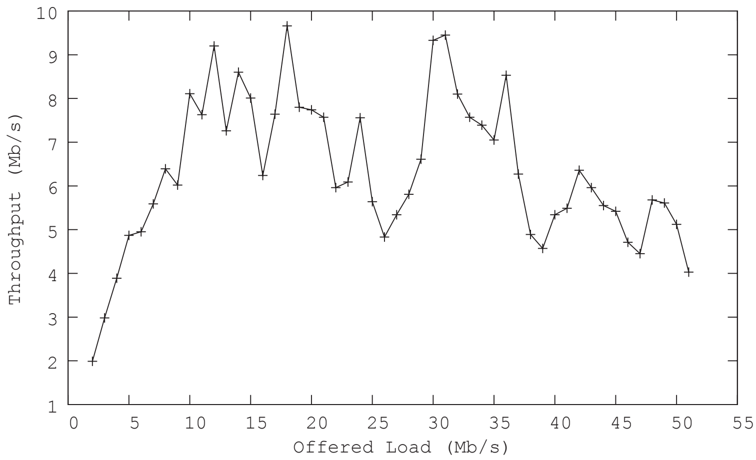

Figure 8.4.2.3: Throughput versus offered load for short-range multi-hop test bed

In Figure 8.4.2.3, we see that throughput continues to increase until the load is about 12 megabits per second. After this point the throughput varies between 10 megabits per second and 5 megabits per second. This variation is mainly due to the different applications on top of the existing network load. It is interesting to note that the maximum throughput is approximately half of that achieved in the point-to-point studies (see section 8.4.1). This is because in single-radio 802.11 networks each relay point must reserve the transmission channel for both receiving and transmitting a packet (i.e. within the transmission range of the transmitter and the receiver, a packet is transmitted twice). This results in the bandwidth being halved at each relay point. This is a known phenomenon with 802.11 wireless networks. However, improvements can be made by using multiple radio and directional antennas. For example, if a node receives data on one radio using a directional antenna and transmits using another radio and directional antenna, this effect could be eliminated.

Packet loss versus offered load results

Figure 8.4.2.4 illustrates the packet loss versus offered load result for the short-range multi-hop test bed.

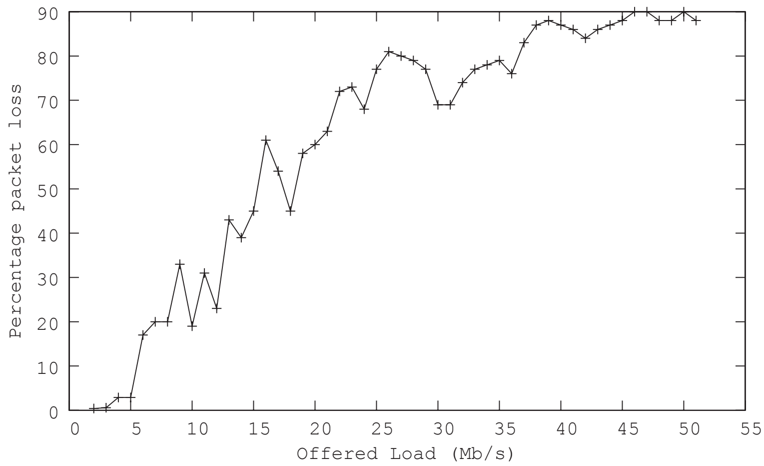

Figure 8.4.2.4: Packet loss versus offered load for short-range multi-hop test bed

It shows that packet loss remains close to zero for up to 5 megabits per second of load. After this point the packet loss beings to rise and the network slowly becomes saturated. However, the network continues to achieve less than 30% packet loss for up to 12 megabits per second of load.

Delay results

The round-trip delay for the short-range multi-hop setup was slightly higher that the point-to-point as we expected. This is because each data packet needed to be processed by an extra node in the network. Therefore, the resulting delay in this scenario was approximately 5.3 milliseconds on average. This kind of delay is still very low and would not significantly affect the performance of real-time applications such as VoIP. With VoIP, packet delays of up to 20 milliseconds (one way between the source and the destination) do not usually affect voice quality significantly.

8.4.3 Long-range point-to-point

The long range point-to-point test involved two SOPHI boxes, one mounted on the Mount Keira lookout pointing down to Oval 3, the other in Oval 3 pointing back up at Mount Keira. The distance between the two nodes is approximately 5 kilometres.

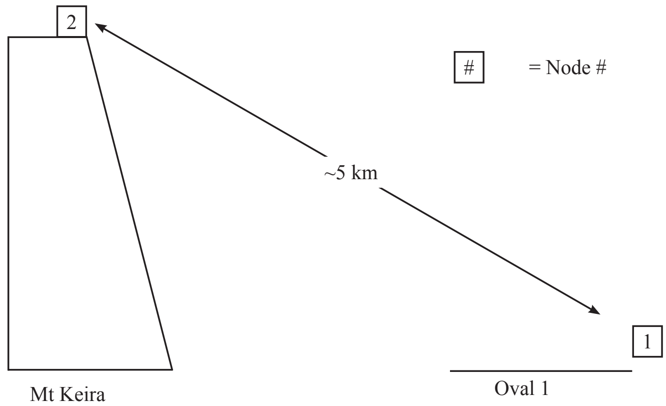

Figure 8.4.3.1: Long-range point-to-point test-bed setup

A semi-omni-directional waveguide is used at node 2 and a dish used at node 1. The waveguide (see Figure 8.4.3.2) simulates a real situation where it could be used to cover a large area. As before, the network was slowly saturated with background traffic while we ran our application programs. The experimental results for this setup are discussed below.

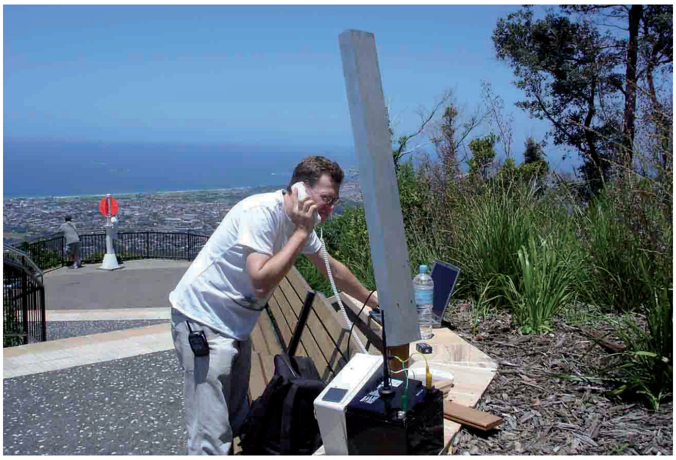

Figure 8.4.3.2: Long-range point-to-point setup with a waveguide antenna

Throughput versus offered load results

Figure 8.4.3.3 illustrates the throughput versus offered load result for the long-range point-to-point test bed.

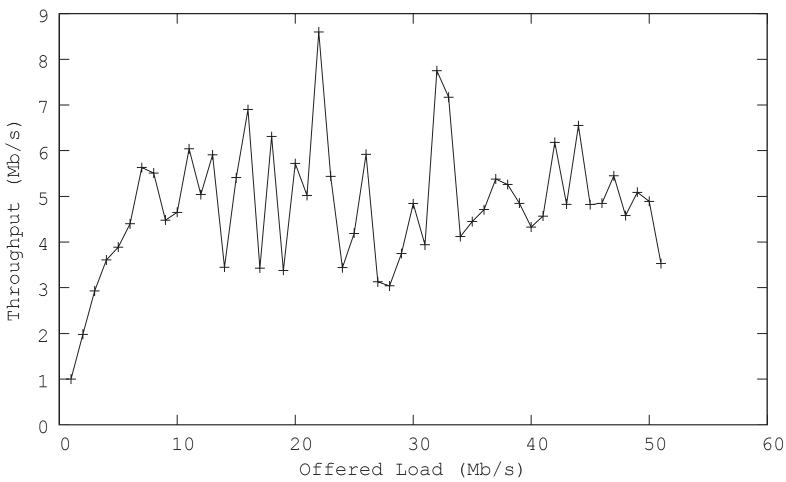

Figure 8.4.3.3: Throughput versus offered load for long-range point-to-point test bed

The network achieves a throughput of up to 8 megabits per second with an average 5 megabits per second across the range of offered loads. This achieved throughput is lower than we have achieved in the short-range scenarios because signal interference from other networks is much higher – our network can see several different networks from the top of the Mount Keira. Moreover, the SOPHI nodes were left on the default power setting of 30 megawatts (the nodes with the current radio are capable of handling double this power) and the antennas were completely aligned with each other. The combination of these two things can result in a lower available bandwidth as the network would reduce its data rate to compensate for the lower signal strength.

Packet loss versus offered load results

Figure 8.4.3.4 illustrates the throughput versus offered load results for the long-range point-to-point test bed.

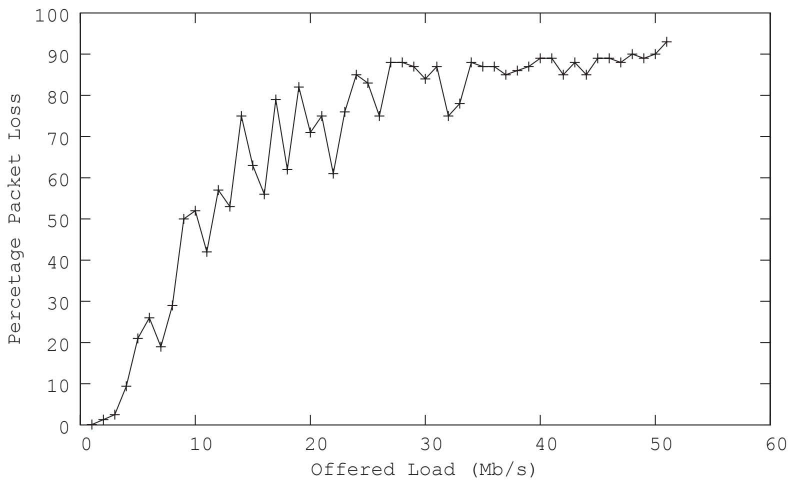

Figure 8.4.3.4: Throughput versus offered load for long-range point-to-point test bed

We see that the packet loss remains less than 10% before the available bandwidth becomes saturated. From Figure 8.4.3.3, we found that the maximum available bandwidth was about 8 megabits per second. This can also be seen in Figure 8.4.3.4 – the packet loss significantly increases as the offered load is increased above 8 megabits per second.

Delay results

As before, we measured delay using ping times. We found that the average delay was approximately 3.6 milliseconds (with a standard deviation of about 2.4 milliseconds). This is slightly higher that the short-range point-to-point tests. However, it is still low and did not adversely affect voice quality when voice calls were made.

8.4.4 Long-range multi-hop

The long range multi-hop test involved three SOPHI boxes. The one mounted on Mount Keira was trying to communicate with an obscured node through some intermediate node. The total distance is approximately 5 kilometres since the obscured node is near the intermediate node.

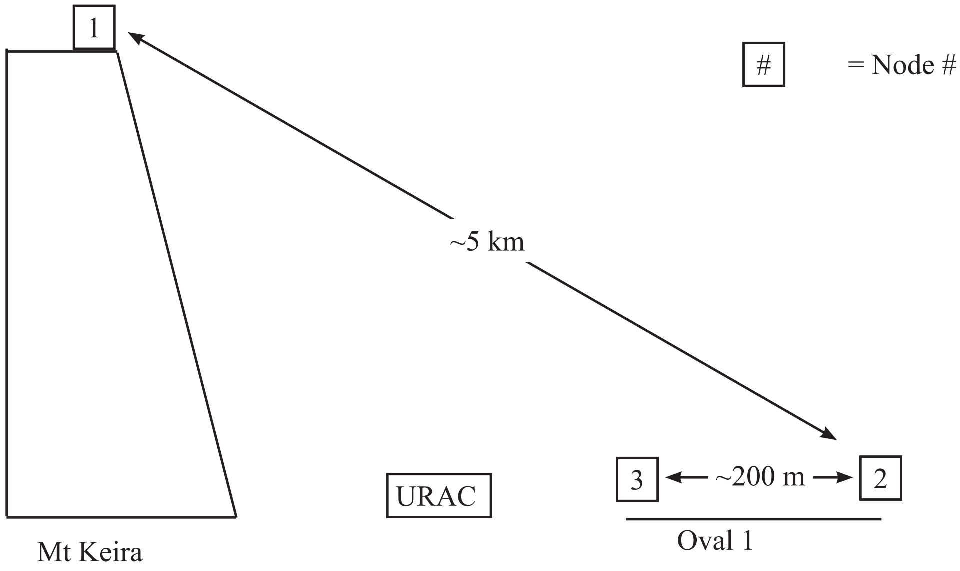

Figure 8.4.4.1: Long-range multi-hop test-bed setup

In this setup, node 1 was connected to the semi-omni-directional waveguide, and nodes 2 and 3 were connected to the directional dish antennas. We placed node 3 next to the University Recreation and Aquatic Centre (URAC) to make sure that it could not communicate directly with node 1. And to make sure we had multi-hop connectivity, we then disconnected node 2 and attempted a voice call from node 3 to node 1, which was not connected as expected. We then turned node 2 back on and re-tried the voice call between node 3 and node 1, which was successful. The experimental results for this set-up are discussed below.

Throughput versus offered load results

Figure 8.4.4.2 illustrates the throughput versus offered load result for the long-range multi-hop test bed.

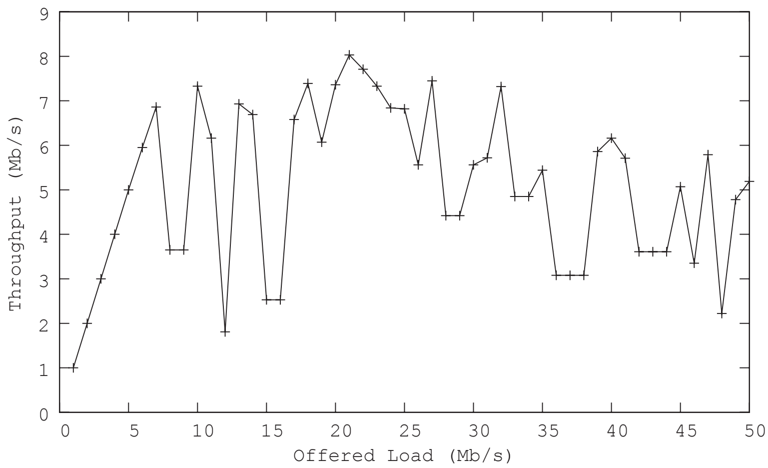

Figure 8.4.4.2: Throughput versus offered load for long-range multi-hop test bed

It shows that the throughput continues to rise for up to 7 megabits per second of network load. The maximum throughput achieved in this scenario is approximately 8 megabits per second. To introduce extra strains on the network, we periodically ran our networking gaming application and voice calls. We found that for a network load of up to 10 megabits per second we were able to establish high quality voice calls. Our gaming application also worked consistently at higher loads.

Packet loss versus offered load results

Figure 8.4.4.3 illustrates the packet loss versus offered load result for the long-range multi-hop test bed. We see that packet loss remains close to zero for up to 7 megabits per second of offered load. The packet loss is then significantly increased at this point. This is because after this point the available bandwidth becomes saturated. Also note the sharp spikes in packet loss due to an increased load caused by running our real-time applications. Therefore, from these observations, we see that the SOPHI clients, as they stand, can easily handle traffic levels of several megabits per second over a radius of a few kilometres.

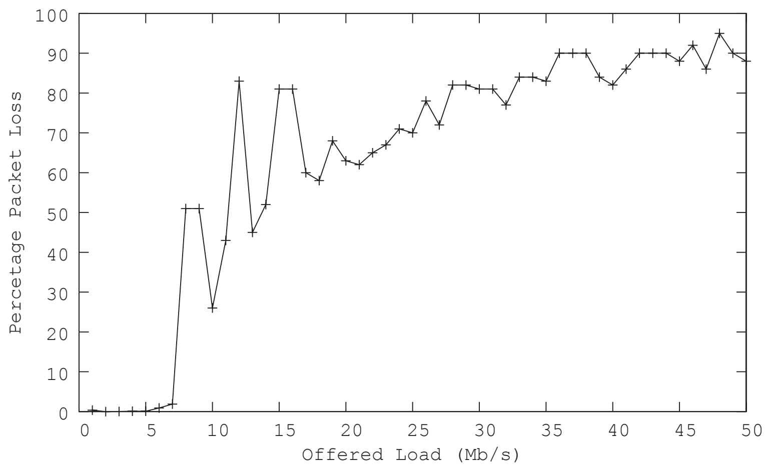

Figure 8.4.4.3: Packet loss versus offered load for long-range multi-hop test bed

Delay results

In this scenario, with an average delay of about 6 milliseconds, the delays were also slightly higher than the short-range multi-hop results. As before, we ran our voice call experiment to observe quality and we did not find significant difference in quality compared to the previous experiments.

8.5 Summary of results

In this report we investigated the short-range, long-range and multi-hopping capability of our SOPHI client nodes. From our experimental results, we can see that we are able to achieve an average of 8 megabits per second of data throughput in most scenarios. In the short-range point-to-point scenarios, for which the SOPHI clients are intended, we saw a throughput of up to 20 megabits per second and a packet loss of less than 5% before the network became saturated. The delay experienced by each data packet in this scenario was less than 3.5 milliseconds on average. This means that we could concurrently run real-time applications, such as VoIP and heavy data transmission, effectively.

In both the short-range and long-range multi-hop (also in the point-to-point) scenarios, we were able to achieve throughputs of up to 8 megabits per second and the packet loss remained less than 10% while the bandwidth capacity was not reached. In this scenario, applications such as voice and video over IP could be run with reasonable levels of quality. We also noted that the delay was less than 5 milliseconds on average. Therefore, the quality of real-time applications was not significantly affected while the available bandwidth was not saturated. For applications such as VoIP, a delay of less than 20 milliseconds is required to establish a high quality voice call. Therefore, from our results we can see that the delays produced are significantly lower than what is required.

9. Performance of the long-range wireless multi-hop ad hoc backbone nodes

9.1 Overview

In this chapter, we describe the results of our field studies and experiments to investigate the performance of long-range wireless ad hoc nodes (also referred to as the High-powered Multi-radio Ad hoc Nodes, or HMAN) in scenarios such as short range, long range, various node density and traffic levels, and multi-hopping. We also ran some common applications on the network to examine their effect on and performance over the experimental network.

We describe the experimental setup and results achieved below.

9.2 Applications and traffic generation tools

To investigate the performance of the HMAN devices, we performed two types of studies:

- artificially generated traffic (quantitative studies)
- real traffic from end-user (client) devices (qualitative studies).

The aim of generating artificial traffic is to dynamically change the network traffic in a controlled manner. This allows you to accurately measure and plot the performance limits of the network and the devices.

Using real traffic allows you to observe the performance of the test bed based on available end-user hardware, and so perform qualitative investigations to predict the real-world (from an end-user perspective) quality of service of the network.

In the following sections, we describe in more detail the applications and traffic models used.

As in the test of the wireless ad hoc clients (Chapter 8), we used TCP and UDP to qualitatively measure the performance of the network. To perform the quantitative performance measurements based on the above traffic models, we developed a traffic generation program. It slowly saturated the network and collected network performance metrics such as throughput, packet loss and end-to-end delay. We installed a copy of the traffic generation program in each HMAN node and synchronised all nodes to provide accurate performance results.

9.3 Performance metrics

The performance metrics we used were similar to those previously described in section 8.3:

- throughput versus traffic level
- packet delivery ratio (PDR)
- round-trip delay.

9.4 Test-bed configurations and results

Our major objectives were to investigate:

- the short-range and long-range capabilities of the HMAN devices
- how multi-hopping affects the throughput and delays introduced into the network
- how increases in network traffic affect the overall performance of the network.

9.4.1 Short range

To investigate the short-range behaviour of the HMAN devices, we deployed the HMAN nodes in different locations around the University of Wollongong's football fields. This provided a mixture of line-of-sight coverage and near-line-of-sight due to obstacles such as buildings and trees. So some parts of the network had direct line of sight between source and destination nodes and other parts required multi-hopping to establish routes.

All HMAN nodes were equipped with low-power omni-directional antennas to provide short-range coverage. We also ran a number of applications, such as voice calls and introduced artificial traffic (using ping tests), over two hops. Figure 9.4.1.1 illustrates an example topology of the short-range test beds using the HMAN nodes.

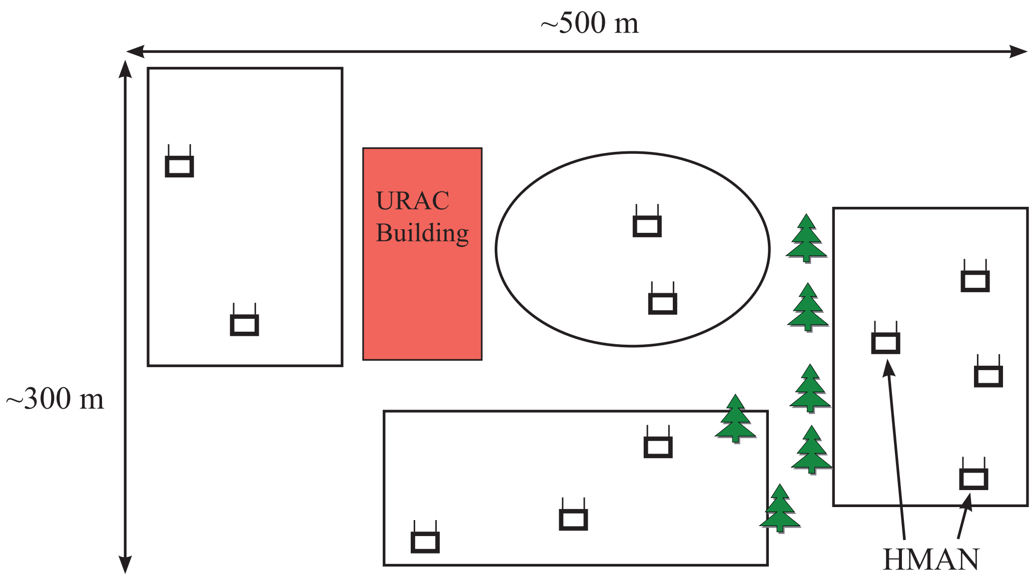

Figure 9.4.1.1: Short-range setup using HMANs

Throughput

Figures 9.4.1.2 and 9.4.1.3 illustrate the throughput achieved as the level of traffic increased in the network, with and without an active voice call running. Both figures show that, as the level of traffic continued to climb, the network was successful in meeting the bandwidth requirements. This can be seen by the linear line shown in the graph. Note that the aim of this study was to investigate the backhaul transmission capability of the HMAN devices over multi-hops – not capacity. We present the results of capacity experiments in section 9.4.4.

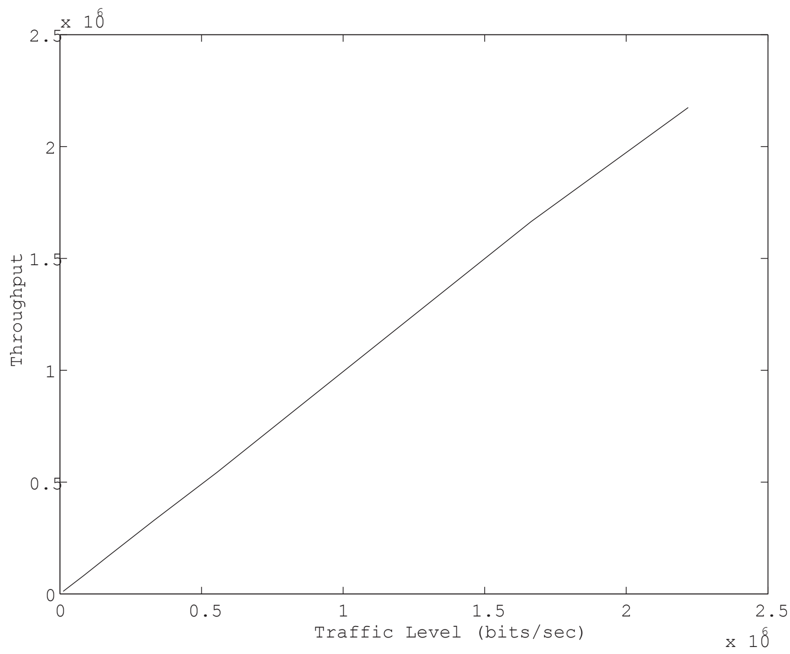

Figure 9.4.1.2: Throughput versus traffic level without voice application

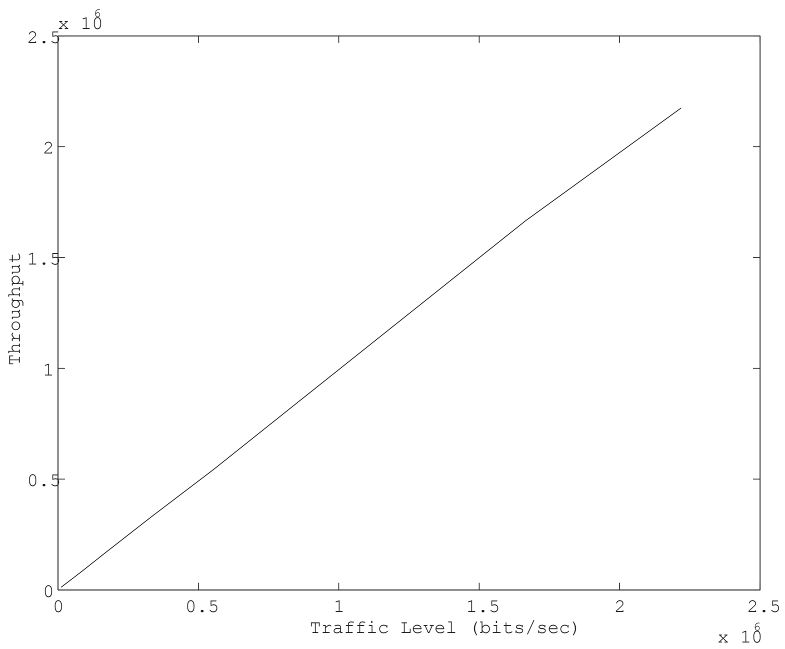

Figure 9.4.1.3: Throughput versus traffic level with voice application

Packet delivery ratio

Figures 9.4.1.4 and 9.4.1.5 illustrate the PDR versus traffic level with and without a voice application running next to our artificially generated traffic. In Figure 9.4.1.4, we can see that the network continued to achieve more than 98% data delivery. In Figure 9.4.1.5, where a voice application was running, the data delivery dropped slightly. However, we did not notice any change in the quality of the voice application as the level of artificial traffic was increased. This is because the voice traffic had higher priority than the other traffic, as we ran the background traffic on low priority.

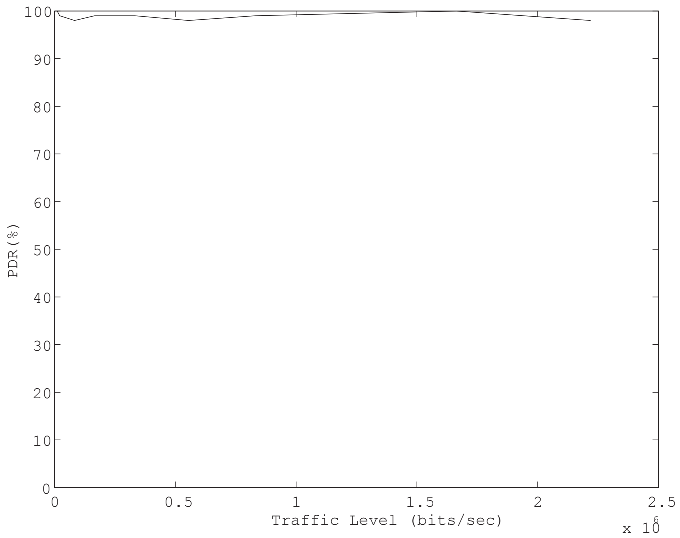

Figure 9.4.1.4: PDR versus traffic level without voice application

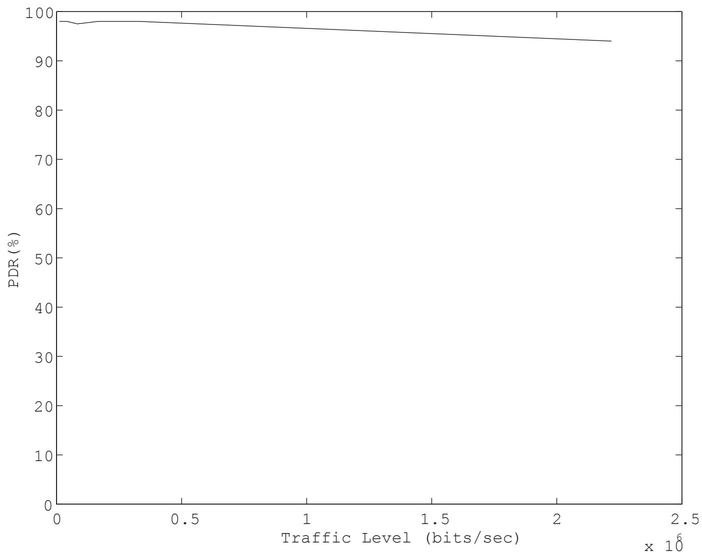

Figure 9.4.1.5: PDR versus traffic level with voice application

Delay

Figure 9.4.1.6 illustrates the round-trip delay between the source and destination nodes in our mesh network. Note that we only present the results of delays experienced when the voice application was present. This is because these delay results were not significantly different to when voice was not present. We can see that the experienced delay was mainly 3.5–4 milliseconds, which means that the end-to-end delay would be close to 2 milliseconds on average. To compare this to the requirements of applications such as real-time voice, this value is significantly lower than the minimum delay requirement for VoIP, which is 20 milliseconds. Therefore, voice applications can be successfully run in such networks as long as enough bandwidth is available. In single radio backhaul networks, the number of hops would also affect the end-to-end delay. Therefore, for a network consisting of more than 3–4 hops, a multi-radio strategy configured to enable full-duplex operation is more beneficial and would scale much higher.

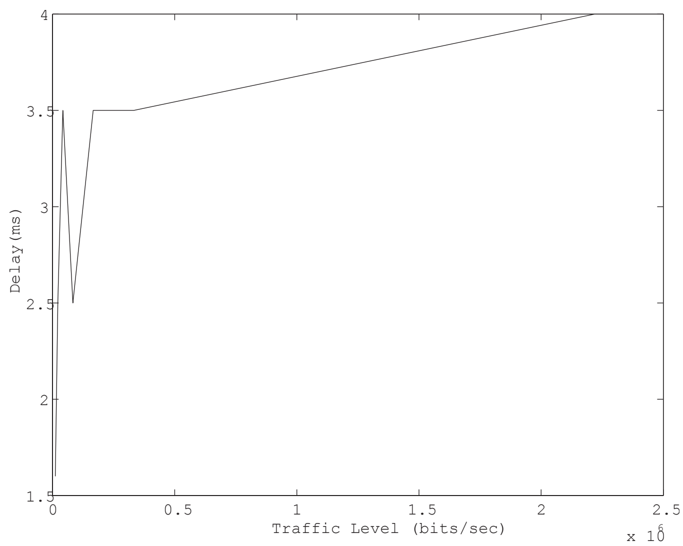

Figure 9.4.1.6: Delay versus traffic level with voice application

9.4.2 Medium range

The aim of the medium-range studies was to simulate a small-settlements network topology. From our studies in Ngaanyatjarra settlements during the first phase of the SAND project, we observed that the hub settlements were often situated near hills (or radio towers) which were used to provide network connectivity (such as the Ngaanyatjarra UHF radio network) in and between the remote settlements. To simulate this, we placed a HMAN node on top of Mt Keira, which is approximately 5 kilometres from the University of Wollongong and has line-of-sight coverage to several kilometres north and south of Wollongong. We also placed a number of nodes at the university and at student houses around Wollongong (see Figure 9.4.2.1.).

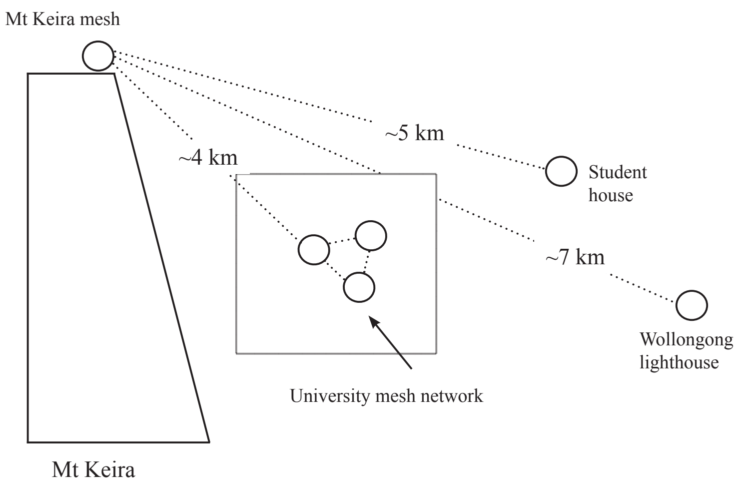

Figure 9.4.2.1: Medium-range multi-hop locations for HMAN nodes

Throughput

Figures 9.4.2.2 and 9.4.2.3 illustrate the throughput versus traffic level with and without an active voice call. Similar to the short-range studies, the throughput continued to increase and meet the bandwidth requirement of the network. We also observed that the voice quality was clear until the network started reaching saturation point. Based on a single radio backhaul, we achieved up to 10 megabits per second for a multi-hop connection (two and three hops) over six kilometres. However, higher bandwidth may be achieved depending on the RF setup (antenna and clear line-of-sight) and lower levels of interference.

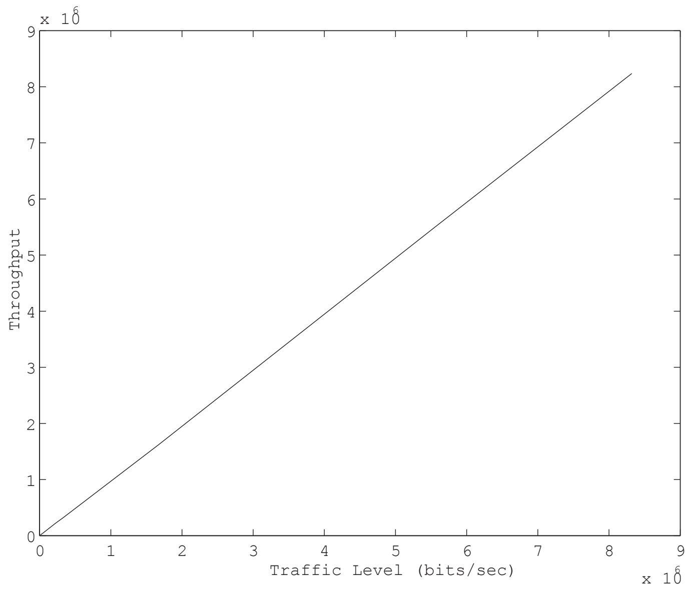

Figure 9.4.2.2: Throughput versus traffic level without voice application

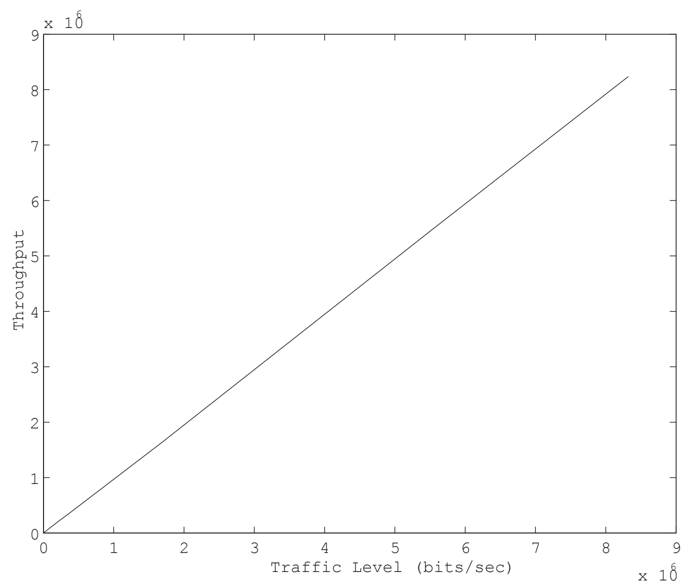

Figure 9.4.2.3: Throughput versus traffic level with voice application

Packet delivery ratio

Figure 9.4.2.4 illustrates the PDR with the presence of an active voice call over two hops. We can see that the network successfully maintains a 98% delivery ratio as the level of traffic increases. We also found that the quality of the voice call stayed clear until the level of traffic reached 10 megabits per second.

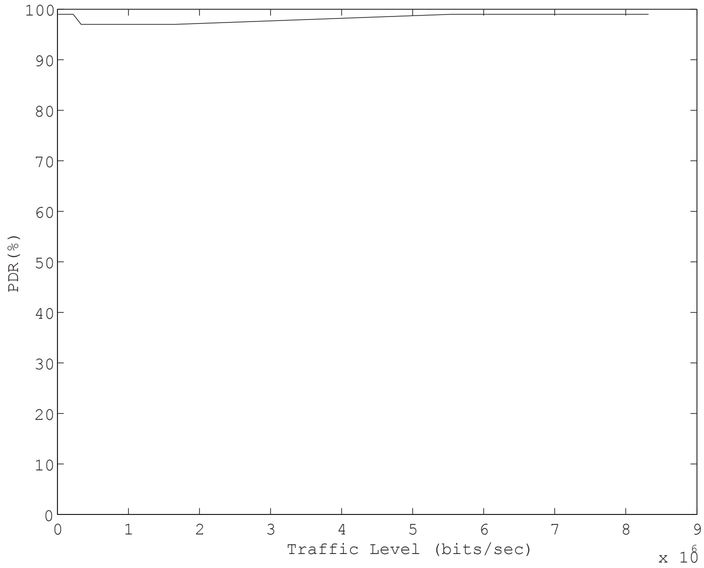

Figure 9.4.2.4: PDR versus traffic level with voice application

Delay

Figure 9.4.2.5 illustrates the average round-trip delay for the data traffic introduced into the network for two hops. The average delay experienced generally varied from 5 to 8 milliseconds, which represents a delay of approximately 2.5–4 milliseconds for an end-to-end connection (depending on link conditions). So, we can see that the network continues to maintain low levels of delay as traffic increases, which means that real-time traffic such as voice and video could be transmitted with high level of traffic while the network capacity is not reached. In these experiments we measured performance loss when more than 10 megabits per second of traffic was introduced into the network. However, this may vary depending on the level of background traffic and RF setup.

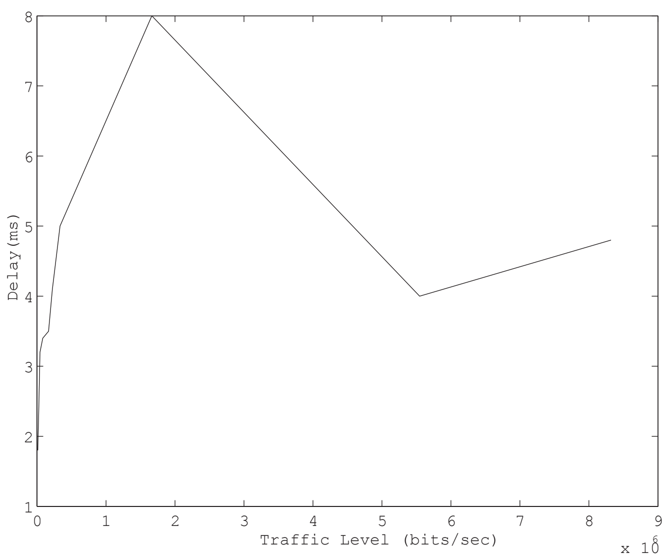

Figure 9.4.2.5: PDR versus traffic level with voice application

9.4.3 Long range

The long-range studies investigate the usefulness of the radio technology used in the HMAN prototypes for interconnecting nearby settlements and outstations in remote desert areas. To simulate such an environment, we distributed our HMAN nodes to a number of locations around the University of Wollongong and to Shellharbour, Balgownie and Stanwell Park; this consists of multi-hops links which cover a range of up to 50 kilometres. Figure 9.4.3.1 illustrates the different locations which we used to investigate the long-range point-to-point and multi-hopping capabilities of the ad hoc mesh networking devices.

To perform the long-range studies, we chose Mt Keira as a central-hub point; we initially thought it would provide clear line of sight to most of the selected points of study, such as Lake Illawarra, Shellharbour and Stanwell Park.

We began by setting up a multi-hop network between Lake Illawarra and Mt Keira (see Figure 9.4.3.1). To establish a near-line-of sight communication, we set up a 4 metre-tall mast equipped with a directional grid antenna (see Figure 9.4.3.2) and pointed it towards Lake Illawara. Our second team at Lake Illawarra pointed a directional grid towards Mt Keira. This represented a point-to-point link of approximately 15 kilometres. With this setup, we established a network connection between the long-range nodes and tested the connectivity of the network using ping tests. Our ping study revealed that the established link was not stable enough to collect results. A voice call across the network was unclear. We concluded that our antenna was not high enough at both ends to maintain a clear uninterrupted link. To overcome this problem, we predict that significantly higher masts (20 metres plus) are required at both ends to achieve line-of-sight-based connection, with more that 60% of the Fresnel zone being clear (for RF connection in the 2.4-gigahertz band, a minimum of 60% clearance of the Fresnel zone is required). We further scanned the Illawarra regions (e.g. Shellharbour and Stanwell Park lookout point) and found that our mast height would not provide a reliable link to Mt Keira due to the density of the surrounding trees and the terrain.

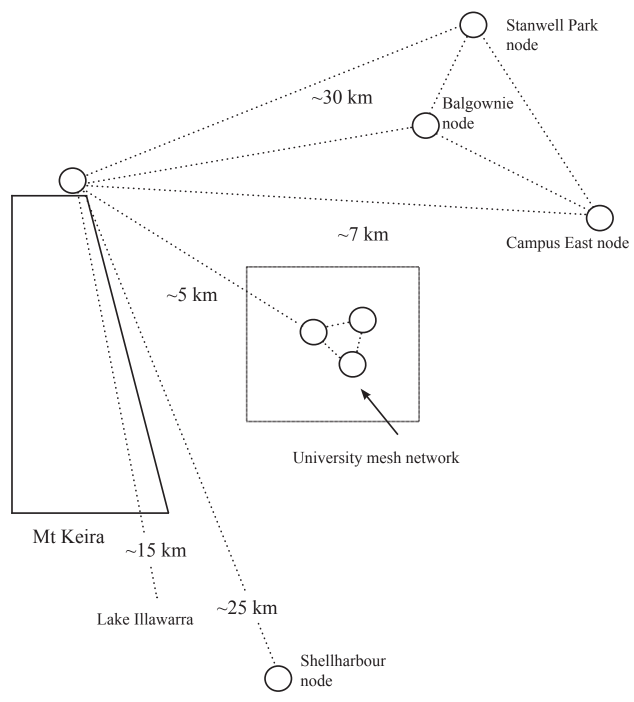

Figure 9.4.3.1: Long-range multi-hop locations for HMAN nodes

In Stage 2 of the SAND project, we aim to continue investigating the performance of our ad hoc mesh nodes over long-range (> 15 kilometres) connections in other locations.

Figure 9.4.3.2: Long-range antenna setup at Mt Keira

Figure 9.4.3.3: Antenna setup at a student house for long-range transmission

9.4.4 Indoor capacity and performance under higher density

To investigate point-to-point capacity of the ad hoc mesh devices over dense networks, we set up 11 nodes in one room. We set all nodes to operate in ad hoc mode and enabled the Optimised Link State Routing (OLSR) protocol (although, in this scenario, multi-hopping is not required). We slowly increased the number of traffic flows and recorded the performance result.

Figure 9.4.4.1 illustrates the throughput results for an increasing number of flows. Our initial run of this experiment showed that as the number of flows increased, the network became unstable. This was mainly due to vital control packets being lost as the level of traffic and the number of flows was increased. We fine-tuned the OLSR parameters to produce fewer interfering packets and we found that stability was dramatically improved. This can be seen in Figure 9.4.4.1, as the level of throughput stays steady when the number of flows is increased. For example, when the data packet dissemination rate was set to 0.2 seconds and 0.02 seconds, the throughput graph stays fairly flat. A slight drop in throughput was experienced when the rate was increased to 250 packets per second (i.e. 4 milliseconds per packet). This drop was again mostly due to the critical control packets being dropped due to high levels of contention. However, such transmission rates are often not required – the most real-time applications such as VoIP require a packet to be transmitted is every 20 milliseconds, which is five times less than what we found in our experiments.

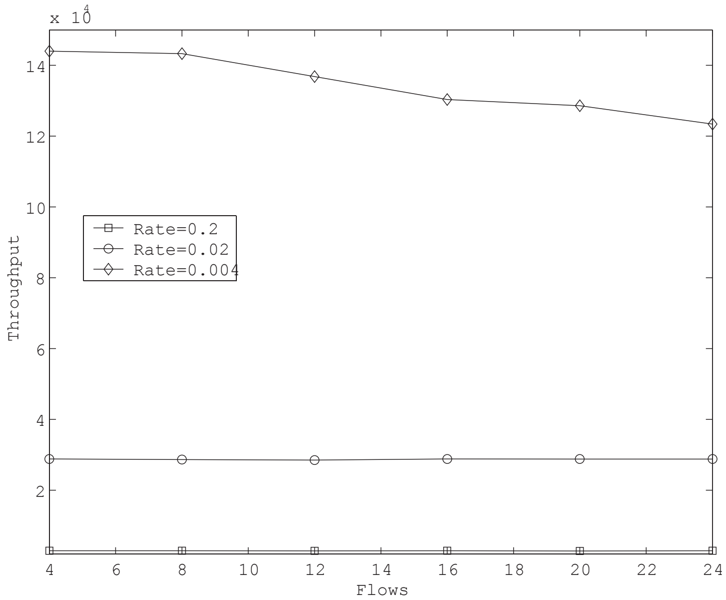

Figure 9.4.4.1: Throughput versus flows

Figure 9.4.4.2 illustrates the packet delivery ratio versus the number of flows. We can see that for both the 0.2 second and the 0.02 second transmission rates, the network achieved more than 98% delivery. In the case of 0.004 second rate, the delivery ratio began to drop as the number of flows was increased beyond eight – this was mainly due to the instability created in the network as a result of control packet loss and interference.

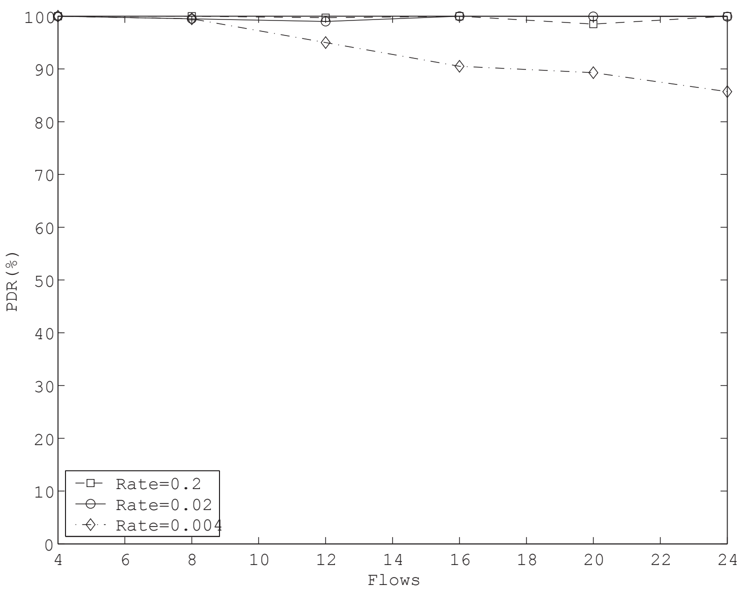

Figure 9.4.4.2: Packet delivery ratio versus flows

Figure 9.4.4.3 illustrates the round-trip delay as the number of flows increased in the network. We can see that the network maintained delays of less than 3 milliseconds for both the 0.2 second and 0.02 second rate scenarios. This represents an approximate average end-to-end delay of less than 1.5 milliseconds. In the 0.004 second rate scenario, the delay began to increase as the number of concurrent flows was increased beyond 12. At this point we also observed that the network became slightly unstable due to packet loss and interference caused by extremely high levels of network traffic. However, these results also suggest that the network is capable of handling several concurrent real-time applications such as VoIP. For example, most VoIP codecs require less than 20 milliseconds delay per packet to establish a high quality communication. Our results indicate that it may be possible to provide up to 100 concurrent voice calls over each radio in the ad hoc mesh cell.

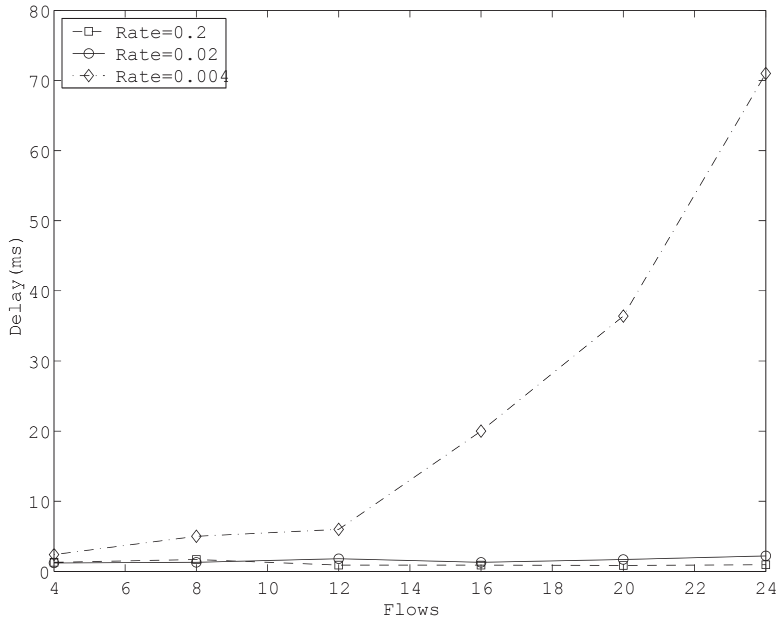

Figure 9.4.4.3: Delay versus flows

9.5 Summary of results

To investigate the performance of the HMAN devices, we designed four different network scenarios to establish an outdoor short-range, medium-range, long-range and indoor ad hoc mesh network respectively.

The short-range test bed was set up in a number of the University of Wollongong's football ovals. We studied the performance of the ad hoc mesh nodes over short distances representing scenarios such as providing last mile network connectivity in a local area (such as a remote settlement). In this scenario, we established voice calls over two and three hops and found that the ad hoc mesh network can successfully deliver the bandwidth requirement for such services. We also tested the limits of the network with artificial traffic and found that bandwidth levels of more than 10 megabits are achievable over two or three hops, depending on various conditions such as interference from other 802.11-based networks.

In our medium-range studies we established a voice call over a two-hop route over a range of 6 kilometres. We continued the voice call while we increased the level of background traffic. We found that while the network bandwidth was unsaturated, we were able to maintain a high quality voice call.

In our long-range studies we established a multi-hop route over a range of 15 kilometres. However, our RF setup (including antenna height) restricted the line of sight, and we could not maintain a continuous voice call. In the second stage of the SAND project we aim to further investigate the long-range transmission characteristics of our network devices by improving the line-of-sight issues (i.e. by performing tests in regions with better line of sight). In this study, we also found that the radio device driver used (MadWifi) has problems over long distances, particularly when used in ad hoc modes. There a few different 'work-in-progress' drivers available for ad hoc networking under the Linux networking environment. In stage two of the SAND project, we will further investigate drivers for the 802.11 radio.

To investigate the capacity of ad hoc networks in indoor environments, we set up a dense one hop network in the TITR lab. We activated 11 ad hoc mesh nodes and slowly increased traffic. Our results show that even in densely populated ad hoc mesh cells, it is still possible to achieve high levels of throughput. In particular, we found that each ad hoc mesh cell based on 802.11 is capable of handling several concurrent real-time applications as well as near-real-time applications.

References

Abolhasan, M and Boustead, P 2007, ‘UHF-based community voice service in Ngaanyatjarra land of Australia’, in LE Dyson, M Hendriks and S Grant, *Information technology and Indigenous people*, Idea Group Publishing, PA, 2007.

Abolhasan, M 2005, ‘A new networking technology to improve communications in under-ground mines’, *The Mining Chronicles*, vol. 10, November edition feature: Remote area communications.

Aboriginal and Torres Strait Islander Commission 2002, *New solution to old problem: Remote Indigenous communications as community economic development*, ATSIC, Canberra.

ATSIC – see Aboriginal and Torres Strait Islander Commission

Australian Bureau of Statistics 1999, 4710.0 *Housing and Infrastructure in Aboriginal and Torres Strait Islander Communities*, Australia, Commonwealth of Australia, p. 17.

Australian Communications Authority 2002, *Report on the Program to Upgrade Telecommunications Services in the Remote ‘Extended Zones’ of Australia*, ACA, Melbourne.

Broadcast Australia 2002, *Submission to the regional telecommunications inquiry*, Broadcast Australia, Sydney.

Commonwealth Grants Commission 2001, *Report on Indigenous funding*, Commonwealth of Australia, Canberra, p. 8.

Commonwealth Grants Commission 2001, *Report on Indigenous funding*, Commonwealth of Australia, Canberra, p. 236.

Department of Corporate and Information Services 2002, *Submission to the regional telecommunications inquiry*, Northern Territory Government, Darwin.

House of Representatives Standing Committee on Aboriginal Affairs 1987, *Return to country: the Aboriginal homelands movement in Australia*, Canberra, p. 125.

PY Media 2007, PY Media Alice Springs, viewed 6 June 2006, <http://www.waru.org/resources/iconnect.php>.

Shire of Ngaanyatjarraku and Ngaanyatjarra Council (Aboriginal Corporation) 2002, *Submission to the regional telecommunications inquiry*, Aboriginal Corporation, Alice Springs.

TAPRIC – see Telecommunications and Action Plan for Remote Indigenous Communities

Telecommunications and Action Plan for Remote Indigenous Communities 2002, *Strategic study for improving telecommunications in regional, rural and remote Indigenous communities*, Department of Communications, Information Technology and the Arts, Canberra.