TECHNICAL REPORT

ACCELERATING PRECISION AGRICULTURE TO DECISION AGRICULTURE

Enabling digital agriculture in Australia

This Project is supported by funding from the Rural R&D for Profit Program

Australian Government
Department of Agriculture and Water Resources

University of New England

A review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia.

D Lamb

Australian Government
Cotton Research and Development Corporation

FRDC

awi Australian Wool Innovation Limited

AMPC

Australian eggs

Australian Pork

LiveCorp

GRDC Grains Research & Development Corporation

Horticulture Innovation Australia

Dairy Australia

AgriFutures Australia

Forest & Wood Products Australia

sra Sugar Research Australia

Wine Australia

mla Meat & Livestock Australia

About the Author

David Lamb is McClymont Distinguished Professor (Research) of the University of New England. A physicist, Professor Lamb has been researching in precision agriculture since 1994 where he has contributed to, or led, more than forty multidisciplinary, multi-organisation R&D projects spanning rain-fed and irrigated grains, sugarcane, viticulture, horticulture and livestock industries. In recognition of his contribution to this rapidly growing area of R&D in Australia and worldwide he received a Vice Chancellor's Award for Excellence in Research in 2007 and in 2015 received a Research Excellence Award from the Cooperative Research Centre for Spatial Information. Professor Lamb established the University of New England's Precision Agriculture Research Group (www.une.edu.au/parg) in 2002 and leads the university's SMART Farm project (www.une.edu.au/smartfarm); a 2,900 ha, 'highly-connected', predominantly grazing property serving as an education, outreach and R&D farm showcasing the latest innovations in digital agriculture. The UNE SMART Farm received a Regional Development Australia 2014 'Innovation of the Year' award. In addition to contributing to the Prime Minister's Forum on the Digital Economy in 2012, Professor Lamb has contributed to numerous state and federal Parliamentary Inquiries into agriculture innovation and related areas. Professor Lamb has co-authored more than 100 peer-reviewed scientific publications, a book and numerous book chapters in the area of precision agriculture. He currently serves as a Science Director in the Cooperative Research Centre for Spatial information and is a member of the National Positioning Infrastructure (NPI) Advisory Board.

Contact: dlamb@une.edu.au

Cover photo credit: Jane Lamb

Acknowledgments

This review would not have been possible without the valuable contributions of many producers, agricultural service providers, technology developers, research providers, industry peak bodies, academic colleagues and many other, unaffiliated, talented individuals well versed in the relevant technologies. The author would like to thank those who generously gave of their time to host site visits, participate in face to face discussions and phone conversations and provide email feedback. The author would also like to acknowledge the contribution of all the P2D project team members throughout the process of compiling this report.

Copyright

ISBN: 978-1-921597-74-9 (Hard Copy) 978-1-921597-75-6 (Electronic)

The project that delivered this report is led by the Cotton Research and Development Corporation and is jointly funded by the Department of Agriculture and Water Resources Rural Research and Development (R&D) for Profit Program and all 15 Rural Research and Development Corporations.

Executive Summary

In 2016 the Commonwealth Department of Agriculture and Water Resources initiated a Rural Research and Development (R&D) for Profit Research Project entitled "Accelerating Precision Agriculture to Decision Agriculture". One of the aims the project, and hence the purpose of this review, is to deliver “recommendations for data communications to improve decision making- or decision agriculture”. During the period of August 2016 – June 2017, a series of eight workshops, numerous phone interviews and site visitations around Australia sought to understand the current status of on-farm telecommunications at the farm level in support of a digital agriculture future. This review has sought a ‘producer-eye’ view, seeking to understand the dimensions of key enabling telecommunications utilized by producers, factors constraining the uptake or adoption of available enabling technologies, as well as investigating the future telecommunications needs and opportunities. Information has been solicited from not only producers, but also providers of technologies and data services to producers, as well as those developing those technologies and services.

The timing of this review could not have been better. In the period 2010-2014 the notion of telecommunications as a ‘critical infrastructure’ for rural and regional Australia, and in particular in agriculture has well and truly taken root. Momentum has grown such that during this review period a number of national inquiries concerning telecommunications have been initiated, and in some cases completed. Many of these outcomes have been echoed by contributors to this present review, and while it is not the purpose of the review to duplicate the work of others, any outcomes provided at the ‘producer’ level that speak to these higher level reviews have been retained to provide granularity; a ‘coal face view of the world’.

At the same time there has been a significant increase in the development of end-to-end telecommunications technologies and services offered to producers. So-called ‘second-tier’ telecommunications providers offer their own transmission backhaul capability and in some cases associated cloud based services. Second-tier providers will help extend the value and potential of existing NBN and mobile telecommunication networks. The role of telecommunications in supporting a digital agriculture future is not necessarily technology constrained; if a farm has access to the mobile network somewhere on the farm, or NBN into the farm house then there is technology available to beam it to where it is needed. The real constraint is likely to be around who assumes technical risk, service and price. Entirely new, innovative, methods of extending connectivity over remote regions are in the R&D pipeline; even surfacing for the first time during the period of this review. Others have been around for some time and overlooked; it is time to visit or revisit them.

The on-farm telecommunications market is rapidly evolving but education is one of the biggest challenges faced by those looking for solutions and those offering solutions. Industry needs well-curated case studies and education must target not only consumers of telecommunications services but also technology developers and service providers.

Producer frustrations around existing telecommunications in Australia are fed by a perception that their challenges are not being acknowledged, nor responded to, by network operators or at the industry or national strategic level. There is a lack of appropriate quantitative data around data use ‘behaviour’ of producers and of the capability of existing or planned network infrastructure to cater for that data use. At a national strategic level there is no centralized knowledge of mobile network data carrying capacity, by location. How can we future proof data connectivity for Australian producers without such basic information?

Bearing in mind the critical need for education at all levels, this review includes an introduction to the key telecommunications technologies and services utilized, or at least on offer, to Australian producers and a small number of illustrative case studies of producers and service providers. The report also includes a discussion of future opportunities and the provision of recommendations aimed at further enabling Australian producers to realize a big-data future for their farming business.

Summary Recommendations

Capability and future proofing

Recommendation 1 - Establish an independent group, tasked to oversee mobile telecommunications development and execution strategies aimed at national coverage, including equitable access in rural and regional areas and future proofing (e.g. speed/volume) in light of changes in usage (e.g. connected devices on farm) and growth and complexity in web based services available to producers.
Recommendation 2 - Develop a national mobile network coverage (data speed and volume) database based on datasets held by Australian Communications and Media Authority and the application of standardized network conditions. This network map should then be integrated with relevant state government property boundary datasets, and utilizing unique property identifiers such as the National Livestock Identification Scheme, to quantify farm coverage as a tool for strategic planning of future national connectivity initiatives (e.g. MBSP).
Recommendation 3 - Relevant producer Research and Development Corporations (RDCs), in collaboration or individually assess total data usage behavior (diurnal and seasonal) of producers related to the business and lifestyle of farming.
Recommendation 4 - Carriage Service Providers (CSPs) make available location-based cell data carrying capacity (as related to speed) to potential/existing consumers of carriage services. This could be made available via a website to allow producers to plan 'data movements' and related data generating/consumption activities.
Recommendation 5 – A Universal Services Obligation that recognizes data in all its forms as opposed to data in support of voice (VOIP), with inclusions around the definition of baseline broadband service that recognizes data 'speed'.
Recommendation 6 - State and federal authorities, and relevant codes related to monitoring, enforcing or mediating on issues of compliance and delivery of telecommunications services to consumers, acknowledge the critical importance of data speeds in consideration of 'service' and 'access'.
Recommendation 7 - A satellite broadband 'Fair Use' policy that factors in periods of increased demand associated with 'significant farm operational activities', for example harvesting
Recommendation 8- Multi-point NBN satellite access, including mobile access be granted to rural properties on the basis of criteria related to multiple occupancy and property size.
Recommendation 9 - Improving wireless backhaul infrastructure to cater for the growing demand for supporting on-farm networks, including efficient methods of using spectrum (including white space) and physical assets.
Recommendation 10 - NBN offer information packages aimed at guiding web service providers on necessary optimisations (e.g. HTTPS versus HTTP) to enable web platforms to function via Sky Muster.
Recommendation 11 - Extend the ACCC Broadband performance monitoring program to include those modes of access to Australian farms, specifically with the aim of understanding broadband access experience related to the business and lifestyle of farmers.

Capitalising on opportunity

Recommendation 12 – RDCs develop educational packages, including case studies illustrating on-farm telecommunications technology options for their stakeholders.
Recommendation 13 - RDCs establish demonstrator sites (e.g. in partnership with exemplar producers) to let them see firsthand some of the innovations on site.

Table of Contents

Part 1 On-farm Telecommunications Today

Introduction

Given the 12 thousand year history of farming, in a relatively short timeframe of only the last four decades farming has progressed from what was considered a two-commodity[1] enterprise, namely centred around the production of food and fibre, to five. The fossil fuels crises of the seventies (last century) spawned sector-wide interest in the farm-based production of biofuels, and with landmark events like Kyoto in the nineties, carbon started featuring in wide spread discussions. Most recently a fifth commodity associated with farming has emerged; data.

Data, or more correctly the information associated with crop or livestock productivity data has always been a key part of farming practice, in particular decision making. Historically producers relied upon objective information around cash flow (e.g. income value of produce, cost of inputs) and, day-to-day, subjective information around the producing environment such as plant health and vigour, soil moisture, animal health and live-weight gain/fleece production. In the last 20 years however the evolution of plant, soil and animal transducers; collectively data generating technologies, be it 'roving technologies' such as yield monitors on harvesters or crop and soil surveying tools, or static sensors; the so-called 'internet of things' (IoT) located on farm lands, are offering enormous amounts of live and latent data for digesting into farm decision support systems (DSS). With all commodities, 'transportation' is a key infrastructure. With data, a telecommunications network[2] is the transportation means and transmission of data through wire, optical fibre, or through the air can be considered, in this vein, as respectively the roadway and railways and airways.

Digital agriculture today and the scope of this review

Many of the farm decisions are made in the farmhouse and telecommunications connectivity to the outside world is a key enabling factor. The recently-released Regional Telecommunications Review (Regional Telecommunications Review, 2015) sought to review the adequacy of telecommunications services in regional, rural and remote parts of Australia. 'Adequacy' was benchmarked against telecommunications services considered significant to people in rural and remote parts of Australia AND currently available in urban Australia. This benchmarking process is interesting because it effectively projected the needs of urban Australia (and hence the telecommunications infrastructure/services that have evolved in urban Australia), back onto those who live and work in rural and remote Australia. Ultimately the review focussed on the communications needs of rural households, 'office' businesses and communities.

However not all decisions are made in the farm house. Increasingly producers are seeking to use time on the move; on tractors for example while undertaking guided operations[3], or while waiting between jobs in the yards or out in the paddock to 'run their office'. It is a fundamental truth of human nature that ideas or strategies are often hatched, or problems solved at the time 'one is doing something else'. Producers want to be connected into their business, all aspects of their business, while outside on the farm and not just while inside the farm office. Add to this the obvious safety of life dimension, and having mobile phone access away from the farm house is a key part of staying in touch with the farm workforce.

Following a request in 2015 from the then federal Minister for Agriculture, the Standing Committee on Agriculture and Industry conducted an inquiry into agricultural innovation during 2015 and the early part of 2016. The Committee tabled its report "Smart farming – inquiry into agricultural innovation" in 2016 (Commonwealth of Australia 2016). Unsurprisingly, telecommunications

[1] In keeping with the definition of commodity as being a raw material (consider 'primary agricultural product') that can be bought and sold.
[2] "Telecommunications network " as defined by the TELECOMMUNICATIONS ACT 1997 - SECT 7, means a system, or series of systems, that carries, or is capable of carrying, communications by means of guided and/or unguided electromagnetic energy
[3] Guided operations here means the situation whereby the tractor steers itself- autosteer- while moving along pre-defined transects, as facilitated by on board, centimetre-accuracy Global Navigation Satellite System- GNSS.

emerged as a key issue with 5 out of the 17 recommendations pertaining to education, infrastructure investment and R&D. In terms of the telecommunications needs of producers, the focus was inevitably on the mobile phone and the national broadband network (NBN). It is impossible to consider on-farm telecommunications without these networks.

Lamb (2013) highlighted the significant opportunities of getting farms connected (ostensibly to high speed internet) using the national broadband network (NBN), and the need to get the business and provider service models (including costings) right. A recent study by Salim et al. (2015) examined the relationship between communications technology (CT) and on-farm revenue for the Australian Grains industry and found a significant positive correlation between investment in CT and farm receipts across all states. That definition of CT was just around internet (in its many accessible forms) and telephone. In 2015, Australian grower representative organisation GrainGrowers conducted a survey of 483 producers on the use of technologies on their farms (Agriculture Technology Survey, 2015). More than 83% of producers surveyed owned a 'smartphone' with more than half seeking to use it more than five times per day (almost a quarter using it more than 20 times per day). More than half identified mobile phone and internet/broadband issues as a problem 'impeding some current or potential business operations'.

In terms of the operation of farms, telecommunications goes beyond telephone or desk-top internet connectivity from the farmhouse to the outside world. Increasingly, the intelligence underpinning many on farm decisions (be they taken in the office or on the tractor or in the yards) is derived from within the farm itself, based on data extracted from the soil, plants, animals and machinery. The concept of a new fourth revolution in agriculture, dubbed in Europe as 'Agriculture 4.0' or 'Farming 4.0', has emerged and in its essence we are talking about 'smart farming'. This encapsulates not only the traditional componentry of 'precision agriculture' (Global Navigation Satellite System- GNSS- positioning and guidance, the mechanics of variable rate fertiliser management and generated data layers from multiple sources), but also the digital enabling technologies around collecting data and then putting it back into action; both through digital decision making and machine control (Zarco-Tejada et al., 2014). Hence the notion of telecommunications as related to farming encapsulates not only the dimensions of connectivity from the farm gate to the outside world, but also connectivity within the boundaries; namely from sensors and technologies deployed across the farm land to a point that it can be taken to the outside world.

In undertaking a review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia, the most challenging task is not in surveying the breath of opportunities and challenges, rather it is in defining the scope of the key context, namely 'Digital Agriculture' and then capturing the breadth of solutions appearing on farms to meet these challenges and opportunities. This would have been easy back in the 1990's when precision agriculture was defined around the use of global navigation satellite systems (GNSS) receivers on harvesters for yield mapping, for soil surveying technologies such as the ubiquitous EM38 and for the, then emerging, controlled traffic farming. In those days the telecommunications issues related to being able to access post-processed data (usually made available from service providers) from host websites, hence the focus being on internet connectivity (upload and download speeds) from the farm office. This remains a critical component of precision/digital agriculture and hence a discussion of at-home connectivity will be included in this review, albeit tempered to avoid redundancy with existing excellent reviews undertaken by others (references provided later).

While digital agriculture today still encapsulates 'spatially enabled agriculture' in all its forms, those forms have dramatically expanded to include spatially-referenced data from roving and static sensors, data 'crowd-sourced' from people anywhere on the farm, the sensors, and of course the data and analytics that ultimately feed into DSSs (Figure 1). This means that the definition of telecommunications, and hence the attendant consideration of challenges and opportunities, must include not only mobile and NBN-type telecommunications, be it to the farm house our out in the paddock, but also those forms of telecommunications that reach into the paddock where the plant, animal and soils sensors and other data generating technologies exist. To this end, this review has been divided into discrete segments.

This first section of this review will provide an introduction to, and overview, of the key telecommunication modes considered relevant to farming. This will provide an indication of how

each telecommunication mode fits in the overall picture. The second section will examine challenges faced by producers and telecommunications service providers supported by a number of illustrative case studies. The third section will discuss the opportunities in front of not only producers but also service providers, technology developers and policy makers in enabling a digital agriculture future from the paddock outwards.

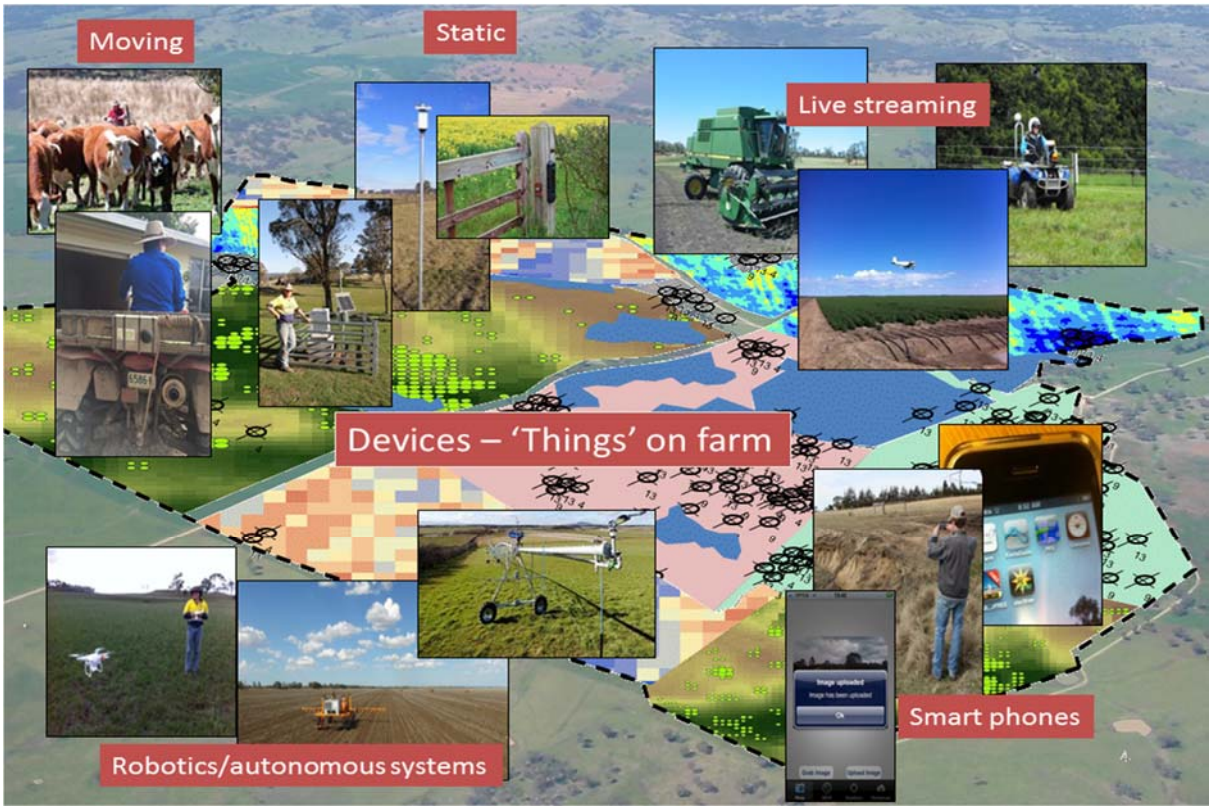


Figure 1. Digital agriculture relies upon all forms of connected 'things' on farms. Examples of data sources (clockwise from top left): 'Moving' such as livestock and vehicle tracking; 'Static' including soil moisture probes, environmental sensors and gate controllers; 'Live streaming' such as machinery telematics, guidance systems and surveying tools'; 'Smart phones' for crowd-sourcing all manner of plant, animal and soil data; and 'Robotic and autonomous systems'. Background map is a composite of example paddock data sets (clockwise from left): Cattle tracking superimposed on pasture biomass; soil moisture maps; crop vigour maps; vegetation class polygons and individual (scattered trees) with identifier and tree class (type).

The anatomy of farm telecommunications

Throughout the process of undertaking this review, discussions involving groups participating in the project workshop series and also with individuals identified by industry participants and stakeholder RDCs, identified three clear priorities that producers see that need to be served by on-farm telecommunications:

1. Safety of life and keeping an eye on things ('peace of mind');
2. The ability to communicate with people and devices to conduct their operations ('function'); and
3. The generation of and access to data on location in the paddock or farm office ('watch and respond').

No single telecommunications technology can be expected to service the needs of all three priority areas, although, for example, a terrestrial mobile phone network, or regional satellite communications network could conceivably do so. Even then could a single network technology or the services (including business models) available with one form of telecommunications technology meet a diverse range of user (producer) needs? The advantage of utilizing a combination of

telecommunications technologies is the ability to access systems that are optimized for specific deployments, for example long-range, low power 'radio' transmitters for small data packets, versus data 'hungry' vision systems that require high capacity, broadband networks.

The boundaries between on-farm and off-farm telecommunications are not distinct. Indeed in undertaking this review there appear as many on-farm telecommunications 'innovations' as there are farms using on-farm telecommunications. Every farm appears individual in terms of meeting the needs of its deployed data generating technologies, its physical communications environment (topography and land systems, access to external connectivity), the requirements for on- or off-farm data analysis, the particular management platform that the data is interacting with, and the ways the information is provided back to the farm management team for decision making and how it is used. Historically (> 5 years ago) this could have been attributable to a lack of widespread, well understood, 'standard solutions' in the market place. This is now changing with the emergence of experienced providers of 'end-to-end' telecommunications solutions for farmers and on-farm devices and link technologies conforming to accepted, established industry standards. A discussion of on-farm telecommunications innovations is not just simply a discussion of telecommunications infrastructure that exists within the farm gate either. It is inextricably linked to the 'outside world' and hence it is useful to also understand the off-farm dimensions as well.

Our telecommunications industry

The first step in understanding how off-farm telecommunications works is understanding how the telecommunications industry functions. The telecommunications industry is regulated by the Australian Communications and Media Authority (ACMA); Australia's regulator for broadcasting, the internet, radio communications and telecommunications. Under the Australian Telecommunications Act 1997, there are two types of persons or organisations that can provide telecommunications services (known as 'carriage services') to the public. These are carriers and carriage service providers (CSPs).

Carriers are persons who own a telecommunications network unit to supply carriage services to the public. Carriage services include services for carrying communications, for example telephone services, Internet access services and Voice over Internet Protocol (VoIP[4]) services.
An owner of a telecommunications network unit used to supply a carriage service to the public must hold a carrier licence, unless an exemption applies or a nominated carrier declaration (NCD) is in place for that unit.

An NCD allows the owner of a network unit[5] that is used to supply carriage services to the public to nominate a licensed carrier to assume responsibility for all carrier-related obligations for that network unit. In turn, an NCD also allows a licensed carrier to accept regulatory responsibility for the network unit on behalf of the owner of the network unit.

The licensed carrier applies to the ACMA for the NCD. The applicant must be able to provide evidence that it will be in a position to comply with all the obligations under the Telecommunications Act in its capacity as the nominated carrier for the network unit. Where an NCD is in force, the owner of the network unit does not require a carrier licence.

At the time of writing (4th October 2016) there are 258 active licenced carriers in Australia. These include the three mobile network operators (MNOs) Telstra, Optus and Vodafone Hutchison Australia (VHA), but also many carriers or Carrier Service Providers (CSPs) that resell access to these three networks. These are called mobile virtual network operators (MVNOs), of which there are more than 60 providing services in Australia (Telstra, 2016). There are presently 85 active NCDs in Australia.

[4] VOIP is the transmission of telephone calls over digital computer networks including the Internet.
[5] There are four types of network units: single line links connecting distinct places in Australia; multiple line links connecting distinct places in Australia; designated radiocommunications facilities and other facilities specified in a ministerial determination under section 29 of the Telecommunications Act (ACMA 2016).

A CSP is an entity that supplies a carriage service to the public using a telecommunications network unit. CSPs can include organisations (MVNOs) that resell time on a carrier network for phone calls, provide access to the internet (Internet Service Providers) or provide telephone services over the internet (VoIP service providers). A CSP uses, but does not own, a telecommunications network unit to provide carriage services to the public. It is the CSP, however, not the carrier which has direct contact with consumers. It is easy to confuse carriers with CSPs. For example Telstra is a CSP for Telstra the 'carrier'. However there are many CSPs that may also utilise the Telstra's (the carrier) network; for example CMobile and ALDImobile. Other examples include Commander, iiNet and TPG Telecom, which utilises the Optus network, and Reward Mobile and GoTalk which utilises the VHA network[6]. Some CSPs offer subscribers the opportunity of nominating the network they wish to utilise. CSPs are not required to obtain a licence from ACMA to supply a carriage service to the public, although many of them hold NCDs enabling them to act on behalf of the network owners. It is worth noting that CSPs may only have access to certain network types from a given MNO, for example CSP 'A' may have access to the 3G network of MNO 'B' but not, for example the higher bandwidth/faster speed 4G LTE (for example, International Direct Dial, 2017). Network types will be discussed later.

Telecommunications networks

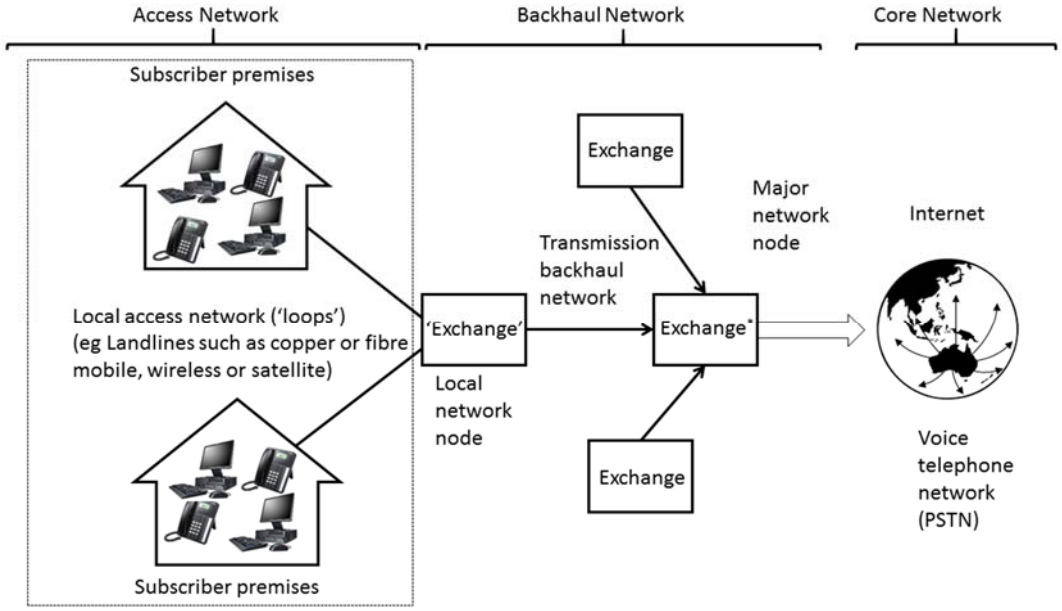
Telecommunications networks are either fixed or mobile and this relates to the level of mobility afforded to subscribers. A fixed network is where a call/data exchange is initiated or received at the subscriber's premises. In a mobile network a call or data can be initiated or received by an individual handset at any place in which the network operates.

A very basic depiction of the structure of a network (or 'network architecture' as it is more formally known) is depicted in Figure 2a (ACMA 2007). In its simplest form, fixed networks consist of multiple local access networks, linked together by a transmission 'backhaul' network. Local access networks are also known as the 'local loop' and represent the 'last mile' of a fixed network. The local access network includes the connection between each subscriber and a local network node, commonly known as an exchange or switching point, by way of particular transmission media such as copper wire, optical fibre, mobile, wireless or satellite technology. Normally, the network also includes a further transmission link from this node to a major network node that aggregates and interconnects traffic from a number of exchange or switching points. This is a general hierarchy although it should be noted that the exact hierarchy of a telecommunications networks varies with carrier or NCD.

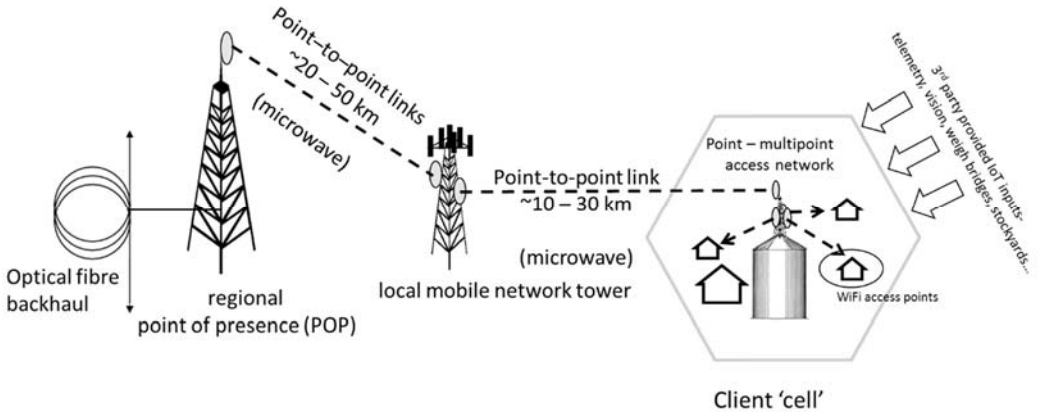
'Backhaul' is a word commonly encountered in telecommunications discussion. Backhaul refers to the medium and long distance optical fibre and microwave transmission networks that connect local exchanges, main exchanges and mobile and fixed wireless towers between all population centres in Australia (Figure 2b). Backhaul networks carry voice and data transmissions (ACMA 2007). Whilst it has a somewhat complicated definition in formal telecommunications network language, it is the intermediate links between the small 'sub-' or access networks and the core network, the latter which connects, effectively, nations. In everyday language, backhaul, which is essentially the wholesale transmission market, is generally associated with the commercial entities that provide and manage it, for example, NBN Co, Telstra and Optus operate substantial backhaul transmission networks. Providers of backhaul guarantee a quality of service (QoS) to other carriers that utilise their networks and retailers (CSPs). Quality of service refers to the performance of the network, in particular as 'experienced' by users of the network. Determining exactly what QoS means is difficult given there is a no internationally-recognised standard set of metrics (Productivity Commission, 1999). In general terms, QoS is a set of specific requirements provided by a network to users, which are necessary in order to achieve the required functionality of an application (service) (Carvalho de Gouveia and Magedanz, 2009). Quality relates to those non-price attributes of a product or service, including performance, reliability and other non-price features (ACCC 2016a). Typically users specify performance requirements and the network commits its bandwidth making use of different QoS schemes to satisfy the request. QoS can be degraded by congestion, which is

[6] Note these examples, while correct at time of writing (January 2017), are subject to change.

caused by traffic overflow (bottlenecks); delays, caused by sub-optimal performance of networking equipment under large loads, as well as caused by distance or retransmission of lost packets; shared communication channels, where collision and large delays become common; and limited bandwidth networks with poor capacity management. This is often confused by quality of experience (QoE) which focusses on user perception of quality. Generally assessments of telecommunications performance, and in particular as it relates to broadband is given to mean data transfer rate (e.g. internet access speed) (ACCC 2016a). A detailed discussion on quality assurance and service delivery safeguards can be found in ACCAN (2015).



(a)



(b)

Figure 2. (a) Schematic diagram of a basic network structure. (b) An alternative view of networks, especially relevant to rural and regional Australia.

A mobile network is one where the last link is wireless. Generally this is accepted to describe a mobile phone network but in fact this equally applies to any form of wireless network including 'radio' as used for telemetry purposes, and Wi-Fi etc. A typical example of a network structure as relates to telecommunications in rural and regional Australia is given in Figure 2b. Much of backhaul is carried on either wireless microwave links or the ever-growing optical fibre network. The

backbone fibre network ‘emerges’ at a regional point of presence (POP) from which point-to-point links, generally microwave transmission towers radiate links out to local POP, for example mobile cell towers (discussed later). Further POP links may be established to local access networks, the later which may support point-multi-point links, such as within a client ‘cell’ comprising a farm with numerous access points (e.g. outbuildings or sensor hubs). Increasingly large and small carriers and CSP’s are reaching out through backbone networks and inside the farm gate offering services that include the on-farm data transmission technologies and infrastructure. These entities are purchasing access to the fibre networks, so-called dark and lit fibre, and segments of spectrum to allow them to operate microwave point-to-point links alongside the larger network operators. Dark fibre refers to the use of unused carrying capacity of existing fibre networks. A service provider (‘client’) can lease unused strands of ‘dark’ fibre optic cable from the network provider to create their own privately-operated optical fibre network rather than just leasing bandwidth. The dark fibre network is separate from the main network and is controlled by the client rather than the network provider. Light fibre refers to cable activated by CSPs. There is a small but growing number of farm telecommunications service providers which are also ‘carriers’. These carriers lease access and then provide fully-managed services (including backhaul) to clients.

Communicating with devices on-farm

There is considerable air-time given to the internet of things (IoT), and in particular the promise of IoT in agriculture. Strictly speaking, and in the context of farming, IoT is a technological subset of ‘AgTech’; the latter being “a collection of digital technologies that provide the agricultural industry with the tools, data and knowledge to make more informed and timely on-farm decisions and improve productivity and sustainability” (StartupAUS, 2016).

In terms of duration, the relatively short history of telecommunications on farm has been dominated by radio communications (~80 years), ostensibly between people. Radio communications in turn was revolutionised with the appearance of cell phone communications (~25 years; where available). However the internet has now matured to a point that it carries a substantial amount of communications, with on farm sensor innovations today relying heavily on it. Indeed it is widely accepted that “Internet networks are set to eclipse the capabilities of all previous forms of distance communication and will provide the communications backbone for farms in the future” (Veldis et al., 2007). Add to this the equally rapid pace of development of transducers; devices capable of rendering chemical, biophysical and physical (including motion) measurements from plants, soil, animals, and, other assets, and of course micro-chip based GNSS sensors, into electrical signals.

The ability of IoT systems to communicate with each other and to the outside world is critical. Worldwide, Bughin et al. (2015) estimate that, on average, 40% of the potential value of IoT data across numerous key sectors, including agriculture, will not be realised unless interoperability is achieved.

The term ‘telemetry’ is used to define the automatic communications process whereby data are collected at one location and transmitted to other locations for the purposes of monitoring. There are a number of possible communications pathways to and from remotely connectible devices on farm and this is largely dictated by the volume of data that is to be communicated, the speed at which it is to be transmitted, and also whether it is necessary to transmit the data live or whether some form of latency is acceptable. This applies equally to whether data is being sent to a remote device, for example for the purposes of actioning a command such as releasing a gate or door latch in a shed, switching on heaters, lights or pumps and panning and zooming a remote camera, or whether data is being sent back from a device such as a weather station, remote camera, or a plethora of other plant, soil, water, environmental, animal or asset sensors.

A sensor is a device that acquires a physical quantity and converts it to a signal suitable for processing. The active element of a sensor is the ‘transducer’; a device that converts one form of energy (input quantity) into another (output quantity), usually an electrical output such as an electric current or voltage. Note that the reverse; a device that converts an electrical (input) signal into a physical quantity (output) is called an ‘actuator’. This is something that can be remotely

commanded to do something, such as a hydraulic piston for opening or closing a farm gate. Remote controlled cameras are an example of a combined sensor and actuator system whereby the camera can be remotely tilted, panned or zoomed (actuators) and then the vision sent back for viewing (sensor). The electrical output of sensors if often analogue (continuous) and this is then converted into a digital signal, via an analogue-to-digital (A/D) converter. Sensors can be connected via a number of means. The lowest cost solution, generally suited to distances up to 50- 100 m, is via direct cable connection. One advantage of this method is that you can also provide power via the same cable and hence do not need solar panels as the power source. Cables can often be connected either into a host computer (e.g. a serial port) or into the local area network (e.g. using a serial to ethernet convertor). However nowadays this option is rarely used. The vast majority of sensors are connected using entirely wireless means.

On-farm radio networks – LANs, WLANs and WANs

When the sensor output is transmitted by a wireless transmitter, the assembly containing the sensor(s) and transmitter is called a sensor 'node'. The transmitting of data from one device to another within the farm effectively constitutes a telecommunications network which includes nodes and communications links between them.

The basic network 'topologies' are depicted in Figure 3. A 'node', which is where the sensors reside, is a connection end point and multiple nodes may communicate with a 'hub' which can store information and forward it on to other hubs (for example 'store and forward' systems), ultimately finding its way to the point at which a connection is made to the outside world; the 'base station' or 'gateway'.

The nodes themselves can also play a direct role in the communication chain. Multiple nodes may relay information between each other in a 'mesh network'. Meshed network designs are becoming more commonplace and sophisticated (Ojha et al., 2015; Noor et al., 2016). 'Self-healing' mesh networks are generating particular interest in the farming context for their ability to transmit/receive information along alternative routes if one of the sensor nodes fail for some reason (Heires, 2015; Kaur et al., 2016). A star network, is a topology where nodes communicate individually, directly with a central gateway. This topology is utilised in low powered wide area networks (LPWAN). At this point, a discussion of network architecture is rather a theoretical exercise. The notions of node, hub and base/station-gateways will be further illustrated when we discuss specific examples later on.

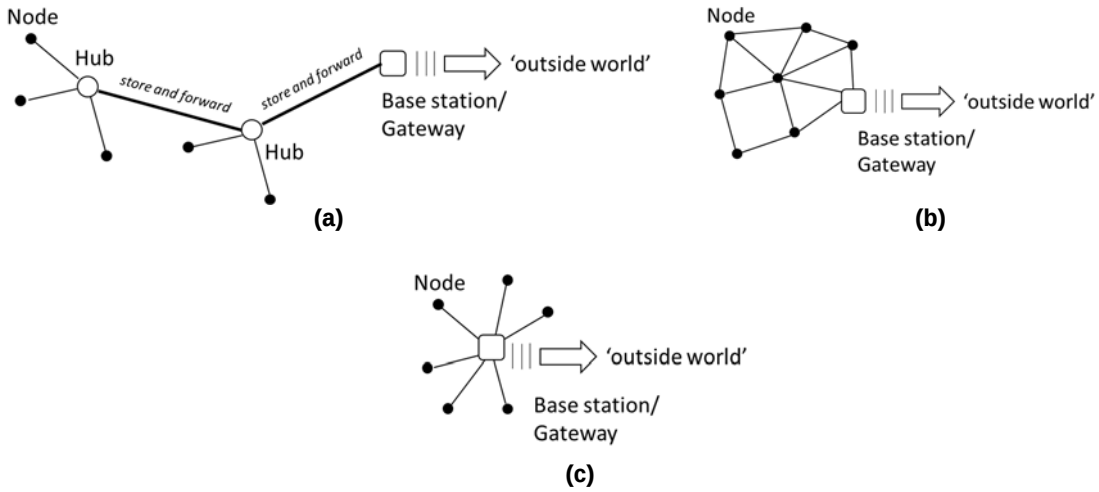


Figure 3. A basic network diagram as relates to (a) 'store and forward', (b) 'mesh', and (c) star farm sensor networks.

There are a number of 'classes' of network based on the spatial scale. A local area network (LAN) comprises fixed links/nodes within a limited area and is generally taken to be within buildings (like

the farmhouse), or a collection of buildings (e.g. shed precinct). A wireless local area network (WLAN) is a wireless version of LAN using a wireless distribution method which gives users the ability to move around within a local coverage area and yet still be connected to the network. A WLAN can also provide a connection to the wider Internet. Most WLANs are based on IEEE 802.11 standards associated with the now ubiquitous 'Wi-Fi' brand name (standards discussed in the following section). A wide area network (WAN) is a network that extends over a large geographical distance. In the context of farms (including the farming land) we are talking about wireless WANs. Often producers talk about Wi-Fi on their farms when talking about farm wide networks. Unless they are talking only about the farmhouse 'Wi-Fi' (i.e. WLAN), when it comes to longer range outdoor use, strictly speaking they are talking about a WAN enabled by radio links utilising the frequencies also associated with their in-house Wi-Fi.

Wireless standards

The Institute of Electrical and Electronics Engineers (IEEE) develops and maintains wireless communications standards (IEEE, 2017). For example, IEEE 802 covers network standards. The sub-group 802.3 is wired Ethernet and 802.11 is for WLANs, also known as Wi-Fi. The 802.15 subgroup of standards specifies a variety of wireless personal area networks (WPANs) with the sub-sub group 802.15.1 dealing with Bluetooth. The 802.15.4 category is highly relevant to on-farm applications as it relates to low-data-rate WPANs. The 802.15.4 category was developed for low-data-rate monitor and control applications and extended-life low-power-consumption uses. The basic standard with the most recent updates and enhancements is 802.15.4a/b, with a special group 802.15.4f for active (battery powered) radio-frequency identification (RFID) uses. Special versions of the standard, such as RFID, still use the same base radio technology and protocol as defined in 802.15.4a/b.

The most widely deployed enhancement to the 802.15.4 standard is ZigBee, which is a standard of the ZigBee Alliance (Zigbee, 2017). This organization, effectively a community of adopters, participants and promoters, maintains, supports, and develops more sophisticated protocols for advanced applications. These enhancements include authentication with valid nodes, encryption for security, and a data routing and forwarding capability. In other words, the standard supports mechanisms that allow sensors to communicate their status/health and to re-route data if necessary to reach the destination. Hence, the most popular use of ZigBee is wireless sensor networks using the mesh structure (Figure 3b). Another standard, 802.15.5, which also deals with mesh networks underpins technology around extending network coverage without increasing the transmit power or the receiver sensitivity, enhanced reliability via route redundancy and easier network configuration and improved device battery life.

Radio transmission and antennas

The transmission range of wireless sensor nodes varies significantly. Radio range basically relies upon three factors- frequency, power and environment. Some are designed for short-range, indoor applications of a 50 – 100 m, while other sensors can transmit data to a receiver located tens of kilometres away. As a general rule, the lower the frequency, which also means longer wavelength[7], then the better is the penetration characteristic and ability to refract (bend) around obstacles. Mind you, the higher the frequency, the better the reflective properties of obstructions and this can sometimes be used to advantage in reflecting a signal off an object rather than passing through it. This is useful in back-scatter devices (which will be mentioned later). Generally the lower the frequency the longer the transmission range; an assumption borne out of the fact that free space (read this to mean open-air, line of sight) attenuation of radio waves increases with frequency. It is a little more complicated because the way radio waves interact with obstacles also is dependent on the frequency. Also the frequency affects the performance of antennae; these are the devices at either end of a link used to convert the electrical signals into radio waves and vice versa.

The frequencies we are allowed to transmit and receive radio signals across our landscapes is governed by laws. Laws vary by country and region as to which parts of the wireless spectrum are

[7] Wavelength is always inversely related to frequency; ie higher wavelength means lower frequency.

available for use without specific licenses. It stands to reason that those portions of the spectrum that do not require licenses are more popular in terms of widespread commercial use. In Australia this includes 915 - 928 MHz and 2.4000 – 2.4835 GHz (Wi-Fi) (Australian Radiofrequency Spectrum Plan 2013), and these are the major frequencies that manufacturers of farm radio devices tend to use. As part of the industrial, scientific, and medical band (ISM), users do not need a radio license to operate on these frequencies. However it is worth noting that there is no such thing as 'unlicensed' spectrum in Australia. Users must be licensed to operate radiocommunication transmitters. However the ACMA management approach to the 915 MHz and 2.4 GHz bands is to apply a 'public park' concept with respect to devices considered 'low-interference potential devices (LIPD)'. Under the 'public park' concept, all LIPD users are able to access a small portion of the total resource (the frequency band) and to share that resource in a way that requires minimal regulatory intervention. Users of WLAN devices operating in these frequency bands are required to comply with a set of conditions. The LIPD class stipulates no interference is to be caused to other radiocommunications users, no protection from interference is offered and there is no licence fee (ACMA 2016c). An excellent discussion of currently available spectrum with respect to IoT is given in IOTA (2016).

It is worth inserting a cautionary note here. Different countries/regions in the world have different licence-free spectrum allocations and any user in Australia needs to be mindful of the fact that a wireless transmitting device built in one country (e.g. for a domestic market) may not be compliant in Australia (i.e. operates outside the allowed frequency bands or does not comply with the requirements of the LIPD class) and hence would be illegal to operate without a specific licence.

For the purposes of introducing the basic principles and ultimately understanding how wireless systems perform in Australia, we can now focus on two frequencies; '915 MHz' and '2.4 GHz' to encapsulate the two most commonly used ISM 'bands'. A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern is known as a 'gain'. The measurement is typically measured in dBi (Decibels relative to an isotropic radiator- or antenna[8]). Antenna are divided into two basic classes- omni-directional and directional. Three commonly used antenna designs are depicted in Figure 4.

(a) (b) (c)

Figure 4. Three common types of antenna (a) Omnidirectional ('Omni'), (b) Parabolic grid (or semi-parabolic grid) and (c) Yagi (Source: (a) http://maxcomm.co.za; (b) http://www.l-com.com; (c) https://www.scmsinc.com).

An omni-directional antenna (Figure 4a) radiates, or collects, radiofrequency energy from all directions equally on a plane. The strength/sensitivity is highest at rights angles to the length of the antenna, decreasing to zero in a direction along the length of the antenna. The parabolic and Yagi antennae (Figure 4b & c) are examples of directional antennae.

[8] An isotropic antenna is purely a theoretical construct; an antenna that can radiate uniformly in all directions- ie out through a sphere. It is a useful benchmark in industry for comparing antenna performance characteristics.

High ‘gain’ antennae are required to cover long distances. The gain of a reflector type antenna, such as a parabolic grid (Figure 4b) increases with increasing area of the parabolic surface, and more so with higher frequencies. For example, for a given physical size, the antenna gain at 2.4 GHz is significantly higher than an antenna at the lower frequency of 915 MHz. Alternatively, for a required gain an antenna operating at the higher frequency can be physically smaller than that operating at the lower frequency.

The deployment of an omni antenna versus directional antenna generally comes down to the structure of the overall wireless sensor network (WSN) and the distances involved. A directional antenna guides and receives energy from a predefined single direction. For example a distant sensor node would use a directional antenna to link with a base station/gateway. That base station/gateway would similarly use a directional antenna if it was looking for just that sensor node (Figure 5a). If the base station/gateway were receiving signals from multiple nodes in different directions then an omni antenna would be used on the base station/gateway (Figure 5b).

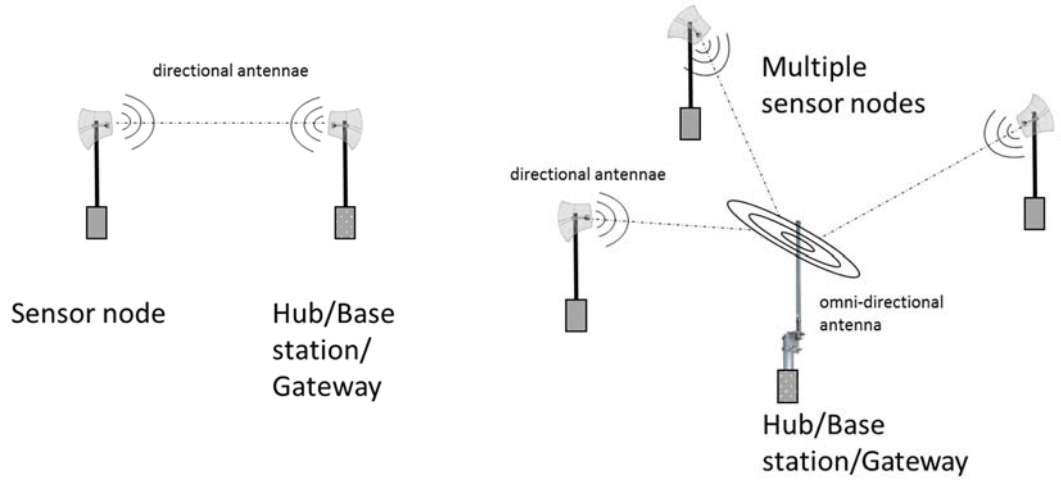


Figure 5. A basic wireless sensor network (WSN) indicating use of different antenna types used in (a) point-to-point and (b) point-to-multipoint links.

Atmospheric water vapour, fog and rain attenuate radio signals and the attenuation increases with increasing frequency. Rain fade is the attenuation or interruption of wireless communications signals resulting from water droplets (rain, mist, fog, snow) when the droplet separation is comparable to the signal wavelength. Ultimately susceptibility to rain fade increases with increasing frequency (shorter wavelengths), typically appreciable at higher frequencies, namely ≥11 GHz.

Both frequencies require "line-of-sight" for reliable operation. In many cases the ability of an obstruction to obstruct a signal boils down to its electrical conductivity (e.g. metal versus non-metal, or water content) and its physical size. Physical size doesn’t mean how big the object is, rather its similarity in size to the wavelength of the radio signal. For example, the higher frequency 2.4 GHz signal has a shorter wavelength of 12.5 cm, whereas the lower frequency of 915 MHz signal has a longer wavelength of 33 cm[9]. Trees with leaves that have dimensions near the wavelength of 2.4 GHz, but which are typically shorter in length than the wavelength associated with of 915 MHz, will cause higher attenuation at 2.4 GHz. Beyond this ‘rule of thumb’ it is difficult to quantify the attenuation due to trees in the radio path. For very long distance links it is recommended that the antennas be elevated to clear all obstructions. Here we don’t just mean obstructions in front of the antenna, or in direct line of sight between antennae. The entire radio beam from end to end

[9] Wavelength is always inversely related to frequency; ie higher wavelength means lower frequency.

looks like a long thin party balloon- thin at the ends and thick in the middle. Attenuation kicks in if any part of that beam[10] 'touches' an obstruction along the way. When transmission distances of 10 km or more are being considered, we need to also factor in the curvature of the earth and atmospheric refraction (bending) in ensuring we minimise 'contact'. The 2.4 GHz has an advantage in this respect because as it propagates through the air from a directional antenna to its receiver, it swells out to a narrower radius than the lower frequency 915 MHz waves. For example, at 2.4 GHz, for a 5 km link the radius of the critical zone is approximately 12 m at the midpoint (2.5 km). Note that over this modest distance, for 'flat' ground, the curvature of the earth lifts the midpoint up another 0.5 m. That would require an antenna 12.5 m high at either end to avoid 'contact' with the ground. At 915 MHz the critical zone is approximately 20 m in radius at the midpoint, plus that 0.5 m of extra ground height, meaning antenna need to be 20.5 m high at each end. Put simply, the higher frequency of 2.4 GHz has the advantage of requiring shorter antenna towers for any given ground, in addition to allowing for smaller dimension (and lighter) antennae for any given gain requirements

Frequency, bandwidth, capacity and speed

The transmission frequency of a particular radio link refers to the 'carrier' frequency- that is the frequency of the signal conduit that carries the information. The information to be transmitted is coded onto the carrier waves; a process known as 'modulation'. There are a number of ways of coding the information onto the carrier, and a discussion of these can be highly technical. The transmission ('carrier') frequency influences the amount of information that can be carried on the signal and the way information is coded also affects the amount of information that can be carried. So it is worth at least covering some basis terms as, again, these are bandied around in communication paraphernalia, often to the confusion of the consumer.

There are two types of signal transmission- analogue and digital. Analog transmission involves the use of a continuous signal and is particularly suited to short range transmission (where repeaters aren't required), and in particular voice communications (e.g. CB/UHF radios). The information is conveyed by modulating by one of two means; Amplitude Modulation (AM) and Frequency Modulation (FM). Analogue transmission systems are increasingly becoming redundant to digital transmission systems. Digital transmission involves the transfer of digital messages originating from a sensor/transducer or from an analog signal such as a phone call or a video signal, digitized into a bit-stream using some form of analog-to-digital (A/D) conversion and data compression method. Digital Modulation is a generic name for modulation techniques that uses discrete signals to modulate a carrier wave. The three main types of digital modulation are Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Amplitude Shift Keying (ASK). IoT type devices and networks involve almost exclusively digital communications.

Bandwidth is the difference between the upper and lower frequencies (in a continuous set of frequencies) used to transmit signals; in other words the frequency range occupied by the coded (modulated) carrier. For example many radio channels have bandwidths of 20 MHz or 40 MHz. The higher the carrier frequency, the higher the bandwidth. It is worth noting some basic definitions here as they are sometimes used incorrectly. The signal bandwidth (as discussed before) is the range of frequencies present in the signal, as constrained by the transmitter. The 'Channel Bandwidth' is the range of signal bandwidths allowed by a communication channel without significant loss of energy (attenuation). Probably the best way to appreciate the value of carrier frequency selection is in terms of the following. The transmission of telephone-quality audio signal requires about 3 KHz of bandwidth, while a TV quality transmission requires about 4 kHz; and there are approximately 10 times more of these bands between 2 and 3 GHz than there is between 900 MHz and 1 GHz. Applying the same logic, the higher frequency of 2.4 GHz has higher available bandwidth compared to the lower 915 MHz frequency.

Finally, the Channel Capacity or Maximum Data rate (or bit rate), generally known simply 'transmission speed' is the maximum rate (in bits per second - bps) at which data can be transmitted over a given communication link, or channel. It therefore stands to reason that the higher the carrier frequency, then the higher the upper limit of the modulation frequency available

[10] Known as the first Fresnel zone

to encode information on that carrier. Signal strength is a key variable in transmission speed of any radio device. Assuming there is no network-imposed constraints at either end of wirleless transmission link, speeds increase in proportion to signal strength (or bandwidth). In the absence of any obstruction effects, halving the distance to an omni-directional antenna increases the signal strength by $2^2 = 4$ times. This is the so-called 'inverse-square law'. A reality of transmission networks, however, is that systems at either end will invariably constrain speed for any given signal strength between the transmitter and receiver.

With ever increasing numbers of radio sources/receivers, interference and security are key considerations. Rather than a single carrier frequency, a transmitter can broadcast the information using a range of frequencies; known as 'spread spectrum'. 'Frequency hopping' (FHSS) involves rapidly switching the carrier wave amongst numerous frequency channels, using a 'pseudorandom' sequence known to both the transmitter and receiver. Another method, direct-sequence spread spectrum (DSSS) involves adding known noise to the transmitted signal.

Spectral efficiency, spectrum efficiency or bandwidth efficiency refers to the data rate that can be transmitted over a given bandwidth. Measured in bits per second per unit frequency slice (i.e. per Hz; namely bps/Hz), spectral efficiency is a measure of how efficiently a limited frequency spectrum is utilized by the communications system and is, for example a measure of the quantity of users or services that can be simultaneously supported by a limited radio frequency bandwidth in a defined geographic area. It may be defined as the maximum aggregated throughput or 'goodput', summed over all users in the system, divided by the channel bandwidth. This measure is affected not only by the single user transmission technique, but also by multiple access schemes and radio resource management techniques utilized. Typical Wi-Fi spectral efficiencies (per site) range from 0.9 to 1.2 bps/Hz.

Transmission power

In addition to the physical design of antennae, transmission power is a key factor in determining the range of wireless systems (and data speeds). The power of a transmitter (or the signal strength experienced by a receiver) is measured in dBm, which is the decibel scale referenced to 1 milliwatt (1 mW). A power level of 0 dBm corresponds to a power of 1 mW. As the decibel scale is a logarithmic scale a 10 dB increase in level (+10 dB) is the same as a 10x increase in power- likewise -10dB equates to $1/10^{th}$ of the power, or in this case 0.1 mW.

The power level of a transmitter is defined in terms of, again, a hypothetical isotropic radiator (antenna). In radio communication systems, the equivalent isotropically radiated power (EIRP) is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in a given direction from the deployed antenna. When installing a wireless system with an external antenna, the EIRP calculation of the assembled device should not exceed the Australian class license limit, for example the LIPD class which is where the majority of connected devices would seek to operate. Ultimately when installing a system, the user either adjusts the transmitter power output, the length of cable between the transmitter and the antenna (which itself introduces attenuation) and/or the choice of antenna (gain). Power levels are capped (ACMA 2016c). As with frequency selection, care must be taken to ensure any purchased equipment, especially from overseas that may be destined for a domestic rather than export market, complies with power caps. Australian regulations allow higher overall output power if the system uses spread-spectrum techniques discussed earlier (ACMA, 2016c). Higher field strengths are allowed because spread-spectrum systems are less likely to interfere with other systems compared to single-frequency transmitters, are more immune to interference from (or causing interference to) other systems, and hence utilise the available bandwidth more efficiency. For example devices operating under the LIPD class licence in the 915 – 928 MHz range are limited to 1W EIRP whereas a maximum radiated power of 4W EIRP is authorised in the 2.4 – 2.4835 GHz band for digital modulation transmitters or for frequency hopping transmitters that use a minimum of 75 hopping frequencies (ACMA 2016b).

In summary, over long distance links several factors contribute to the radio link performance. It is not the purpose of this review to recommend designs. Even though the open-air (free- space) loss at 915 MHz is lower than at 2.4 GHz for purely physics reason, when you consider the typical

antenna gains and antenna heights required to clear obstructions, a 2.4 GHz radio link often has the advantage.

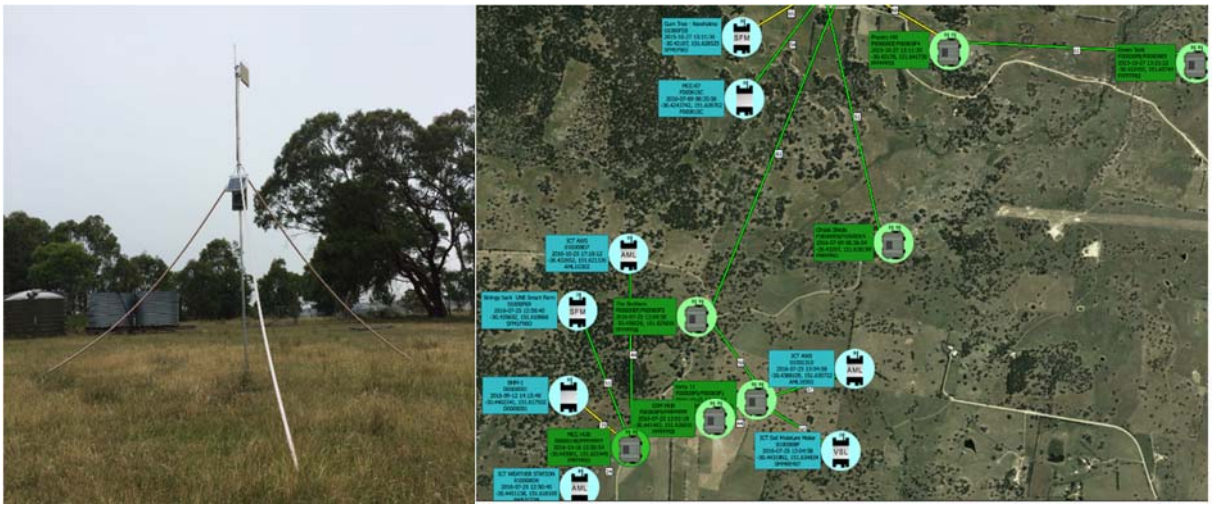
Users of the two key frequency bands, and in particular the 2.4 GHZ band, are experiencing increasing levels of interference because so many devices around us use the same band. The unregulated 'public park' concept applied to this band renders responsibility of managing interference on the user. The extension of wireless WANs over longer ranges, and the concentration of multiple separate systems on common infrastructure such as local towers often brings the challenge of interference to a head. There are community wireless groups that work to grow awareness of such issues and promote open communications between networks to mitigate the effects of interference when designing and deploying WANs. One example, Air-Stream Wireless Inc. (ABN 63553275830; Walkerville SA) is committed to "minimizing the impact of interference through public awareness, and providing an open platform for wireless LAN users to share information to maximize the effectiveness of their equipment and minimizing interference" (Air-stream Wireless, 2016).

Given the undeniable (and unavoidable) physics at play, the regulatory environment within which all producers and technology providers have to work and the increasingly congested airspace within which we are all trying to co-exist, there is one certainty all producers must face in deploying WSNs on their farms. The transmit/receive performance of any WSN will never be as it is 'on the box'. Without a doubt, the first step for any producer wishing to deploy or modify a WSN on their farm is to undertake a radio strength test across the farm landscape to ascertain the best locations for those transmitters and receivers.

Store and forward telemetry

Store and forward telemetry systems are useful where large distances are involved. Intermediary hubs act as repeaters[11]. Numerous innovative systems have been designed with the capability to receive and store information, and then retransmit them onwards as available bandwidth allows. As the name suggests, these systems retain data at the hubs until successfully passed on to the next hub or gateway which is good for data security. Typical examples, such as the 2.4 GHz Dosec Design/ICT International system (Figure 6) will store data at the nodes and hubs whenever the communications channels fail or during congested transmit/receive periods, and synchronously forward packets whenever the channel is open. The data packets ultimately end up at the network gateway.

[11] A repeater as the name suggests is a device that receives a radio signal and retransmits it. In a farming context, they receive signals from transmitters at the edge of their transmit range, and/or located behind an obstacle such as a hill, and re-transmit it onwards to the next hub or base station/gateway.



(a) (b)

Figure 6. (a) Example of a 2.4 GHz store and forward telemetry system developed by Australian companies ICT International (www.ictinternational.com) and Dosec Design (www.dosec.com.au). Note the omnidirectional antenna on the top of the tower for receiving signals from nearby nodes and the directional antenna beneath it for forwarding the signal to the next node/gateway. (b) Web server user interface providing updated signal strength and hub/node health information (nodes = blue icons, hubs = green icons) (Source: UNE SMART Farm).

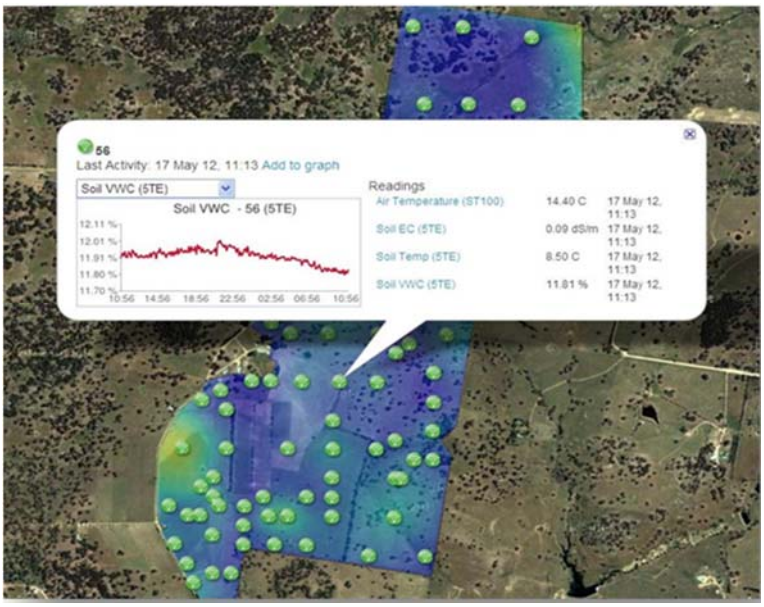
Mesh networks

Like the other network architectures, mesh networks are finding increasing use on farms. The use of the ZigBee radio standard (802.15.4) which facilitates a 'self-healing' capability is particularly desirable given the harsh environmental conditions of which many sensors nodes have to exist (e.g. cattle grazing, weather). ZigBee radios allow the network to actively change pathways to suit conditions. Moreover, typical mesh sensor networks have the added capability to hold data for an end or router node while waiting for it to 'wake up'. This offers a level of data security but also supports the use of devices that can be allowed to 'sleep' when not being used to collect measurements, and hence save battery power.

Given that the each 'hop' in communicating data from a given sensor to the gateway penalises the bandwidth/speed, mesh networks are particularly suited to relatively small scale deployments on farms, or where node density supports low signal strength transmissions, small bit messages and the landscape provides for high node visibility (Figure 7). One example is Australian company AirMesh (www.airmeshelectronics.com.au) which utilises Modbus, a serial communication protocol over ZigBee.

Whilst not related to deployed 'things' directly, the use of mesh network technology is also being trialled for providing internet access to users who would otherwise not have it, by creating intelligent community networks bridging to those locations that do have it. One example is WYSPS (www.wysps.net.au) which is undergoing some limited trial work in Bega, NSW (Eckelmann, 2017). While in its infancy, the use of low cost Wi-Fi nodes (~$20) (Figure 8) is desirable, but with 'hop' ranges of only up to 50 m, multiple hops are required to reach the neighbour's boundaries which subsequently penalises bandwidth/speed to that neighbour. Moreover, it has been found to be difficult to find neighbours willing to share their bandwidth into the mesh community when their own bandwidth (e.g. ADSL2 or wireless NBN) is already being fully utilised at home.

(a)



(b) (c)

Figure 7. (a) 3 nodes (circled) of a (b) 100-node self-healing mesh network and user interface, (c) mesh gateway receiver and mobile network modem (Source: UNE SMART Farm).

Figure 8. An example of a low-cost Wi-Fi node capably of forwarding internet access as deployed in a community WYSPS mesh network (Source: Carsten Eckelmann, 2pisoftware).

Long range/lower power WAN– 915 MHz

While limited in bandwidth compared to 2.4 GHz, a significant focus area of on-farm network technology and for data/information service providers is long range and/or lower power radio devices (LoRaWAN/LPWAN) utilizing the 915 MHz band. LPWAN technologies are designed for

machine-to-machine (M2M) and IoT networking environments. With decreased power requirements, longer range and lower cost than a mobile or 2.4 GHz network, LPWANs are considered by many to enable a much wider range of M2M and IoT applications which, to date, have been constrained by budgets and power issues. Importantly, LPWAN data transfer rates are very low, often less than 5 kbps and only 20-256 bytes per message are sent several times a day. Consequently the power consumption of connected devices is very low, often supporting battery life in the range of years; up to 10 years in some cases. LPWAN enables connectivity for networks of devices that require only low bandwidth and typically utilises a 'star' topology (Figure 3(c)). The networks can also support more devices over a larger coverage area than consumer mobile technologies and have better bi-directionality. While Bluetooth, ZigBee and Wi-Fi are generally favoured for consumer-level IoT implementations, the need for a technology such as LPWAN is much greater in agriculture where distance is a major consideration, sensor numbers will likely be high, power consumption needs to be low and where small packets of information, such as from soil moisture probes, device sensors (e.g. pumps, gates and weather stations) are only required (Figure 9).

Taggle (www.taggle.com.au) is an example of a LPWAN system. Operating in the 915 MHz LIPD band, these transmitters are designed to send small packets of information (for example water meters and weather station data) over long distances, typically up to 5 km, but observed up to 50 km in rural environments.

(a) (b) (c)

Figure 9. (a) A water tank sensor and transmitter, (b) close-up of low power transmitter and (c) Taggle LR/LP base station receiver (vertical aerial) and mobile network gateway (small white 'bulb' antenna located on protection cage) (Source: UNE SMART Farm).

LORA-WAN

LoRaWAN is a particular LPWAN specification intended for battery-powered devices that support low-cost, mobile, long range and secure bi-directional communication for IoT and M2M (LORA Alliance 2017; The Things Network 2017). The LoRaWAN protocols are defined by the LoRa Alliance and formalized in the LoRaWAN Specification. The LoRA Alliance is an open, non-profit association initiated by industry leaders to standardize LPWAN being deployed around the world. LoRaWAN is designed to allow low-powered devices to communicate with Internet-connected applications over long range wireless connections. Devices operate in the LIPD class spectrum, namely 915 – 928 MHz band, and are optimized for low power consumption and is designed to support large networks with considerable numbers of devices. LoRaWAN features include support for redundant operation, geolocation, low-cost, and low-power. A LoRaWAN Specification document describes the LoRaWAN™ network protocol (LORA Alliance 2017).

A key desirable aspect of LoRaWAN devices, as it relates to agriculture (and other industries) is the commitment to a set of standard specifications, allowing developers of sensors to provide

immediately compatible, fit-for-purpose devices on farm. At the other end, service providers can develop web-based information delivery systems, or utilize bespoke cloud-based solutions. The Things Network (The Things Network, 2017) is a global initiative, an open network, that provides resources and supports developer forums, virtual labs and communities (www.thethingsnetwork.org/labs).

Companies in Australia such as Meshed (www.meshed.com.au) consider themselves as technical and service facilitators of connected technologies, and focus on the provision of development kits and bespoke gateways, allowing developers to focus on sensor innovations and the development of decision support and information delivery systems at the other end. Thinxtra (www.thinxtra.com) offers additional connectivity and cloud capacity through partner SigFox (www.sigfox.com). Both offer developer kits suited to Australian conditions (including spectrum) (Figure 10 (a,b). Thinxtra partners with developers around the world to develop solutions (Figure 10 (c,d)). Example devices include irrigation flow sensors, flood/inundation sensors, beehive monitors, soil sensors and wearable livestock monitoring devices.

(a)

(b)

(c)

(d)

Figure 10. IoT device development kits specifically targeting the Australian market (a) Meshed 'Multitech mDot Micro Developer/Programmer Kit' (Source: http://meshed.com.au/product/multitech-mdot-micro-developer-kit/), and (b)Thinxstra 'Sigfox Pi' designed to support Rasberry Pi devices (Source: http://www.thinxtra.com/devicemakers-dev-kits/). Examples of third party-developed devices; (c) wearable animal devices from Spanish company Digit Animal and (d) remote beehive scales, developed by Thinxstra's French partner 'Optibee'. (Source: http://www.optibee.fr/index.php/caracteristiques). Both examples are fully compatible with the SigFox data management system.

Communicating through the mobile phone network

Probably the most important means of communicating from the paddock to the outside world is via the mobile phone network. The subject of mobile connectivity in rural and regional Australia has

been the subject of considerable interest, and numerous forums have been conducted with a view of understanding the challenges, limitation and needs of Australian producers for mobile connectivity. Notably we have the recent Regional Telecommunications Review (2015), as well as producer surveys conducted by NSW Producers (NSWF, 2014; 630 respondents) and the Victorian Producers Federation (VFF, 2015; 533 respondents).

This review does not seek to duplicate these efforts, however it is nevertheless necessary to revisit elements of these earlier surveys as they relate to connecting devices on farms. When we talk about mobile phone connectivity on farms, people generally take this to mean mobile 'voice' connectivity or using mobile phones (or similar smart devices) to access the internet. The latter involves 'data' connectivity. There is some difference between the two, as we shall see shortly, so for the purposes of this following section we will continue with a distinction between mobile 'voice' and mobile 'data' connectivity. In addition to being the vehicle through which a producer may access the internet, for example web-based DSSs that producers seek to access while in their paddocks, mobile data connectivity is also a vehicle through which we can connect 'things' on the farm.

In terms of the two surveys referred to earlier, the NSW Producers survey (NSWF, 2015) focussed on internet and mobile phone usage (effectively data and voice). The Victorian Producers Federation survey (VFF, 2015) acknowledged connected 'things', for example cattle tracking and irrigation systems, also as a key component/driver/consideration of on-farm connectivity. In particular the VFF survey highlighted that poor mobile broadband connectivity "limits the functionality of, and their ability to invest in broadband reliant machinery and technology" (VFF, 2015).

It is acknowledged that the mobile phone network is one of the wonders of the modern world, and indeed is one of the more complex systems ever devised (Shephard, 2011). Hence it is no easy task to review the challenges and opportunities of the mobile phone network without delving into fantastic detail. Given that the mobile phone network is still the most important connectivity option for producers, the following section attempts to cover enough of the basics in relation to how mobile networks operate in Australia to render coherent the subsequent discussion of what this means to producers in support of a digital agriculture future.

Mobile phone basics

A mobile phone network (alternatively known as a 'cellular network') is made up of signal areas called cells. Mobile phone coverage in rural Australia is a recurring point of contention, and here we are describing the gaps that exist between or within the cells, and in many cases the capacity of existing cells to carry data and voice traffic. The system spectral efficiency (bps/Hz) (introduced previously in radio networks) also applies to a cellular network. Here it may be expressed as the maximum number of simultaneous phone calls per area unit over 1 MHz frequency spectrum in E/MHz per cell, E/MHz per sector, E/MHz per site, or (E/MHz)/sq. metre. In many locations (for example urban and peri-urban areas) cells overlap such that users can cross from one cell into another and maintain continuity of service. At the heart of each cell is a mobile base station (i.e. mobile phone tower) which, by using an array of sector antennae divides the cell into sectors. These base stations are connected to a digital exchange, usually by a microwave or optical fibre transmission link where the communications are sent on to other telephone or data networks (Figure 11). Base stations have a fixed carrying capacity for both voice and data. For example, base stations may handle 168 voice channels, as well as a making a limited bandwidth available for internet and data use. It is worth noting that a mobile phone network makes a distinction between voice and data, and this is important when we consider the various generations (G). This point will be revisited later. With increasing demand for voice channels and data carrying capacity (internet usage), carriers have to increase the density of base stations (i.e. reducing cell size) and increase the channel bandwidth[12]. Note that increasing the channel frequency is one way of increasing bandwidth but this then reduces range (coverage). Base stations are radio transmitters/receivers, and hence the geographical extent of coverage by a mobile tower is dictated by the same considerations of power and frequency as well as environmental constraints of topography, land cover, obstructions and weather conditions.

[12] As discussed earlier, the wider the channel bandwidth, expressed in MHz, the greater the data carrying capacity.

In rural Australia, overlaps between base stations may not exist. Typically when a base station becomes congested it would hand-off some of its load to other nearby base stations but in the case of an isolated base station this is not possible and the user would experience a decrease in data transmit/receive speeds and/or voice/data drop outs.

There are numerous types of base stations, generally categorised in terms of the spatial size of the cell they support (Figure 11).

Macrocells are the ones typically encountered in rural Australia, with towers typically having ranges out to 30 km, although heavily reduced in hilly terrain etc. In a situation where mobile signal is weak, mobile phone boosters, sometimes referred to as repeaters, can be deployed. These take an existing cellular signal and amplify it. While they are network agnostic, it is important to note that a mobile signal is required for them to work. Boosters are valuable for transmitting an existing, stable and strong signal into areas whereby the signal would otherwise be weak, patchy or non-existent. It is important to note that boosters do not necessarily 'amplify' the speed of a connection.

Microcells, picocells, and even femtocells (not indicated in Figure 11) are examples of 'small cells'. Categorised based on their notional ranges (microcells < 2 km; picocells < 200 m; femtocells < 10 m) these are deployed in small areas to add extra carrying capacity or to improve coverage in cluttered environments such as buildings and train stations. They are often also temporarily established (for example sporting events and shows), and can be quite expensive to operative. They are also carrier specific. Unlike boosters/repeaters, these small cells create their own signals and are connected into a service provider's network through the internet (for example via landline or another broadband connect such as NBN; NBN will be discussed later). Small cells do have carrying limits ranging, handling from <5 (femtocells) up to <20 access points.

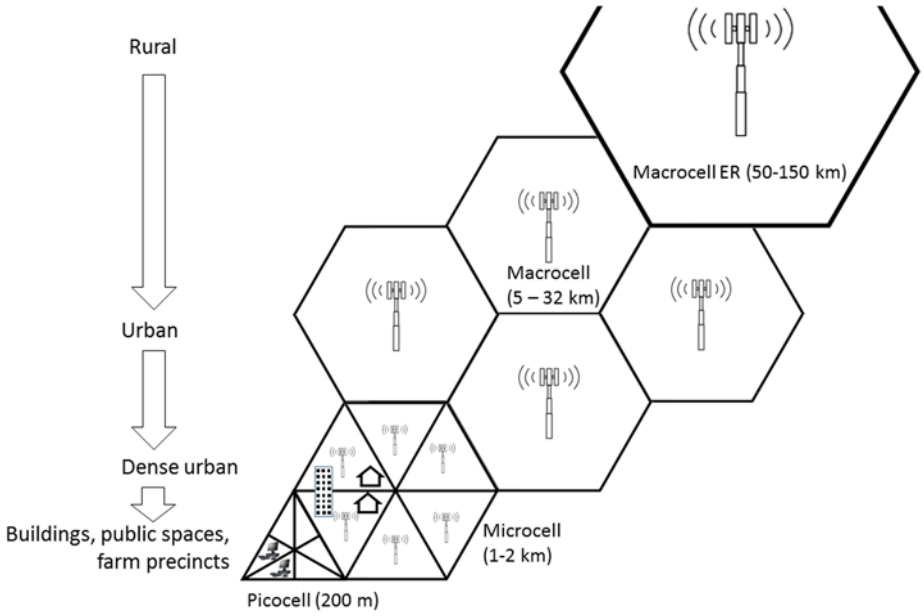


Figure 11. Basic mobile cell types. Indicative cell radius (in km) included (Adapted from MobileNetworkGuide 2016).

As with telemetry devices, the ACMA governs the frequency bands used for mobile phone communication. The basic physics of radio is at play here too; higher frequencies carry greater bandwidth and lower frequencies have greater range/penetration power (into obstacles). The available frequency bands are auctioned off to the carriers, each getting an allocated frequency range within a particular band. In Australia the current mobile frequency bands are listed in Table 1.

Table 1. Summary of network type and frequencies utilized by Australia's three major MNOs. (Source: International Direct Dial, 2017).

MNO	Network type	Frequency (MHz)
Telstra	3G	UMTS 850, 2100
	4G (incl. 4GX)	LTE 700, 900, 1800, 2100, 2600
Optus	2G	GSM 900
	3G	UMTS 900, 2100
	4G (incl. 4Gplus)	LTE 700, 1800, 2100, 2300, 2600
VHA	2G	GSM 900
	3G	UMTS 850, 900, 2100
	4G (incl. 4G+)	LTE 850, 1800

Transmission speed and carrying capacity are interlinked 'performance metrics' in wireless communications, and the mobile phone network is no exception. Generally speaking, the 'generation' or 'G' of the network is an indicator of the speed and capacity (Table 2). Before interpreting the 'G's in Tables 1 and 2, it is worth inserting a brief cautionary note. The speed experienced by a mobile device user isn't just about what the network can offer. The mobile device itself imposes limitations on achievable speeds. 'Category 6' (Cat 6) devices, for example, can achieve theoretical maximum speeds of 300 Mbps, while 'Category 4' (Cat 4) devices achieve only half that; 150 Mbps. The higher the Category number, the faster the speeds.

With the progression of wireless networks from analogue to digital, the second generation (2G) was first used (1G was used only retrospectively after 2G was introduced). From the early years 2G/GSM was on the 900 MHz/1800 MHz band, although Telstra closed its 2G (GSM, 900 MHz) network on 1 December 2016 and Optus shut down its 2G service in Northern Territory and Western Australia April 2017. This may have implications for farm users of older telemetry systems. The third generation (3G) network, utilising the 2100 MHz band is the current base standard of mobile telecommunications, offering from 384 kbps up to 420 Mbps downlink, and between 384 Mbps and 22 Mbps uplink speeds. As the demand for mobile internet and coverage increased the carriers introduced 3G on their 850 MHz and 900 MHz bands. Ultimately 3G was a technology designed for voice, and data effectively went into any spare capacity (not being utilised by calls). The subclasses of 3G specified in Table 2 are all technical enhancements emanating from the innovative use of data 'packets'- the small units of data that are transmitted. Note that UMTS Data sub class refers to downlink only. Often referred to as $3G^{+}$ these offer progressive improvements in transmission speeds/reductions in latency[13]. A technical discussion of the methods of achieving these enhancements is beyond the scope of the review. In plain language, 3G is a system optimised for voice with technical enhancements aimed at bolstering capacity to meet the increasing demands for data. Ultimately if voice usage spikes on the 3G network, data capacity will suffer.

[13] Latency in telecommunications is the time taken from the source sending a packet of information to the destination receiving it ('one-way'). The more common variant is two-way latency which is the flight time of the packet from the source to the destination, and for the response to travel from the destination back to the source. It does not include processing time at the destination. This is often tested using a 'ping' and is often displayed (in milliseconds- ms), along with data speed (bps) when running a speed testing app on a smart phone.

Table 2. Typical Mobile data speeds in Australia (Source: MobileNetworkGuide, 2016).

3G	Downlink speed	Uplink speed	Remarks	Spectral system efficiency (bps/Hz (per site)
UMTS Data	384 kbps			Indicative;
HSDPA (High-Speed Downlink Packet Access)	7.2 Mbps	384 kbps		ranging
HSUPA (High-Speed Uplink Packet Access)	14.4 Mbps	5.76 Mbps		between
HSPA+	21 Mbps	5.76 Mbps		0.5 – 4.2
DC-HSPA (Dual Channel / Dual Carrier HSPA)	42 Mbps	22 Mbps		
4G				
LTE (Long Term Evolution)	100 Mbps	50 Mbps		16
LTE Advanced (Cat4 device)	150 Mbps	50 Mbps	1 x 20 MHz Band (single band)	Indicative;
LTE Advanced (Cat6 device)	300 Mbps	50 Mbps	2 x 20 MHz Bands (carrier aggregation)- i.e. 40 MHz bandwidth	ranging
LTE Advanced (Cat9 device)	450 Mbps	75 Mbps	3 x 20 MHz Bands (carrier aggregation)- i.e. 60 MHz bandwidth	up to
LTE Advanced (Cat11/12/13 device)	600 Mbps	150 Mbps	4 x 20 MHz Bands (carrier aggregation)- i.e. 80 MHz bandwidth	30
LTE Advanced (Cat15 device)	1 Gbps	500 Mbps	5 x 20 MHz Bands bandwidth (carrier aggregation)- i.e. 100MHz bandwidth	

Fourth generation, or 4G is a system really optimised for data, not voice, and indeed it is 3G that continues to carry voice[14]. 4G devices must be capable of supporting at least 100 Mbps download speeds (50 Mbps upload) (Table 2). What is often confused when talking about 4G is 'long term evolution (LTE)' and often 4G and LTE are interchanged, or co-mingled. LTE is about the enabling technology to achieve 4G speeds and reliability; the 4G refers, in essence, to the achievable speed

[14] Mobile phone users will have noted that the phone displays 3G when making a call.

with a particular connection, sub-categorised in terms of the capability of the portable device (Cat class). With the introduction of 4G the carriers are turning off their remaining 2G/GSM 1800 MHz service and using the space to operate their 4G service. The entry-level of 4G connectivity is, as depicted in Table 1, 100 Mbps (downlink)/50 Mbps (uplink). As with the 3G sub-classes, the various 4G subclasses represent advances in speed, although this time through aggregation of available bands across a carrier. 'Carrier aggregation' uses multiple bands to speed up data transfers. It is worth briefly mentioning the two main of methods of doing this as they are often encountered in marketing literature; namely "Frequency Division Duplexing" (FDD) or "Time Division Duplexing (TDD)". FDD is a method of carrier aggregation where data is transferred across multiple bands. For example, Telstra combine the 700 MHz and 1800 MHz bands to deliver 4G data in some areas. Rather than aggregate different bands, TDD divides the packets across time allotments on the same frequency to achieve a similar speed boost. For example Optus uses TDD on its 2300 MHz band. Ultimately, and opposite to 3G, data get priority on 4G. Putting voice on 4G using Voice over Internet Protocol (VoIP) could mean a less efficient data network, hence voice and video are not guaranteed on 4G.

In May 2013 the ACMA auctioned off the 700 MHz bands freed up with the move from analogue to digital television, and new 2.5 GHz bands that would eventually be used for 4G services. The remaining portion of the 700 MHz spectrum not sold in 2013 (2 x 15 MHz blocks; 733-748 MHz and 788 – 803 MHz) was put to auction by the ACMA earlier this year (ACMA 2017), and ostensibly under similar rules as the earlier 2013 auction. TPG Internet Pty Ltd secured 2 x 10 MHz and Vodafone Hutchison Australia secured 2 x 5 MHz portions.

Early trials are underway on a fifth generation (5G) technology (Dohler, 2016) with a number of Australian carriers reporting bench-testing plans and/or outcomes. Telstra recently reported using 800 MHz of spectrum "in a previously unattainable [unspecified], high frequency band". For comparison, this is approximately 10 times the bandwidth used with the existing 4G service (4 x Band carrier aggregation; Table 2). Total download speeds were reported exceeding 20 Gbps (Telstra Exchange, 2016). In Australia 5G is not likely to be rolled out until 2020.

The carriers generally utilise the lower available frequency bands, such as 700 MHz, 800 MHz and 900 MHz, for regional cells because they offer much better range and building penetration than the higher bands. The higher 1800 MHz/2100 MHz bands are useful to the carriers in highly populated areas due to the increased user capacity that they offer. Telstra 4GX utilises the 700 MHz spectrum to achieve greater coverage and LTE-Advanced technology is used to combine the 1800 MHz and 700 MHz 4G bands to increase speeds on 4GX Cat6 and 4GX Cat9 devices when within a 4GX area. Optus 4G plus works on a similar basis, accessing the 700 MHz band. Vodafone similarly employ the 850 M MHz band in their 4G+.

Mobile devices and congestion

When a mobile device (phone or 'thing') connected on a cellular network decides to make a call or transmit data, it first sends out a signal on a random access channel (RACH). This effectively notifies the nearby base station of the need to synchronise transmission either for a call setup or a burst of transmission (e.g. data packets from a sensor). Since RACH channels are shared, there can be a situation whereby more than one mobile device transmits at the same time and their transmissions collide. When this happens they will not be granted access to the network, however then the mobile(s) each wait for a random period of time and then re-transmit. Once the RACH is received the nearby base station will establish the link through an allocated channel (frequency). If the device is moving then the signal strength will vary and if the device is on the fringe of a cell heading into another then the base station will hand off the call to the adjacent cell. Sometimes it is unable to hand off the call, either because the adjacent cell is congested, or there is no adjacent cell, and in this case the call will not be sustained. If within a cell a mobile user accessing a 4G connection may find this is degraded to 3G due to congestion/reception. Ultimately this is referring to the standard of which the actual speed is rated.

Mobile phone coverage for Australian producers

A 2012 survey of Australian producers conducted by NSW Department of Primary industries indicated that between 40 and 61% of producers and advisors own smartphones or tablets (Roberts and McIntosh, 2012). As mentioned previously, there have been numerous recent forums focussing on mobile phone coverage in rural Australia. It is impossible to avoid this topic in this review given the increasing reliance upon mobile connectivity for data communications.

What do we mean by coverage? Most people accept that coverage is a region on a map whereby the user would expect to receive phone reception. Of course in practise most people assume reception equates to useable data speeds and call quality and this is not the case. Behind a coverage map are many proprietary technical assumptions. Different mobile network operators may apply different assumptions. For example one MNO may base 'coverage' of the premise that 95% of devices- handsets- would work 95% of the time given a certain signal strength. Another may assume 75% of devices are to work only 80% of the time, which results in larger footprints. Moreover all of the assumptions include the metrics around base station power and design etc. Mobile coverage maps refer to the probability of a certain percentage of devices working- that is, experiencing sufficient signal strength to 'work'. The major mobile network operators publish coverage maps in one form or another (Figure 12).

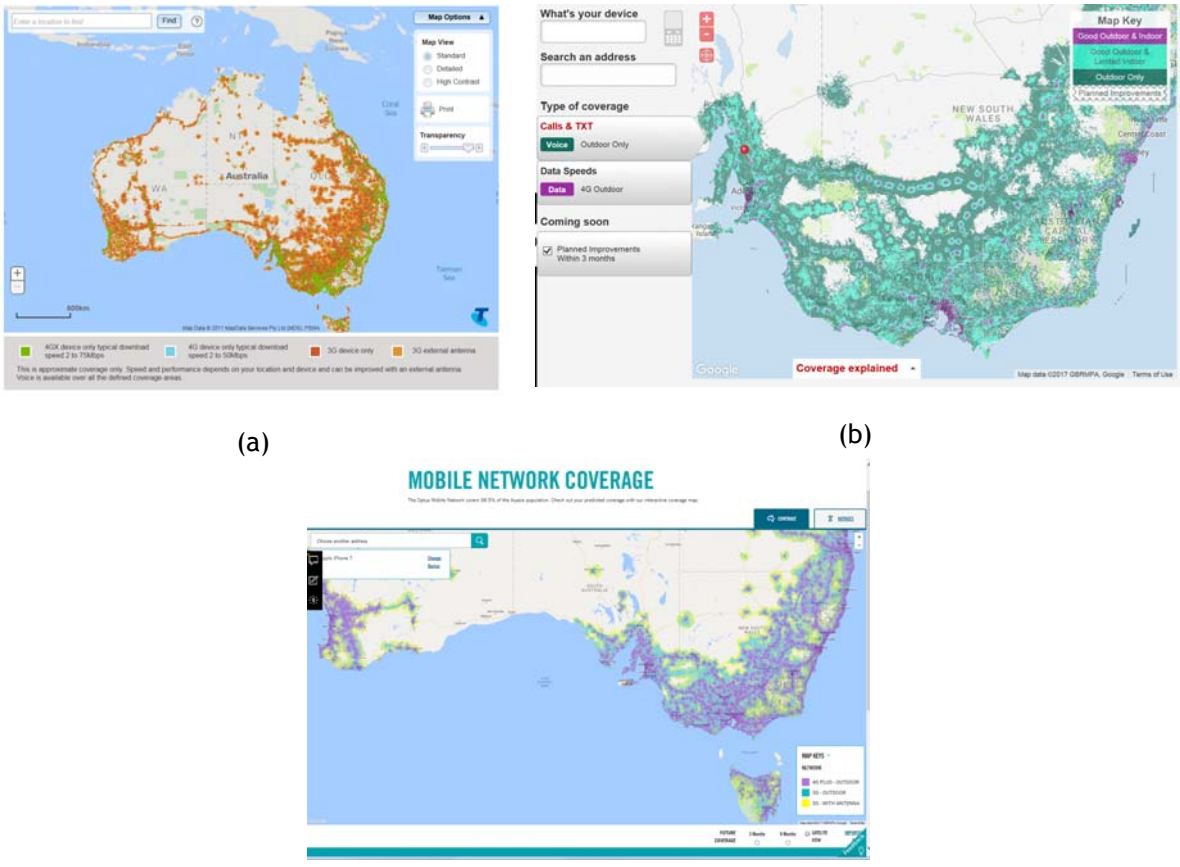


Figure 12. Examples of mobile network coverage maps (a) Telstra (Source: Telstra, 2017), (b) VHA (Source: VHA, 2017), and (c) Optus (Source: Optus, 2017). In addition to providing a visual overview of regional coverage, most websites have the functionality of examining coverage on a location basis.

This is not to be confused with any form of speed or carrying capacity map given that speed/quality may be downgraded based on priority (for example voice priority over data in 3G, vice versa in 4G), the backhaul configuration of the cell etc. Also the quality of the receiving/transmitting devices plays a role, as does the use of external antennas on these devices. Coverage maps are indicative,

and aren't often that far off the mark given the mobile network providers do have quite sophisticated models which they apply. The reality however is that it is not easy to compare one MNO with another in terms of accessing a network for a given connectible device.

Mobile networks in Australia, like anywhere else in the world concentrate coverage around the consumers, and this means that while MNOs purport to reach in excess of 95% of the population, this leaves considerable swathes of the landmass devoid of any coverage (Figure 12). Telstra provides the largest geographical coverage (3G ~ 2.4 million sq. km; Telstra, 2016), with VHA and Optus accounting for another, approximately, 1.6 million sq. km between them. Taken side by side, without overlap, this would account for more than 50% of Australia's geographical area. However, in the business reality of telecommunications, where the major MNOs compete for consumers in areas of greatest population density, the coverage footprints of the two smaller MNOs is virtually completely superimposed on that of the largest MNO (for example Figure 13). Geographical coverage is therefore only effectively that provided by the largest MNO; namely ~30%.

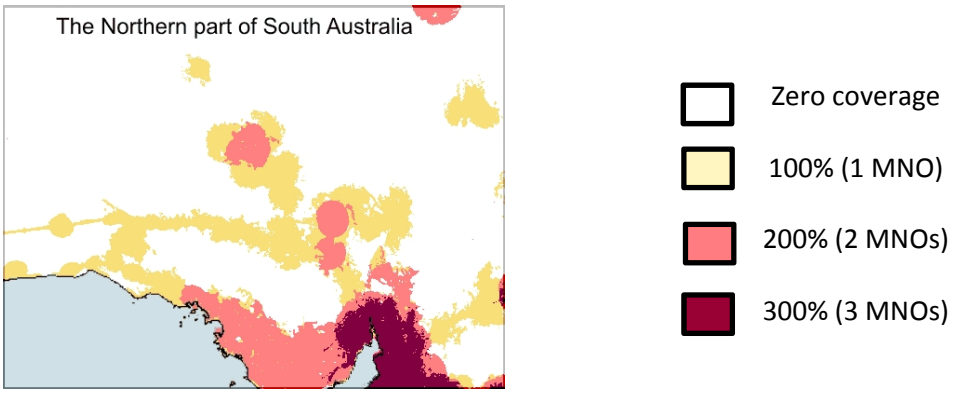
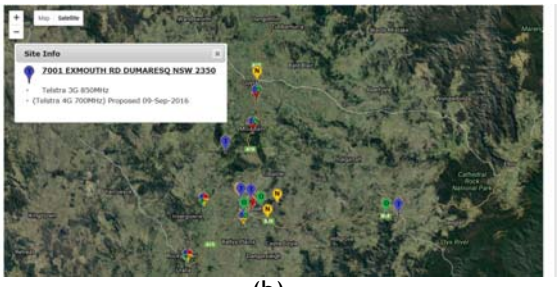


Figure 13. Map of coverage overlap in a segment of South Australia (Source: Lamb, 2015).

The ACMA has a comprehensive database of radiofrequency device locations, including mobile towers (http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Register-of-radiocommunications-licences/radiocomms-licence-data; 'Spectra dataset'). Oztowers (Figure 14) also has a searchable database which supports some limited mapping of mobile towers in postcodes (https://oztowers.com.au/Home/Query). Ultimately these databases can be put to work in mapping coverage however in addition to the necessary details concerning tower location, power, antenna design, frequency and bandwidth, mobile coverage data is generated by the mobile network operators using 'proprietary' assumptions and associated backhaul capability and antenna configuration remains confidential.

SITE_ID	LATITUDE	LONGITUDE	NAME	STATE	LICENSING	POSTCODE	SITE_PRECISION	ELEVATION
1000	-12.471947	130.845073	Fort Hill Wharf DARWIN	NT	4	800	Unknown	
10000	-33.756158	150.698182	Cnr Castlereagh & Lethbri PENRITH	NSW	2	2750	Unknown	
10000002	-28.77766	114.63426	Optus 50m Lattice Tower 71 Eastward Road Utakarra	WA	4		Within 10 meters	
10000003	-12.464597	130.840708	6 Knuckey Street Darwin	NT	4		Within 10 meters	
10000004	-39.5964	143.9339	Cape Wickham Links Clubhouse KING ISLAND	TAS	5		Within 100 meters	
10000006	-28.913583	153.320278	LPON02 1 Tucki Road TUCKI	NSW	4		Within 10 meters	
10000007	-32.67373	152.183366	LPON06 Ocean Side Hotel 100 Booner Street HAWKS NEST	NSW	4		Within 10 meters	
10000008	-33.554239	150.733037	LPON09 1057 Kurmond Road NORTH RICHMOND	NSW	2		Within 10 meters	
10000009	-36.416261	143.611158	LPON15 90 High Street WEDDERBURN	VIC	4		Within 10 meters	
10000010	-33.315074	115.726263	LPON19 Glen Huon Primary School 9 Monash Bvd EATON	WA	4		Within 10 meters	
10000011	-33.307414	115.734614	LPON20 45 Millbridge Bvd MILLBRIDGE	WA	4		Within 10 meters	
10000012	-33.357333	115.624897	LPON21 Bethanie Elanora 37 Hastie Street SOUTH BUNBURY	WA	4		Within 10 meters	
10000013	-28.687008	153.523194	LPON 22 Foodworks Building 3/2-6 Byron Street BANGALOW	NSW	4		Within 10 meters	



(a) (b)

Figure 14. (a) Example of ACMA database output ('site') and (b) output of tower location search via OzTowers in map form (Source: https://oztowers.com.au).

Mobile Roaming

From an operational and business perspective, each of the MNOs are entirely independent of the other. Mobile roaming refers to the ability of a user to use their mobile phones for calls, text messages and to access data services by means of another network in Australia when outside the coverage area of the network to which they subscribe (ACCC, 2016b). Mobile phone users who

travel overseas are familiar enough with international roaming. In this case there are numerous links in the chain that facilitates the seamless extension of coverage for the user. This is enabled by a roaming agreement between the mobile user's home operator and the visiting mobile operator network. A summary of the technology/operations involved is depicted in Figure 15.

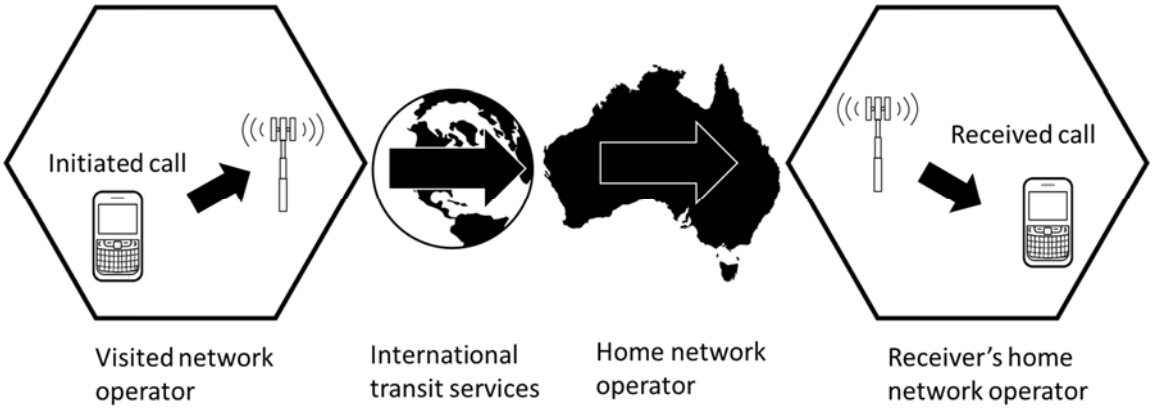


Figure 15. Summary of international roaming and technologies (Adapted from GSMA, 2017).

The mobile user is first required to establish an international roaming service with their home network operator. Technically and operationally speaking, on initiating a call when overseas, the mobile user is then automatically connected to the visited network. This process would have been pre-empted by the exchange of data between the visited network operator and the home network operator when the user first enters coverage by the visited network. In simple terms, the exchanged data includes verification of the roaming status, status of the handpiece (not stolen) etc. With a roaming agreement in place, any calls made by the user will involve the exchange of network data (the 'control signal') between the visited network and the home network which forms the basis of call records and billing, for example, as well as the voice/SMS or data components (the 'voice signal'). These are all routed to an international transit service provider to arrive at the home network provider (Commonwealth of Australia, 2009). Domestic roaming is something Australians are less familiar with simply because there is little of it available. What we are referring to, of course is the ability for a user to roam between MNOs in areas in Australia where the user's MNO does not offer coverage, but where it is available through another MNO, in effect extending coverage available to the user. Domestic roaming works on the same principals as international roaming, minus the intermediary transit carrier.

Domestic roaming is available on other countries, for example in the U.S, New Zealand, France, Canada and Spain. In Australia Optus has been providing domestic mobile roaming to VHA since early 2013, including sharing of infrastructure (Optus, 2016). Of course the value of roaming is derived where different MNOs have coverage in different geographical regions. Here we have one MNO with almost 3 times the geographical coverage as the two other MNOs, with the geographic coverage of the two smaller MNOs virtually completely superimposed on that of the former (Figures 12-13).

The Federal Government Department of Communications and the Arts manages the Mobile Black Spot Program (MBSP), seeking to improve mobile phone coverage in regional and remote Australia, with two rounds of funding completed or in progress, and a third round expected to commence in 2017 (AGDCA, 2016). On one hand sharing of infrastructure between MNOs, for example co-locating mobile infrastructure on a single tower, offers efficiencies and this was one aspect of the assessment criteria in allocating funding under the first and second rounds of the Mobile Black Spot Programme (MBSP1, 2014; MBSP2, 2016). It should be pointed out that co-locating MNO infrastructure is not the same as allowing a single MNO to install its own infrastructure with a view to sharing it (via roaming for example) with other MNOs.

Will domestic roaming make a difference in terms of improving coverage in rural/regional Australia? This was the subject of an Australian Competition and Consumer Commission (ACCC) inquiry (ACCC 2016b, 2016c) with a draft decision released in May 2017 (ACCC, 2017). Ultimately the crux of the enquiry was exploring the extent to which domestic roaming would promote competition among mobile providers and its effect on investment in mobile infrastructure. Through domestic roaming, the cost of building and upgrading mobile networks could conceivably be shared between two or more mobile providers and ultimately competition would no longer be based on the notion of infrastructure advantage. Rather, consumers could receive the benefits of choice, as multiple mobile providers would then compete on the basis of one mobile network in many rural and remote areas. In its draft decision, however, the ACCC found that retail mobile services are "exhibiting signs of reasonably effective competition" and that with the current state of the market, a "declaration would not promote the long-term interests of end-users to an extent that would justify a declaration".

Device connectivity and data speeds

As mentioned earlier, mobile coverage maps are based on certain assumptions by MNOs which, while highly developed and technical, are not necessarily consistent between the MNOs. As mentioned earlier in our discussion of how radio works, signal strength is the key variable for wireless data speeds and mobile phones or other cellular devices are no exception. This is an invariant regardless of the MNO- the underlying physics is still the same. We are used to measuring signal strength on our cellular devices (e.g. mobile phones) by the number of 'bars' on the device. This is based on the 5 x 5 scale for readability used in radiotelephony (1 = unreadable – 5 = very good). These 'bars' on our mobile phones are a received signal strength indicator (RSSI) and are related to the signal strength as measured in scientific units of dBm (discussed earlier). A typical 3G mobile tower/phone may emit +27 dBm (500 mW), whereas in terms of RSSI of a mobile phone located within a cell, the signal received is considerably attenuated (hence dBm typically associated with received signal strength is a negative number- e.g. -70 dBm which is a fraction of 1 mW; i.e. 1/10,000,000 mW). In terms of mobile phones and RSSI, we are talking about receiving signals at miniscule power levels. The selection of brand and model of smart phone can also influence mobile phone reception as the design and performance of the phone's internal antenna system varies between handsets. A tool called "field test mode" enables a user to compare the signal level of various phones. The field test mode gives a reading in decibels (dB) of the phone signal in its current location (Uber Signal, 2013). For an iPhone, the field test mode can be accessed by selecting *3001#12345#* on the phone number keypad and then pressing send. This will see the "bars" of service replaced with a signal reading. An indication of the types of signal strengths we are talking about is given in Table 3. Most farmers find a reception of 1-2 bars on their mobile phones precludes reliable and timely data access.

When dealing with signals of such low levels, 'device hygiene' is paramount. What we mean by this is that simple things like how the device is orientated relative to absorbing materials (yes, even the human head is an effective absorber of radio signals), and whether external antenna are used rather than the integral antenna in the device, whether the antenna (external or integral) is placed in high or low ground, and what obscuring features are in the path of the signals. All of these could result in sub-standard (or possible none at all) performance of a device supposedly within a cellular network coverage region.

Table 3. Indicative signal strengths for mobile phones

RSSI	Signal strength	Bars
greater than -70 dBm	Excellent	5
-70 dBm to -85 dBm	Good	4
-85 dBm to -100 dBm	Fair	3
-100 dBm to -110 dBm	Poor	1-2
less than -110 dBm	No signal	0/'No Service'

Smart phones do not have a physical connection for an external antenna, however a phone cradle and an appropriate external antenna will improve the reliability and quality of calls in vehicles. The cradle should have both a power charging connection and a patch cable for an external antenna and should match the specific model of the phone because the location of the phone's internal antenna differs for each model and must be aligned with the coil in the cradle to enable the best signal transfer via electromagnetic induction. Selection of an external antenna for a vehicle is important. A lower gain antenna is less directional, meaning it has a higher angle of transmission which makes it more suitable for hilly areas. A higher gain antenna has a shallower angle of transmission, and therefore, transmits for longer distances making it more suitable for flat areas. In most rural areas, a 5-7dBi antenna is most suitable (Ware, 2014). When optimizing mobile phone connectivity, voice calls and data should be considered separately as they operate on different frequencies (Table 4). Even the large 'fat stick' car antenna (9 dBi gain, 2 m tall) only marginally increases data performance (internet speed) for a smart phone because while the antenna has a 9 dBi gain at 850/900 MHz (voice), it only has a 3 dBi gain at 1800/2100 MHz (data) (Ware, 2014).

Table 4. Mobile phone frequencies in Australia (Source: MobileNetworkGuide, 2016)

Mobile Carrier	GSM Band	3G Band	4G LTE Band
Telstra		850MHz (voice) 2100Mhz (data)	1800Mhz 900Mhz (2015) 700MHz (2015) 2500MHz (2015)
Optus	900MHz 1800MHz	900MHz (voice) 2100MHz (data)	1800Mhz 2300MHz 700Mhz (2015) 2500MHz (2015)
Vodafone	900MHz 1800MHz	850Mhz, 900Mhz (voice) 2100MHz (data)	1800Mhz

In summary, whether it be in the paddock or in the farm office, the data speed experienced by producers utilising the mobile network is governed by a number of factors. Starting with the factors that producers have least (if no) control over, there is the mobile network itself. Is the base station (tower) is capable of handling 3G (various sub-classes) and 4G? Then there is the number of users the tower has capacity for (which is especially noticeable during peak times such as Friday afternoons) as well as the connection speed between the tower and the rest of the network- the backhaul capability. Finally the wider the frequency channel bandwidth the carrier is using the greater the capacity for transmission, and if using 4G (LTE Advanced) then there is the number of bands the carrier is utilising for carrier aggregation (Table 2). From a producer's perspective, more devices connected to the base station at one time will reduce the data speed as will increasing the distance between the base station and the device. Clearly signal level on the device will be a key factor but speed for a given signal strength is no guarantee (Figure 16). In terms of the device itself, the antenna system being used, for example multiple input multiple output (MIMO) antennas where multiple antennae carry data to and from the device, is important, as is the 'Cat number', hence data speeds capable of being supported.

It is fair to state that many mobile network users underestimate the breadth of issues that need to be considered when planning mobile network access.

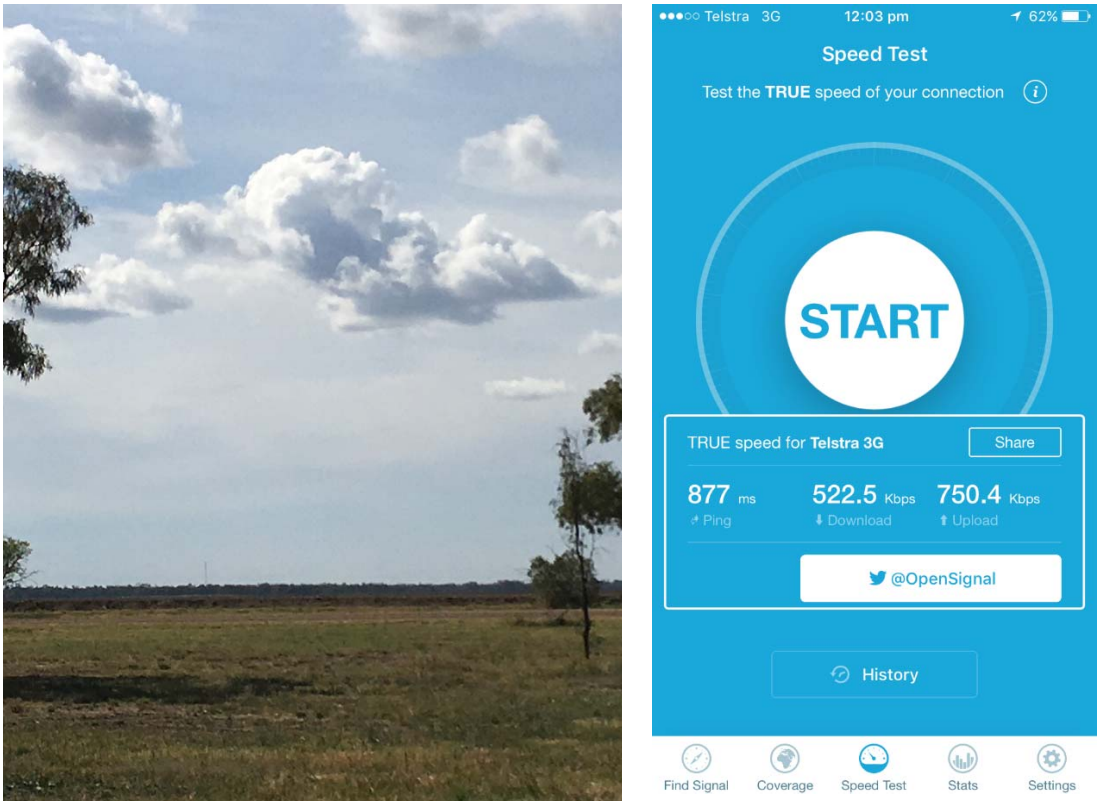


Figure 16. (a) A distant mobile network (3G) tower within line of sight (~ 9 km) of a farm office and (b) the results of a speed test. Note the signal strength (3 'bars') and time of day (on a Wednesday).

Cellular devices on farms

Devices that utilise the mobile phone network can be integrated units which include sensors and the mobile link (in effect acting as their own gateway). This connection method is particularly suited to devices that transmit only small amounts of data, such as sensors that record position or environmental parameters, primarily because of the costs of data on the mobile network. Weather has always been a principle decision point in farming. The GrainGrowers Agriculture Technology Survey (Agriculture Technology Survey, 2015) identified automatic weather stations (AWS) on grain producing farms as the next most popular technology following GNSS-enabled auto-steer and yield monitors on harvesters, and weather websites remain one of the most valued apps accessible on mobile devices.

Capable of recording and transmitting at regular intervals, at the very least, rainfall, temperature, humidity, wind speed and direction, AWS require only modest data transfer rates and AWS incorporating mobile network links are a popular sensor available on the market to producers (Figure 17a). For example, the device depicted in Figure 17a, which transmits data every 15 minutes, consumes only 5 Mbytes data per month. Mobile network gateways, capable of receiving (via radio link) data from outlying sensors are also increasingly popular. These 'extenders' can operate via Bluetooth/Wi-Fi (2.4 GHz) (Figure 17b) or UHF radio, such as the Observant system (www.observant.net) (Figure 17c).

(a) (b) (c)

Figure 17. (a) Automatic weather station (AWS) incorporating mobile phone network link (Source: Leighton Wilksch, AgByte). (b) Mobile phone network gateway. Note the 2.4 GHz receiver (square panel) for linking to outlying nodes, in this case an AWS and bee hives, and the triangular mobile phone 'signal booster' (Source: UNE SMART Farm); (c) Mobile network gateway with UHF expansion kit allowing inclusion of up to remote 10 nodes (via UHF) outside of mobile coverage (Source: Geoff Goldburg, Observant)

The use of mobile network gateways on moving objects is more challenging as mobile devices may experience varying levels of connectivity due to terrain and other obstructions. An example of a moving sensor/gateway is a 'quad tracker' used for monitoring speed and attitude of all-terrain vehicles (ATVs). With an average of around twenty fatalities per annum in Australia since 2011 (QuadWatch, 2016), and a recent call for safety ratings (Australian Producers, 2017) it is not surprising that there are a number of Australian innovations in this space; for example USee (Figure 18) (www.usee.com.au) and Austracker (www.austracker.com).

Observation: Those who offer IoT services that support safety of life applications (e.g. quad trackers), and that rely upon the mobile network need to be able to guarantee the service. Even with reception, many are concerned about the resilience of the backhaul network, with its reliance upon wireless point-to-point links. Many providers consider these links are 'underbuilt' and 'fragile'; for example reduced performance due to adverse weather and also smoke/ash. Others are considered over-subscribed and congested.

(a) (b) (c)

Figure 18. (a) 'USee Quad Tracker' including mobile network antenna, installed on ATV. (b) Example of a live screen display indication location on farm. (c) Example email alert. (Source: UNE SMART Farm).

Telematics

Many of the larger farm machinery manufacturers for example John Deere, Case IH and New Holland offer mobile network-enabled, 2-way data transfer capability between machines (Figure 19) and a centralised data management capability. Such 'remote telematics' capability allows on-the-go performance diagnostics and, in some cases supporting navigation (for example network RTK). Performance diagnostics support a range of capabilities/tools including curfew alerting (unauthorised use of machinery outside of designated windows), geo-fencing (to alert operator of approaching or broached boundaries), 'breadcrumb trails' (to confirm coverage), and engine and performance diagnostics (fuel efficiency, hydraulic pressures and temperatures, speeds etc.). Examples on the market today are listed in the Table 5. There are also numerous telematics service providers in agriculture which are not brand specific, and who offer both hardware and 'air time'[15] products. One example is Agtrix, a company that specialises in spatially-enabled data systems for improving harvest management and supply chain logistics in more than 85% of the sugar industry (www.agtrix.com). Sector agnostic telematic businesses such as KORE (www.korewireless.com.au/iot-solutions) with heritage in fleet management and/or heavy equipment (e.g. mining) monitoring are now also exploring agriculture opportunities.

[15] 'Air time products' is generally taken to mean 3G, 4G or satellite connectivity and data/information management, often cloud based, services.

Table 5. Examples of remote telematics capability offered on farm tractors.

Manufacturer	System	Source
John Deere	JDLink™ MyJohnDeere	https://www.deere.com.au/en_AU/products/equipment/agricultural_management_solutions/information_management/jdlink/jdlink.page? http://discoveroperationscenter.com/en
New Holland	PLM® Connect	http://agriculture1.newholland.com/eu/en-uk/precision-land-management/products/data-management-telematics/plm-connect-essential
Case IH	AFS Connect™	CASE IH AFS Connect (https://www.caseih.com/anz/en-au/products/advanced-farming-systems/afs-connect)

(a)

(b)

Figure 19. Examples of telematics systems (a) tractor and spreader, and (b) sugarcane harvester (Source: (a) Andy Duncan, 'Urara' WA and (b) Rob Crossley, Agtrix).

While most systems offer a standard capability of storing data on-board whenever there is no mobile connectivity, for later transfer when in mobile reception, some software or firmware upgrades may need to be completed on the spot via online connection and in some instances producers (or dealer support staff) have reported having to drive their machines to a nearby mobile phone reception area in order to facilitate upgrades or are required to store performance or hold on to harvest data important for logistic management until the machines are in a mobile reception area.

Another example of cellular-enabled data finding increasing use on farm is in the form of centimetre-accuracy positioning/guidance signals sent to machines in the field. A national network of permanently-located, continuously operating GNSS receivers, known as a continuously operating reference station (CORS) network, observes and corrects satellite navigation signals to generate

correction information to support high accuracy positioning (~ 2-5 cm) of machines in paddocks. The network itself comprises of receivers located in areas of cellular cover sufficient to facilitate back-haul between them and the centralised analysis centre whereby the correction data is generated. The correction data is then streamed via General Packet Radio Service (GPRS)[16] to users via a wireless internet connection, ultimately relying upon 3G cellular network access at the user device end. Data consumption rates can be typically 1-2 Gbytes data per month for farm machine guidance use.

Vision

Images, on the other hand are larger data files and transmission, especially live video, requires significantly higher bandwidth and consumes more data. The transmission of vision from remote devices is usually achieved by transmitting single video frames every few seconds. For example RMCam (www.rmcam.com) have developed a system capable of capturing and transmitting video frames in low mobile signal strength environments (next-G), and in some cases to 50 km from mobile towers (Figure 20). Single image frames of 200 x 300 pixels (15 kbytes) can be transmitted every 2-3 seconds for live viewing[17] or, at pre-set times (e.g. every 15 minutes), into a gallery for catch-up viewing. Individual cameras can also be pre-programmed to look in specific directions (pan and zoom) as part of their routine scan. Importantly the cameras can also be controlled 'live'. Systems like RMCam, when used in a 'typical' combination of live and gallery view, consume approximately 1 Gbyte per month.

Live streaming of high resolution, live video (namely > 5 frames per second) is problematic as the quality of live streamed video is affected by packet loss[18] and delays (latency); exacerbated by network congestion. In the absence of QoS support from the network, the end users must employ QoS at the application end of the process. A detailed discussion of the technical challenges can be found elsewhere (for example Pradhan and Wood, 2012). In a farming context, live video is rarely used in this way. However there are some noteworthy innovations that are occurring in this space. One system under development utilises remote cameras transmitting high quality video (for example 2 Megapixel images at 25 frames per second) directly to a nearby storage point located up to 30 km away by radio link (the storage point is known as 'edge of cloud'[19]). From there the mobile network is used to transmit 'thumbnails' representing 200 Mbyte video segments to a gallery for viewing. The user then selects the video segment which is accessed from the edge storage by the cloud (and the mobile network).

[16] General Packet Radio Service (GPRS) is a mobile data service on the various 2G and 3G cellular communications networks.
[17] There is no formal definition of 'live viewing', and the term is often interchanged with 'live streaming'. With streaming video, the information is sent in a continuous stream of data and is played as it arrives. The user does not have to download a file to play it.
[18] A packet is a unit of data that is sent through a network. Packet loss refers to the loss of small packets of data, usually through network congestion.
[19] Edge of cloud storage refers to the use of local storage (eg onsite), that is connected to the cloud (Zhu et al., 2011). Data can then be backed up onto the cloud or is otherwise discoverable via cloud access.

(a)

(b)

Figure 20. An example of a remote vision system designed to operate in low mobile signal strength regions, the RMCam system allows both 'live' viewing (images refreshed 2-3 seconds), pre-set single image acquisition, and cameras can be remotely controlled (tilt, pan, zoom). (a) Remote weather station and vision system installation in a vineyard. Note the camera dome located beneath the integrated rain gauge/anemometer used for frost detection/alerting (photo courtesy Brendon Doyle, RMTek and Peterson's Armidale Vineyard); (b) An example of live vision from a remote poultry shed (Source: UNE SMART Farm).

Accessing data and information via the mobile phone network

A considerable proportion of connectable devices on farms or the cloud based management tools that producers use, offer access via smart phone or tablet via team viewer or similar web interface. In addition to these are the specifically developed apps. The South Australian Ag Excellence Alliance (www.agex.org.au) released the second edition of "Smart Phone Apps for Smart Farmers" in 2014 (Ag Excellence Alliance, 2014). This publication describes 414 apps, of which 235 are iOS apps for iPhones and iPads and 179 are Android apps for brands such as Samsung, HTC and Nokia. The guide identifies both paid and free apps considered useful to "help farmers in their day-today work". The listing includes include categories such as farm business management, farm operations management, sustainable farming, improved and enhanced production, farm marketing and agricultural market advice, natural resources management (NRM) on farms and social and community access.

Some examples (amongst many) of apps recommended by producers during this present review are depicted in Figure 21. These examples were indicated for their value in using them on site (e.g. in the paddock or shed) rather than in the farm office, and are indicative of the value that can be derived from smart phone/tablet data connectivity everywhere on the farm.

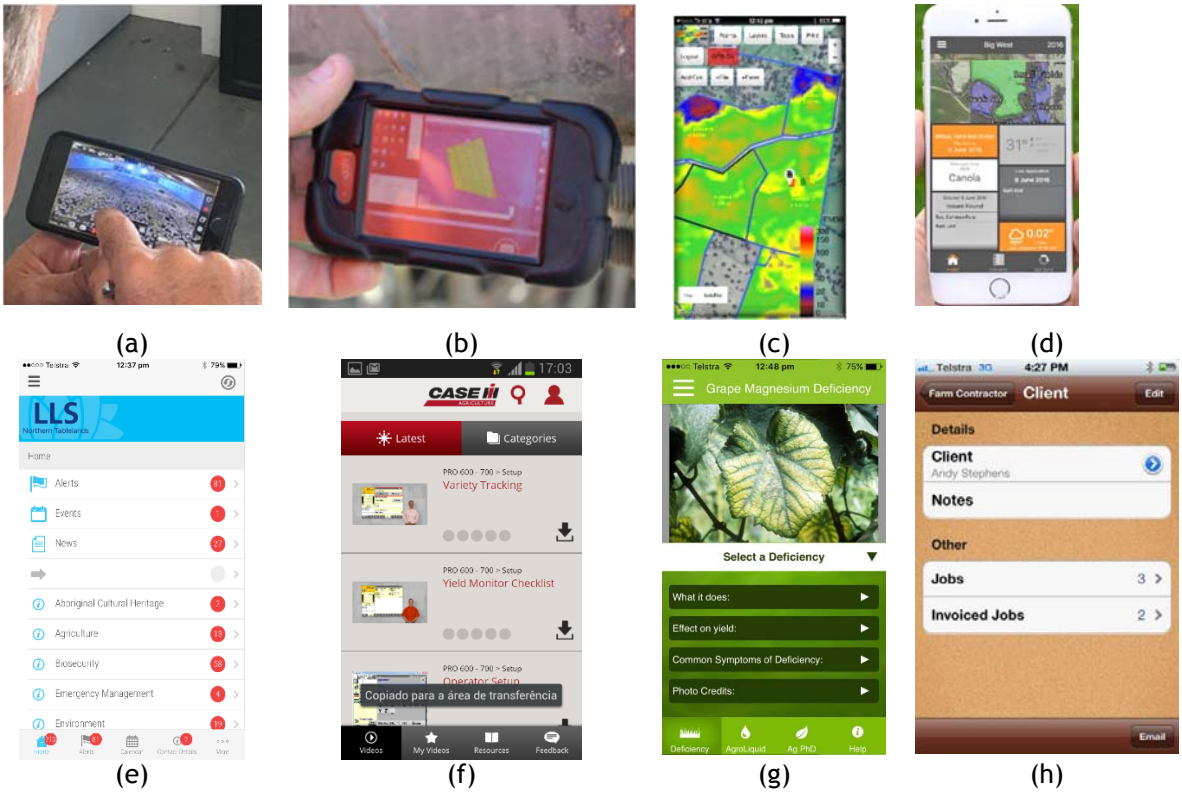


Figure 21. Examples of smart phone tools that allow Australian producers to access device status, visually monitor or record aspects of their operation or enable data sharing. These have been selected based on the value from accessing them on site, namely in the paddock or shed; (a) remote vision (e.g. poultry), (b) pump control (e.g. sugarcane) (Source: www.canegrowers.com), (c) field scouting (e.g. grains), (d) paddock data sharing and zoning for management (Source: www.sstsoftware.com), (e) animal management and biosecurity alerting (e.g. livestock), (f) onsite learning and tutorial tools for farm machines (Source: www.caseih.com) (e.g. crops and horticulture), (g) crop health diagnostics (e.g. winegrapes), and farm contactor management.

Landline- ADSL and ADSL2+

Our basic telephone voice service relies upon copper wire ('twisted pair') linking the subscriber to the exchange. Asymmetric digital subscriber line (ADSL) is a data communications technology that enables faster data transmission over copper telephone lines compared to the 'useable' voice frequencies utilized in a voice conversation. The term asymmetric refers to the fact that the bandwidth and bit rate (transmission speed) is skewed to provide greater download speeds than uploads. ADSL2+ extends the capability of basic ADSL by doubling the number of downstream channels, effectively doubling the download speed. A key limitation of ADSL/ADSL2+ is that data speeds depends on the distance between the access point and the local exchange (Figure 22).

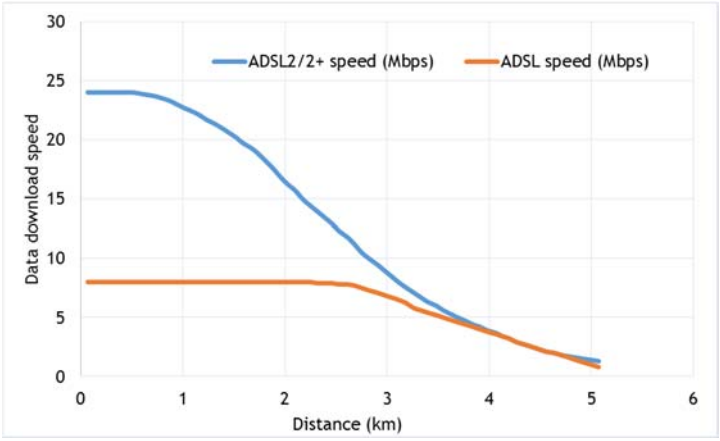


Figure 22: ADSL and ADSL2+ download speeds relative to distance between subscriber and local exchange (Source: http://www.adsl2exchanges.com.au/).

Under normal circumstances the ADSL/ADSL2+ access point is at the client's premises (i.e. the phone line) and multiple lines are required for multiple access points unless it is extended via a private WAN.

Satellite communications options

Satellite systems provide both voice and data coverage, through satellite phones, pagers and other digital devices such as telematics and static IoT devices. There are numerous providers of satellite communications services to rural and regional Australia, ostensibly through 'roaming agreements' but only a small number of satellite systems providing those services.

Communications satellites fall into two general categories based upon their orbital characteristics. Low earth orbit (LEO) satellites are placed at heights between ~100 - ~2,000 km high and orbit very quickly. As a consequence they move in and out of view (and hence access) regularly with often only 9-10 minutes in line of sight. In a given location, continuity of access (line of sight) requires that the provider has large numbers of satellites in orbit to allow hand-over from one to the other as they depart line of sight from a given user. In Australia, the more common LEO satellite systems include U.S. based Iridium constellation of 66 LEO satellites. It is a truly global satellite service. To alleviate the fact that a link to a single satellite can only necessarily be short each satellite in the constellation maintains contact with two to four adjacent satellites and routes data between them to effectively create a large mesh network; all while maintaining the link with the on ground user. Areas closer to the equator such as the gulf country of northern Australia can suffer from interruptions as the satellites are spaced further apart. Owing to their proximity to ground, LEO communications satellites have comparatively low latency times and can support high bandwidth. Iridium offers a low-latency Short Burst Data (SBD) service that is tailored to the M2M/IoT market (Figure 23a). Globalstar is another LEO satellite communications system which differs from Iridium in that 'calls' are passed from satellite to local gateways in Australia (Mt Isa, Dubbo and Meekatharra). As there are only 24 satellites and they are required to be in range of ground stations during data/call exchange, they are prone to interruptions, especially for locations near the equator.
Myriota (www.myriota.com) is an example of an IoT service provider which offers low powered micro-transmitters that presently access two satellites of the Canadian ExactEarth LEO satellite constellation (Figure 23b, c). This system is appropriate for devices that only require periodic monitoring, for example a remote water storage, once or twice a day. What is noteworthy of the Myriota system is the behind-the-scenes analytic capability whereby a single LEO satellite can receive, and have processed, messages from hundreds of thousands of individual devices at any given time.

(a)

(b)

Figure 23. (a) An example of an Iridium IoT hub and (b) a Myriota-developed LEO satellite transmitter connected to a tank water level sensor. (Source: (a) Ric Otton, Dosec Design and (b) Tom Rayner, Myriota)

The second class of satellite communications is the geostationary satellites which are placed directly over the equator at approximately 35,800 km high and revolve in the same direction as the earth rotates. These satellites appear to 'hover' in the sky and can therefore be accessed using a directional antenna pointing at a fixed location in the sky. Optus operates a fleet of 5 geostationary satellites over Australia and New Zealand with access to a further 9 third-party satellites in the Pacific and Indian Ocean regions. These support M2M and IoT applications. Inmarsat, a British satellite telecommunications company that provides data and voice communications via 12 geostationary satellites provides satellite connectivity to Vodafone's IoT platform. The Thuraya network relies on two geostationary satellites covering over 140 countries, and in Australia, reception exists in line of sight areas. The NBN Sky Muster satellites (NCN Co 1A and NBN Co 1B) are geostationary satellites too which enables them to maintain each of their 101 fixed spot beams on specific regions over Australia. The NBN Sky Muster satellites do not support IoT directly insofar as access is provided to satellite dishes located on residential and business premises. The NBN Sky Muster satellite will be discussed in more detail in the following section.

A number of other examples of on-farm satellite-direct IoT devices are given in Figure 24.

(a)

(b)

(c)

Figure 24. (a) JDLink™ satellite modem which transfers data such as engine hours, location, geo-fencing, curfew, maintenance tracking, and machine utilization information, through LEO satellites. (Source: https://www.deere.com.au). **(b) A remote livestock management system (RLMS; walk-over-weighing) on a remote set of yards. The system, developed by Precision Pastoral P/L (Source: www.precisionpastoral.com.au) sends data directly to satellite (square antenna positioned above solar panel). (Source: Tim Driver, Precision Pastoral P/L); (c) An automatic weather station also serving as an Iridium satellite gateway and hub for other nearby sensors. (Source: Derrick Thompson, Hitachi Australia).**

Data through satellites can be expensive, although most IoT/M2M applications require only small packets (~20-50 bytes) per transmission. Generally most devices would consume up to 1000 byes per month.

Satellite based telecommunications is an important feature of Australia's commercial fishing industry, supporting operational data communication such as real time weather and location data, crew welfare such as voice and SMS, safety communications robust enough to work under adverse weather conditions (e.g. minimising rain fade). For example, in Australia electronic monitoring (e-monitoring) of fishing activity aims to augment, if not ultimately replace the need to have 'observers' on fishing vessels. E-monitoring incorporates video cameras and sensors capable of monitoring and recording fishing activities. These can be reviewed later to verify what is reported in vessel logbooks. Data such as vessel location are transmitted live via satellite modem, and these systems can provide hourly updates (Figure 25). These systems are now compulsory for most commercial fishing boats in 3 domestic Australian fisheries; the Eastern Tuna and Billfish Fishery, the Western Tuna and Billfish Fishery and the Gillnet, Hook and Trap fishery. With currently 75 boats equipped with this system (Australian Fisheries Management Authority, 2017), the Australian Fishery Management Authority (AFMA) is planning to expand the program to more domestic fisheries (SPRFMO, 2015). It is noteworthy that currently fishing boats are required to physically post data drives, containing recorded data, to the service provider by the end of each month and should the system fail during a fishing trip there are scenarios whereby fishing must be suspended (e.g. if fishing in certain wildlife 'Management Zones'). The onus of maintaining the system in good order rests solely with the vessel owner. Ultimately someone fishing in a 100 per cent monitoring coverage zone without a fully operational system is required to make arrangements for an observer.

While not used in Australia at present, a live remote monitoring system, with ability for technicians to REMOTELY access and trouble shoot the system, live, would be a benefit to the industry.

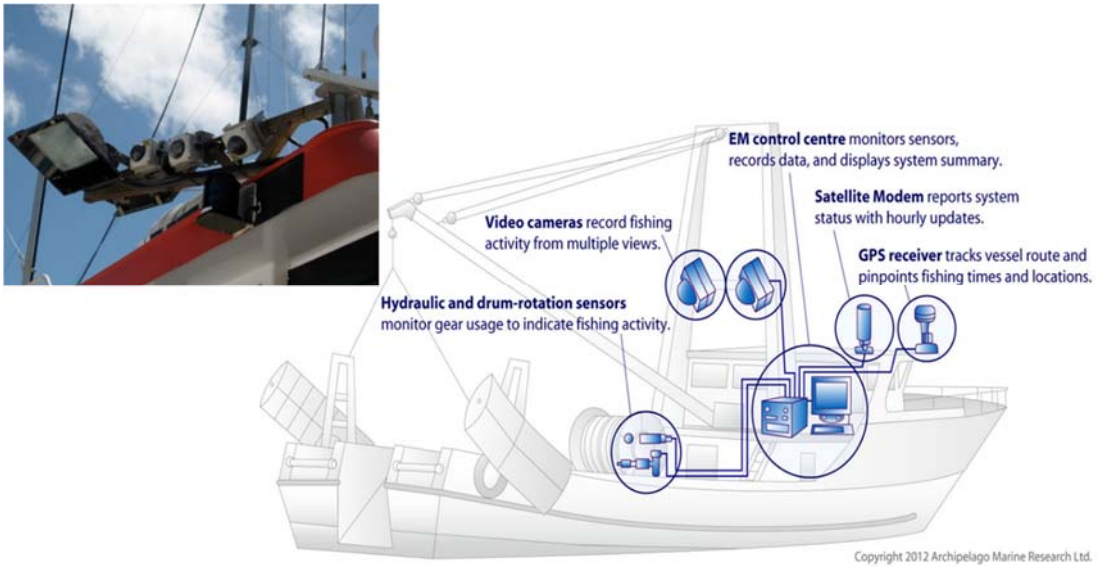


Figure 25. A schematic diagram (and photo – inset) of the e-monitoring system (Image extracted from Australian Fisheries Management Authority, 2017).

Satellite telecommunications systems operators offer marine-specific telecommunications product and services. For example Thuraya Telecommunications recently (January 2017) launched a new voice terminal for maritime communications; Thuraya SeaStar (http://www.thuraya.com/seastar). SeaStar offers voice (VoIP and RoIP- discussed later), SMS, data and tracking, and Inmarsat offers, for example a fleet broadband (K_u wavelength which has better rain fade performance than K_a band) capability with speeds up to 0.5 Mbps (https://www.inmarsat.com/service-collection/fleetbroadband/).

The NBN

The national broadband network (NBN), considered Australia's largest ever infrastructure project is set to profoundly change the way rural and regional Australia communicates. The NBN will play a large role in the digital agriculture future of Australia. The NBN relies upon three delivery platforms. The 'wired communications' platform comprises four subsets, namely fibre to the premises (FTTP), fibre to the node (FTTN), fibre to the building (FTTB) and hybrid fibre coaxial (HFC). Fibre to the premises connection is used in circumstances where an optical fibre is connected from the nearest available fibre nod, to the subscriber premises. A FTTN connection is utilized where the existing copper network will be used to make the final part of the NBN network connection to the subscriber's premises. Similarly FTTB refers to the situation when an entire building (for example at its internal communications cabinet) is connected to the NBN fibre network, but the building's internal existing telecommunications infrastructure then makes the final link to the subscriber's premises. The HFC connection is used in circumstances where the existing 'pay TV' or cable network to a subscriber can be used to make the final part of the NBN network connection. The 'FTTx'/HFC options are focused on urban centres; currently 1% of producers utilize it as part of their farm business (Zhang et al., 2017).

The two NBN network technologies involving 'wireless 'communications are fixed wireless and satellite. These are designed for wide space applications such as rural and regional areas and are the key platforms utilized by producers. Satellite NBN was initially available through an interim satellite service (ISS) which was shut down in February 2018, and now facilitated through the Sky Muster satellites. Fixed wireless and satellite NBN access is effectively the only platforms available to producers. With effect of 18 May 2017, 2.2 million premises were actively serviced by NBN

across Australia (Table 6), with approximately 35% of premises covered by fixed wireless activated and 17% of those covered by Sky Muster activated.

It is important to note that NBN Co is concerned with building the national broadband network (the national access network) as well as providing the technology connecting a user's premises to the national broadband network. NBN Co offers wholesale service packages to phone or internet service providers who are then responsible for the plans, the speed and the capacity of the service offered into the user premises. NBN Co is a wholesale service provider not a retail service provider.

Table 6. Number of premises activated for NBN service, including percentage of premises covered by available service. Date with effect of 18 May 2017 (Source: http://www.nbnco.com.au/content/dam/nbnco2/documents/nbn-rollout-metrics/nbn-rollout-metrics-18052017.pdf).

FTTP/FTTN	% of premises declared ready for service	Fixed wireless	% of available coverage	Satellite	% of available coverage
1,960,323	53.7%	177,779	35.2%	72,455	17.4%

There is an enormous amount of publically available information (both technical and for the non-specialist) available on the NBN (for example www.nbnco.com.au) and it is beyond the scope of this present review to cover all the detail. A technical review of NBN fibre to node (FTTN) and fibre to the premises (FTTP) is given by Tucker (2017). In the context of producers (on farms), fixed wireless and satellite (Sky Muster) NBN are particularly relevant and a brief introduction to both fixed wireless and satellite NBN follows.

Fixed wireless

Fixed wireless NBN is a wireless solution with transmit/receive ranges up to ~14 km between towers and receivers (Figure 26). In essence, fixed wireless is a 4G LTE connectivty. Fixed wireless towers are erected, generally around the periphery of major centres, where good backhaul is available via microwave link or fibre networks.

(a) (b)

Figure 26. (a) NBN fixed wireless tower and (b) fixed wireless antenna on nearby farm office. Note the microwave link on the fixed wireless tower.

NBN ISS and Sky Muster

Sky Muster are the two geostationary communications satellites operated by NBN Co and built by the U.S. based SSL. Launched in 2015 and 2016, respectively, they were configured to provide fast broadband in very remote areas and offshore, with wholesale speeds of 12/1, meaning 12 Mbps download and 1 Mbps upload, up to 25/5 Mbps, meaning 25 Mb/s download and 5 Mbps upload. As geostationary satellites, each Sky Muster has 101 static spot beams which cover a specific geographic area. The two-way signals are transmitted in the 'K_a band', which is the 26.5 – 40 GHz spectrum range. This frequency range is good for transmission bandwidth, and each satellite offers 80 Gbps of bandwidth. However it is noteworthy this very high frequency band can also be more susceptible to rain fade.

As an interim measure while planning for Sky Muster was underway, NBN Co commenced an interim satellite service (ISS) in 2011; 'SkyMesh', utilising satellite capacity from Optus and IPstar. The ISS was shut down in February 2017 with all subscribers required to 'seek an alternative NBN service', including migration over to the new Sky Muster service.

Optical fibre to farm

The significant data carrying capacity of optical fibre (FTTx) has seen a growing interest by individual farmers, farmer groups (for example geographic cooperatives) and second tier network providers in running optical fibre direct to farms. The reason farms don't have fibre connections boils down simply to cost, and a large proportion of that cost (i.e. 70%) is in trenching/laying and interconnection work; so called 'deployment costs'. The 2010 NBN Implementation Study (NBN, 2010) identified the cost of implementing fibre as "prohibitive" beyond 93% of serviced premises (Figure 27). The remaining 7% included, of course, the bulk of Australian farms.

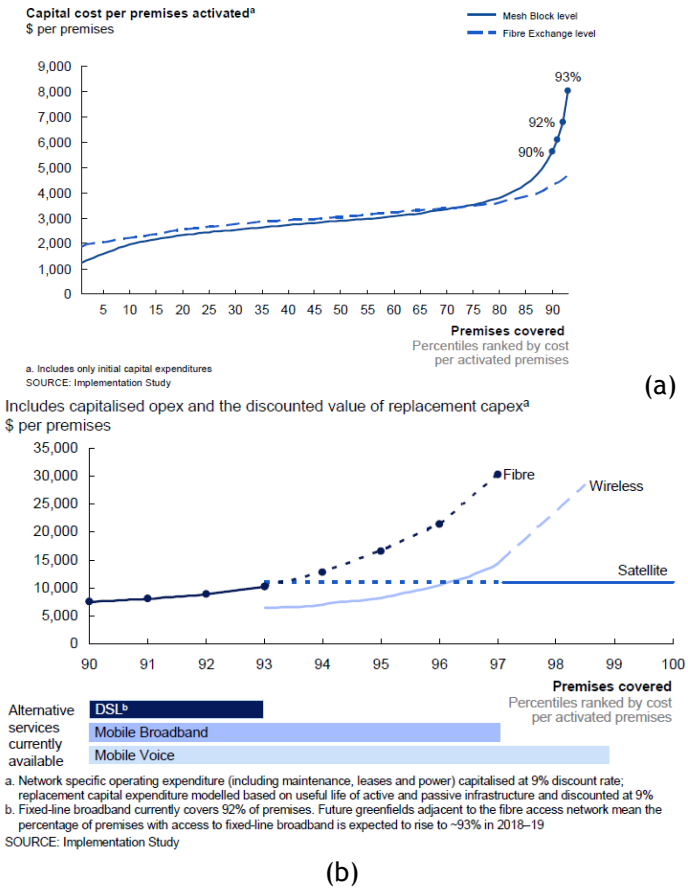


Figure 27. Rapidly escalating costs of FTTP (a) up to and (b) beyond the 93% threshold. (Source: NBN, 2010).

In 2013 it was estimated by one telecommunications analyst that deploying FTTP for the next 5 percent (i.e. 94th – 98th percentile) would cost $16.3 billion (http://www.abc.net.au/technology/articles/2013/01/31/3680486.htm).

In the United Kingdom, for example, the organisation Broadband for the Rural North Ltd (B4RN; https://b4rn.org.uk/) has focussed on reducing deployment costs and are installing fibre to previously unconnected areas 'DIY', involving volunteers and local landowners. In Australia, private fibre networks such as SMARTFarmNet (www.smartfarmnet.com) are now developing fibre install packages tailored for Australian farmers. At the time of writing, SMARTFarmNet, which had initially proposed constructing an optical fibre loop in central NSW will now extend 150km from Yass to Rye Park to Boorowa (NSW).

Bonded broadband

Bonded broadband is where multiple broadband connections are effectively combined into a single aggregated connection to deliver greater download and upload speeds. This is an options being considered by increasing numbers of data services providers and producers located in the urban fringe areas where multiple connections (lines) are feasible. A schematic of bonding is given in Figure 28. Bonding efficiency is quoted at usually greater than 85% and is related to the speed stability of the lines supporting the bond. In most cases uplink bonding can be as high as 95% and downlink 90%. Examples of bonding include multiple ADSL/ADSL2+ lines (up to 12; http://www.increasebroadbandspeed.co.uk/adsl-bonding) and hybrids, for example ADSL + 4G where the ADSL line is used for download and the 4G link for upload (http://www.fusionbroadband.com.au/fusion-hybrid/). Examples of bonding businesses includes Fusion Broadband (www.fusionbroadband.com.au) and Redwifi (www.redwifi.com.au). Whilst Redwifi is both an ISP and bonding service, Fusion Broadband is not an ISP, it simply bonds the broadband links provided by network operators. On top of what the CSP charges for each broadband link, these businesses generally charge on a 'per link' basis per month for the bonding service, which may include onsite hardware and customized data management services (for example Fusion Broadband, 2017).

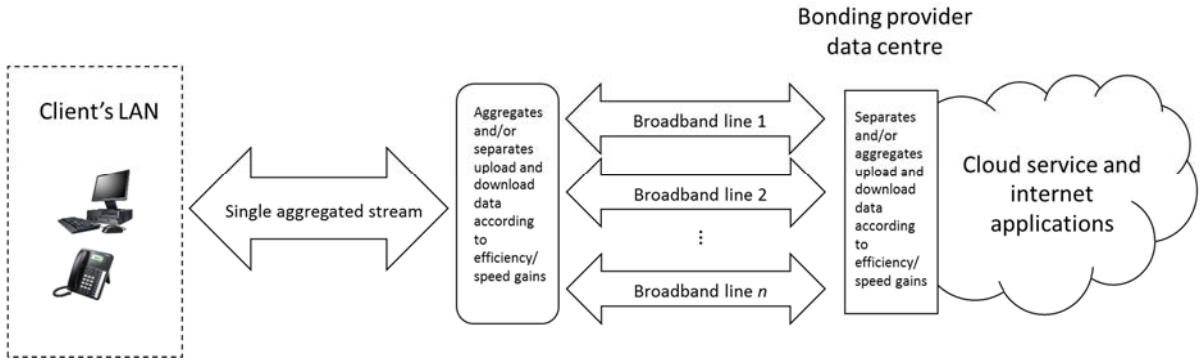


Figure 28. Schematic of broadband bonding.

Part 2 Identifying Issues

Identifying how producers view on-farm telecommunications

A series of 8 stakeholder workshops were conducted during December 2016 – April 2017 as part of the broader P2D project (Table 7 and Figure 29). Participants were encouraged to offer their views about on-farm telecommunications; both challenges and opportunities, and invited to share any experiences to illustrate their particular points. The session "Identifying future needs" within each workshop also provided an insight into the future needs of on-farm telecommunications which are documented below.

Table 7. Stakeholder workshop schedule

Date	Workshop Location	Industry foci
5 December 2016	Gatton, Qld	Horticulture
1 March 2017	Townsville, Qld	Sugarcane
2 March 2017	Tamworth, NSW	Cotton, Grains, Livestock
16 March 2017	Northam, WA	Grains
28 March 2017	Wagga Wagga, NSW	Grains, Wine grapes
29 March 2017	Tatura, Vic	Horticulture, Dairy
30 March 2017	Launceston, Tas	Forestry, Fisheries
27 April 2017	Tanunda, SA	Wine grapes

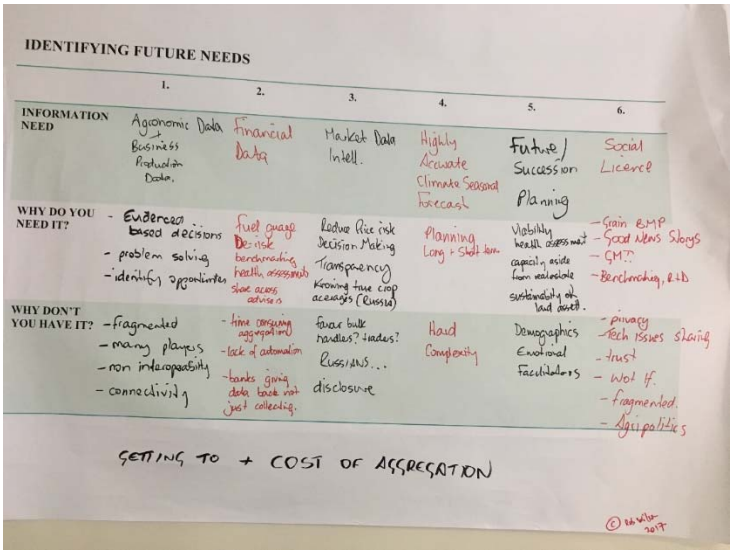


Figure 29: An example of recorded outputs from a table of producers and service providers at a regional workshop

Stakeholder experiences

The main focus of discussion around on-farm telecommunication experiences tended to be in relation to either mobile network or NBN Sky Muster, including migration from the Interim Satellite Service (ISS). Whilst the presence or absence of mobile connectivity was one recurrent issue, speed

was the other, and in particular data speed when 'within mobile range'. Many participants outlined frustrations with slow download speeds when using their smart phones to access time critical cloud-based farm data management services; even websites such as the BoM weather radar or allied herbicide application advisory services. Participants considered '1-2 bars' of mobile reception unusable for practicable internet access. Many participants identified the need for education around telecommunications options. Often they were aware of exemplar 'operations' that seemed to be embracing the latest in network technologies on their farms, but many felt overburdened by the need to learn and master 'yet another technology'; recognizing nonetheless that it was a necessity. Participants expressed a reluctance to invest even in turn-key solutions. Many felt their own personal lack of knowledge in the area of telecommunications technologies put them at risk of investing in sub-optimal solutions when a better system may be 'around the corner'. On the other hand there were examples at each workshop of producers who felt confident in establishing their own on-farm telecommunications infrastructure, had done so and, in the process, 'taught themselves a lot'. In the majority of these instances, producers shared learning 'on-the-go' with the solutions provider they worked with.

Observation: Producers and telecommunications solutions providers alike identify the need for education around on-farm network and connectivity options.

A summary of the key activities requiring on-farm telecommunications as outlined by participants in the workshops are grouped, by industry, in the following sections.

Horticulture

Table 8. Identified activities requiring on-farm telecommunications- Horticulture

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access-telecommunications mode
Weather- actual (including ΔT)	Radio or mobile network devices (shared)	Internet access (Office)
Weather forecast (including ΔT)	Internet- BoM	Smart phone (in situ) Internet (Office)
Irrigation decisions via soil moisture	Radio or mobile-connected probes	Smart phone (in situ) Internet (Office)
Irrigation control	Radio connected valves	Smart phone (in situ) Internet (Office)
Pest and disease management	Internet advisory services	Smart phone (in situ) Internet (Office)
Compliance (e.g. spray chemical batch, time/date application)	Manual entry	Smart phone app (in situ- e.g. on tractor)
Staff/machine management- drivers, operation records	Manual entry	Smart phone (in situ- e.g. on tractor), RFID (remotely accessible)
Field scouting- recording and access- e.g. SST, Sirrus, Backpaddock, Phoenix software	Internet- Cloud-based farm data management services	Smart phone/tablet
Field sensing of crop fertility- e.g. using handheld Greenseeker	Manual measurements, calibrated using app (offline)	App updates via mobile network

Market	Internet- Cloud-based market advisory service	Internet (Office)- although considered valuable to access in-situ (mobile phone network)

Sugarcane

Table 9. Identified activities requiring on-farm telecommunications- Sugarcane

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Yield monitoring/mapping and quality (TCH, CCS)	Harvester operations- store on board to later access	Mobile network
Logistics- transportation scheduling (e.g. during harvest)	Pre-arranged- verbal (phone when in mobile range)	Mobile network
Weather- actual (including ΔT)	Radio or mobile network devices (shared)	Internet access (Office)
Irrigation decisions via soil moisture	Radio or mobile-connected probes	Smart phone (in situ) Internet (Office)
Irrigation control	Radio connected valves	Smart phone (in situ) Internet (Office)
Compliance (e.g. fertilizer, spray chemical batch, time/date application)	Written records/offline entry onto smart phone/tablet	Smart/tablet phone app (in situ- e.g. on tractor)- live
Field scouting- e.g. crop biomass- recording and access- e.g. Agtrix, SST	Internet- Cloud-based farm data management services	Smart phone/tablet

Cotton

Table 10. Identified activities requiring on-farm telecommunications- Cotton

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Yield monitoring/mapping and quality (Bales)	Harvester operations- store on board to later access	Mobile network to allow streaming
Weather- actual (including ΔT)	Radio or mobile network devices (shared)	Internet access (Office)m Smart phone (for live 'alerts'- e.g. departure from spray conditions
Irrigation decisions via soil moisture (Cotton)	Radio or mobile-connected probes	Smart phone (in situ) Internet (Office)
Irrigation control (Cotton)	Radio connected valves	Smart phone (in situ) Internet (Office)
Weed management	Patch maps (generated insitu) and then robotics (?)	Mobile access for guidance and control

Compliance (e.g. fertilizer, spray chemical batch, time/date application)	Written records/offline entry onto smart phone/tablet	Smart/tablet phone app (in situ- e.g. on tractor)- live
Field scouting and decision making- nutrition	Internet- Cloud-based farm data management services	Smart phone/tablet
Decision support- e.g. for CottASSIST (www.cottassist.com.au/)	Internet- Cloud-based farm data management services	Smart phone/tablet, NBN (Office)

Grains/Rice

Table 11. Identified activities requiring on-farm telecommunications- Grains

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Yield monitoring/mapping and quality	Harvester operations- store on board to later access	Mobile network to allow streaming
Planting decisions via soil moisture	Radio or mobile-connected probes	Smart phone (in situ) Internet (Office)
Weed management	Patch maps – patch spraying	Mobile access for guidance and control
Compliance (e.g. fertilizer, spray chemical batch, time/date application, SunRice portal https://growersweb.sunrice.com.au/)	Written records/offline entry onto smart phone/tablet	Smart/tablet phone app (in situ- e.g. on tractor)- live
Field scouting and decision making- pest and disease monitoring, nutrition	Internet- Cloud-based farm data management services	Smart phone/tablet access- mobile network
Market	Internet- Cloud-based market advisory service	Internet (Office)- although considered valuable to access in-situ (mobile phone network)- e.g. to confirm sales when price comes up
Decision support- e.g. for Yield Prophet	Internet- Cloud-based farm data management services	Smart phone/tablet, NBN (Office)

Livestock

Table 12. Identified activities requiring on-farm telecommunications- Livestock

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Compliance (e.g. fertilizer, spray chemical batch, time/date application)	Written records/offline entry onto smart phone/tablet	Smart/tablet phone app (in situ- e.g. on tractor)- live

Inventory tracking and rotation/pressure scheduling (grazing)	Yard measurements, farm paddock records (farm office).	Smart phone/tablet, satellite-direct for in-paddock, NBN for office
Field scouting and decision making- biomass, nutrition	Internet- Cloud-based farm data management services	Smart phone/tablet for in-paddock access- mobile network
Safety (in yards and when mobile in paddocks)	Mobile phone- if available, handheld/vehicle UHF- if available	Vehicle (including quad bike) safety monitoring systems- satellite phone, satellite monitoring
Market	Internet- Cloud-based market advisory service	Internet (Office)- although considered valuable to access in-situ (mobile phone network)- e.g. to confirm sales when price comes up
Decision support- e.g. Pastures from Space, PAM	Internet- Cloud-based farm data management services	Smart phone/tablet for in-paddock use, NBN (Office)

Wine grapes

Table 13. Identified activities requiring on-farm telecommunications- Horticulture

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Field scouting and decision making- vine balance, fruit load, pest, diseases, fruit quality – 'every day'	Collection of data using smart phone- access to cloud based diagnostics/advisories(many 'online not 'offline')	Smart phone/tablet for in-paddock access- mobile network
Compliance (e.g. fertilizer, spray chemical batch, time/date application)	Written records/offline entry onto smart phone/tablet	Smart/tablet phone app (in situ- e.g. on tractor)- live
Bin/consignment tracking	Truck/driver records- mobile network	Mobile network for vehicles, NBN for offices/logistics centres- e.g. winery)
Yield monitoring/mapping and quality (not much changed since nineties)	Harvester operations- store on board to later access	Mobile network to allow streaming
Irrigation decisions via soil moisture and weather(e.g. for shoot growth)	Radio or mobile-connected probes and AWS	Smart phone (in situ), radio networks Internet (Office)

Dairy

Table 14. Identified activities requiring on-farm telecommunications- Dairy

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Milking- robotic dairy (also applies to manual) Robotic	ADSL (currently better than Mobile network or	Mobile network (or fixed wireless NBN) that is reliable

milking is 24/365 and autonomous.	fixed wireless NBN)- unreliable	
Safety (in dairy and when mobile in paddocks)	Mobile phone- if available, handheld/vehicle UHF- if available	Vehicle (including quad bike) safety monitoring systems- satellite phone, satellite monitoring
Field scouting and decision making- biomass, nutrition	Internet- Cloud-based farm data management services	Smart phone/tablet for in-paddock access- mobile network
Grazing management	Fully manual but seeking assessment tools coupled with 'grazing movements' (Virtual fencing?)	Mobile network (or equivalent) in paddocks

Forestry

Table 15. Identified activities requiring on-farm telecommunications- Horticulture

Identified operations/functionality	Source of data - telecommunications mode	Existing or required access- telecommunications mode
Tagging trees and to instruct transport logistics. (Comment: Opportunity for connectivity to underpin shift to quality drivers in forestry)	Manual but opportunity for mobile apps- mobile network, using mobile (app) to instruct transport logistics. (Woodchip is easier to follow as a single transformation. The saw log logistics is more complex and less transparency in supply chain)	Smart phone/tablet, satellite-direct for in-paddock, NBN for office
Logistics- transportation/mill scheduling (e.g. during logging)	Pre-arranged- verbal (phone when in mobile range); Physical monitoring with e-book record keeping rather than remote sensors.	Mobile network
Producer management	Managing data with 'closed loop production system', quality thresholds and associated payment systems. Web based.	Smart phone/tablet, NBN for office
Producer management	Managing data with 'closed loop production system', quality thresholds and associated payment systems. Web based.	Smart phone/tablet, NBN for office

Phone Survey

A telephone survey of 1000 producers across 15 industries was conducted by P2D project partner CSIRO Data61 during the period of 7 March to 18 April 2017 (Zhang et al., 2017) (Table 16). Within the survey, respondents were asked to rate the importance of connectivity to their business, specify how their business was connected to the internet, rate their satisfaction with their internet connectivity, describe their mobile phone coverage across their farm, identify their on-farm telecommunications infrastructure, and rate the degree of difficulty in managing and maintaining that infrastructure.

Table 16. Number of respondents per industry by state (Source: Zhang et al., 2017).

Industry	State							Total
	NSW	QLD	VIC	TAS	SA	WA	NT	
Beef only	23	63	22	1	7	9	1	126
Beef/Grain Mixed	28	21	4	1	5	5	0	64
Beef/Sheep Mixed	59	9	17	0	3	6	0	94
Sheep Meat Only (Lamb)	29	2	19	1	5	3	0	59
Sheep/Grain Mixed	45	0	20	1	15	13	0	94
Sheep Wool	37	3	20	2	11	16	0	89
Dairy	21	9	58	5	1	0	0	94
Pork	1	6	3	0	4	1	0	15
Poultry Eggs/Meat	19	1	9	1	0	0	0	30
Aquaculture	9	4	5	4	5	1	2	30
Grain Only	19	8	13	0	14	23	0	77
Grain - Grain/Beef/Sheep	18	4	12	0	12	27	0	73
Cotton	17	13	0	0	0	0	0	30
Rice	15	0	0	0	0	0	0	15
Sugarcane	7	58	0	0	0	0	0	65
Vegetables	13	8	5	0	3	1	0	30
Wine Grapes	4	1	2	0	6	2	0	15
Total	364	210	209	16	91	107	3	1,000

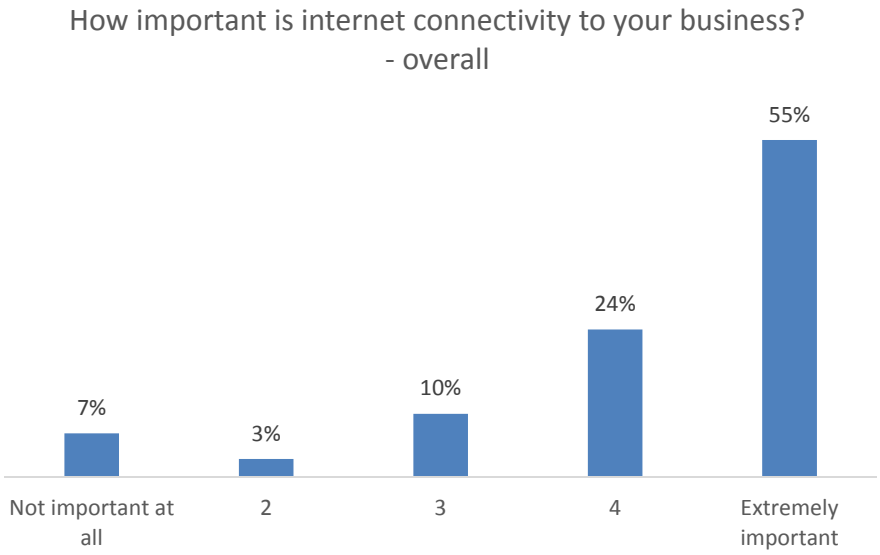
Table 17. Average farm size and business intensity by industry (Source: Zhang et al., 2017)

Industry	Farm size (ha)	Business Intensity Unit	Mean	Median
Aquaculture	130	Annual production in kg or	434,855	63,500
Pig	998	Total Number of Sows	1,809	700
Beef only	11723	Total Number of Beef Cattle	1,868	775
Beef/grain mixed	6779	Total Number of Beef Cattle	1,516	430
Beef/sheep mixed	6792	Number of beef cattle	662	270
		Number of sheep	4,046	3,000
Dairy	397	Total Number of Cows Milked	314	240
Poultry Eggs/Meat	140	Total Number of Hens/Birds	199,193	42,500
Sheep Meat Only	8726	Total Number of Sheep	21,154	2,800
Sheep/Grain mixed	3466	Total number of sheep	4,287	3,000
Sheep Wool	7281	Total Number of Sheep	4,954	3,000
Cotton	6866	Hectares planted to cotton	3,595	403
Grain only	3936	Hectares planted to grain	2,464	2,020
Grain – Grain/beef/sheep	4569	Hectares planted to grain	2,516	2,023
Rice	2424	Hectares planted to rice	171	100
Wine grapes	882	Hectares planted to wine	144	24
Sugarcane	335	Hectares planted to sugarcane	159	80
Vegetables	589	Hectares planted to vegetables	110	27.5

Table 18. Demographics of respondents by industry (Source: Zhang et al., 2017)

Industry	Number of respondents	Gender (women)	Average age (years)	Average years in industry	Education							
					Did not complete year 12	Completed year 12	Post-secondary qualification - agriculture	Post-secondary qualification - other	Undergraduate degree - agriculture	Undergraduate degree - other	Postgraduate degree - agriculture	Postgraduate degree - other
Aquaculture	30	3%	52	24	20%	13%	0%	3%	10%	10%	30%	13%
Pork	15	20%	55	34	47%	13%	7%	7%	27%	0%	0%	0%
Beef only	126	16%	60	41	44%	27%	8%	4%	10%	6%	1%	1%
Beef/Grain Mixed	64	13%	57	37	44%	17%	9%	8%	13%	8%	0%	2%
Beef/Sheep Mixed	94	19%	58	40	33%	20%	13%	6%	14%	9%	2%	3%
Dairy	94	9%	58	39	57%	14%	7%	9%	8%	3%	3%	0%
Poultry Eggs/Meat	30	13%	62	35	57%	17%	7%	10%	0%	7%	0%	3%
Sheep Meat Only (Lamb)	59	3%	58	39	54%	19%	12%	2%	9%	3%	2%	0%
Sheep/Grain Mixed	94	12%	56	37	47%	20%	12%	6%	9%	1%	3%	2%
Sheep Wool	89	17%	60	38	42%	25%	10%	8%	6%	3%	5%	2%
Cotton	30	17%	50	23	10%	17%	23%	3%	17%	17%	3%	10%
Grain Only	77	8%	53	33	34%	25%	7%	7%	12%	8%	5%	4%
Grain - Grain/Beef/Sheep	73	10%	55	36	40%	27%	11%	3%	8%	8%	3%	0%
Rice	15	27%	56	35	27%	13%	13%	13%	0%	20%	7%	7%
Wine Grapes	15	13%	54	25	33%	20%	20%	0%	13%	7%	7%	0%
Sugarcane	65	5%	58	39	54%	14%	12%	12%	2%	3%	3%	0%
Vegetables	30	3%	58	30	40%	10%	7%	10%	7%	10%	7%	10%
Total	1000	12%	57	35	42%	20%	10%	6%	9%	6%	4%	2%

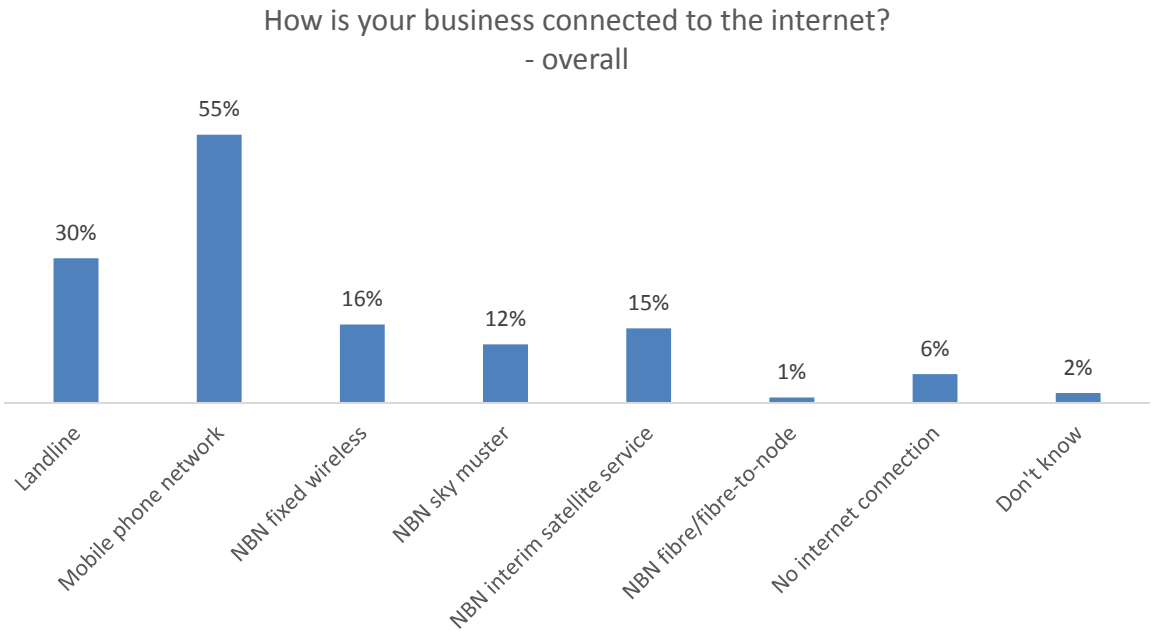
How important is internet connectivity to your business?



(Source: Zhang et al., 2017)

There is a consensus across industries, where over three-quarters of respondents find internet connectivity to be moderately-to-extremely important to their business and 55% find internet connectivity extremely important.

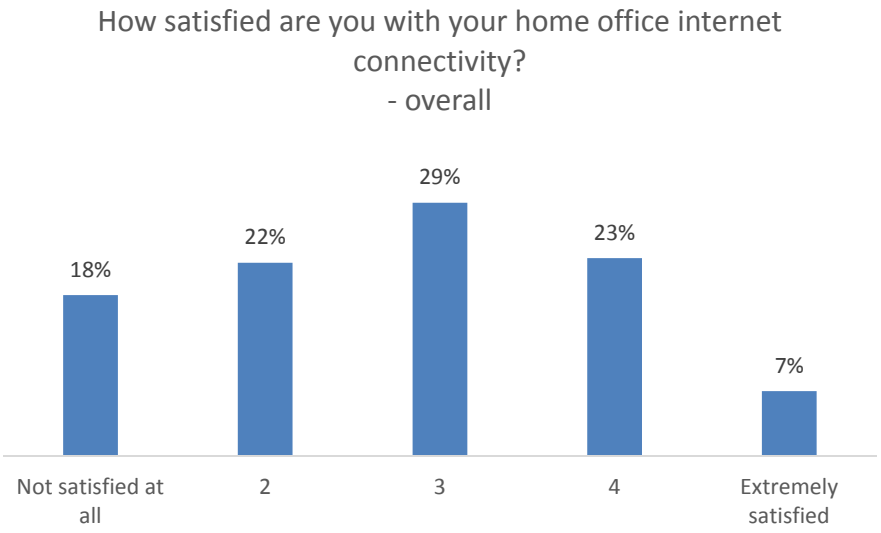
How is your business connected to the internet?



(Source: Zhang et al., 2017)

The vast majority of respondents (94%) have an internet connection for their business with the largest proportion (55%) relying upon the mobile phone network, and 30% of respondents rely upon landline, ostensibly ADSL/ADSL2+ for internet connectivity. There are a number of contributing factors to the popularity of mobile network access, including the relative freedom of users to access the internet at any time and place, rather than from a single fixed location namely their office, and the type of business-related activities that are supported by internet that are amenable to interaction via mobile devices. No distinction was made between the nature of the internet activity, for example whether this also included social media or involving more 'serious' activities such as financial transactions, for example. On this basis there is a need to fully understand the nature of internet use by producers comparing office use to mobile use.

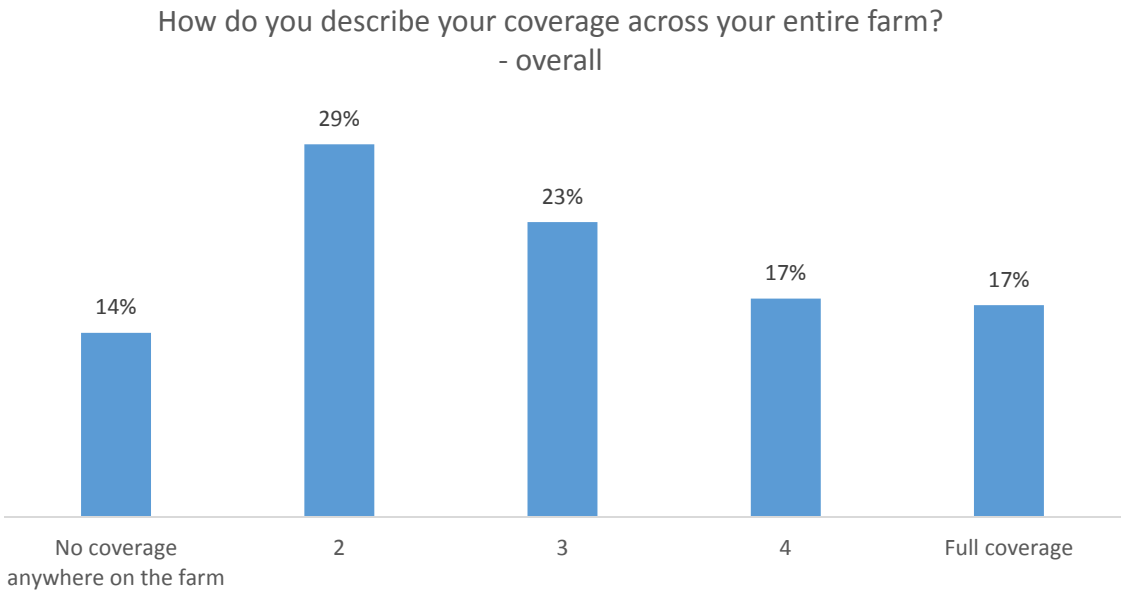
Satisfaction with internet connection



(Source: Zhang et al., 2017)

Among the producers who had internet connections (N = 941), about one-third of respondents were satisfied with their home office internet connectivity, and nearly one-fifth were not satisfied at all. Across industries, most show moderate levels of satisfaction (mid-point of the scale -3). Of the surveyed industries the beef/grain mixed, poultry eggs/meat, cotton, and grain only industries were less satisfied.

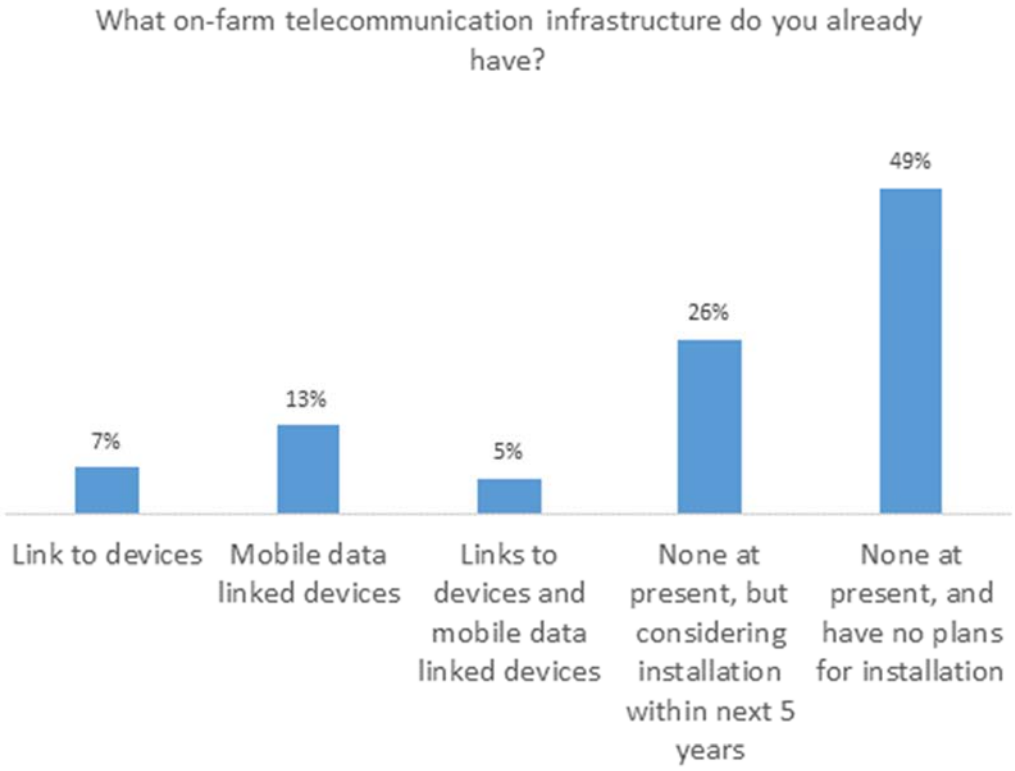
Mobile coverage across farm



(Source: Zhang et al., 2017)

Approximately 43% of respondents reported very patchy to no coverage across their farm, 34% had almost-complete to full-coverage on their farm, dominated by dairy and sugarcane industries. Beef and cotton reported most strongly in the patchy or no coverage classes and this is likely reflective of the spatial density of these farms and proximity to urban centres. It is interested to note that at the grape and wine industry Workshop (Tanunda) producers reported 'no problems' with mobile phone access, and this was accepted by them to be on the basis of the spatial density of vineyards, proximity to urban centres and the significant allied tourist industry associated with them.

On-farm telecommunication infrastructure

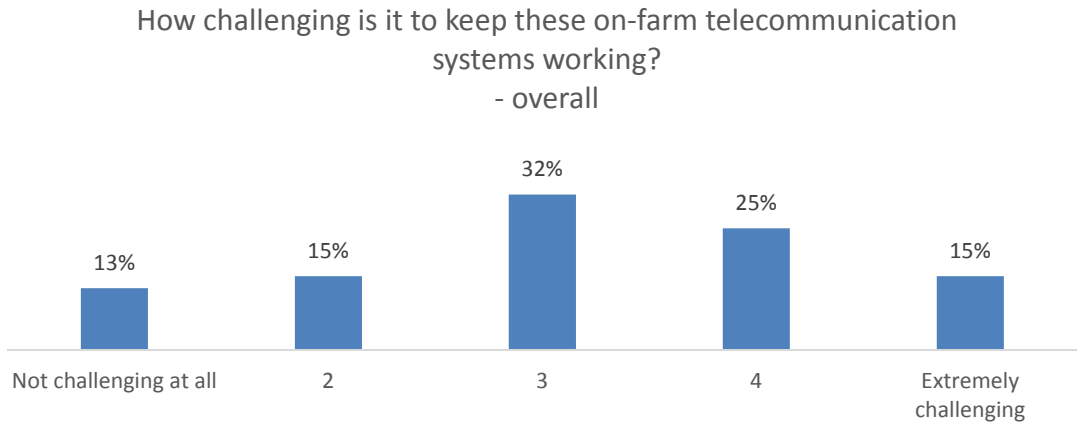


(Source: Zhang et al. 2017)

Almost 75% of producers surveys (all industries) have no devices on their farms that utilize on-farm telecommunications links (radio or mobile) While more than a quarter of those surveyed indicated they were considering installing some form of infrastructure within the next 5 years, almost half of them had no plans to do so within 5 years. Nearly half of the cotton industry (47%) had links to devices on their farms. The cotton industry (47% deployment) is particularly advanced in their use of connected devices on farms, primarily because of the critical importance of soil water management for irrigation. Of these producers with devices, 85% had them connected via the mobile phone network. Of the vegetable producers surveyed, 30% reported having connected devices with almost all of them utilizing the mobile network. Aquaculture/pork reported 22% deploying linked devices and poultry eggs/meat industries 20%. Lower deployment rates were reported for beef (9%), mixed (beef and grain) (13%), mixed beef and sheep (7%) and sheep (wool) (6%).Between 10 and 30% of those respondents without any connected devices on their farms indicated considerations to installing some form of device in the next 5 years, with poultry showing the least inclination. Approximately half of the respondents from beef only, dairy, poultry eggs/meat, sheep/grain mixed, sheep wool, rice/wine grapes and sugarcane industries had no farm telecommunication infrastructure and have no plans of installing any. Significantly, 20-63% of those respondents indicated no propensity to install devices.

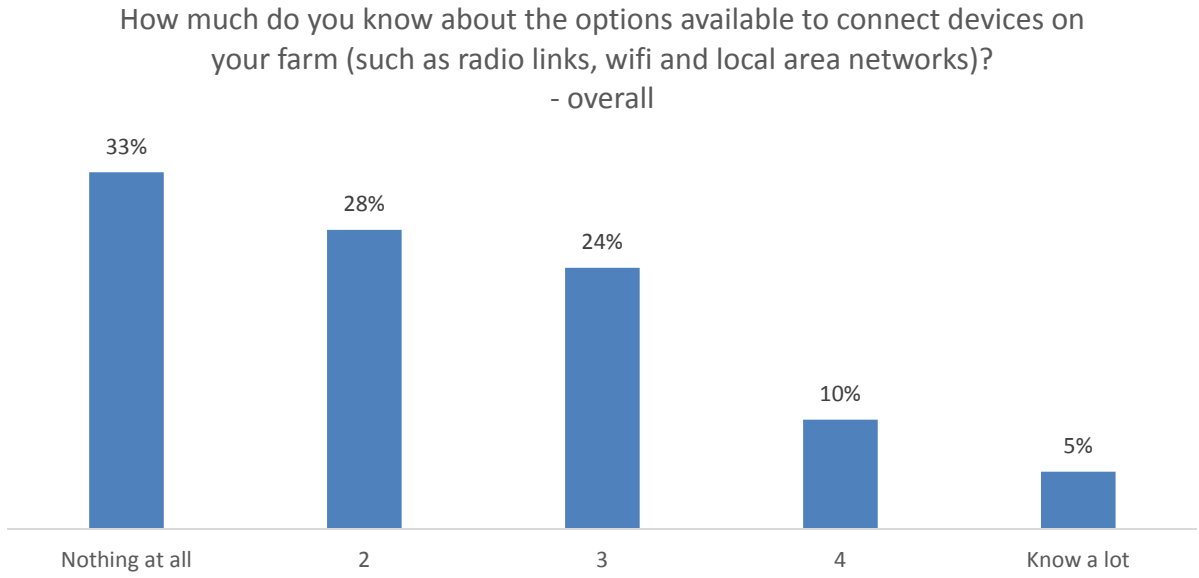
Management of on-farm telecommunication infrastructure

Of those respondents that already had linked devices (radio and/or mobile) on their farm (N = 244) three-quarters of respondents found it moderately-to-extremely challenging keeping on-farm telecommunication systems working. Only a very small proportion (25%) indicated little or no challenge associated with maintaining and operating their infrastructure. Respondents from the dairy and sugarcane industries found it least challenging to keep on-farm telecommunication systems working



(Source: Zhang et al., 2017)

Understanding opportunities and options for on-farm telecommunications infrastructure

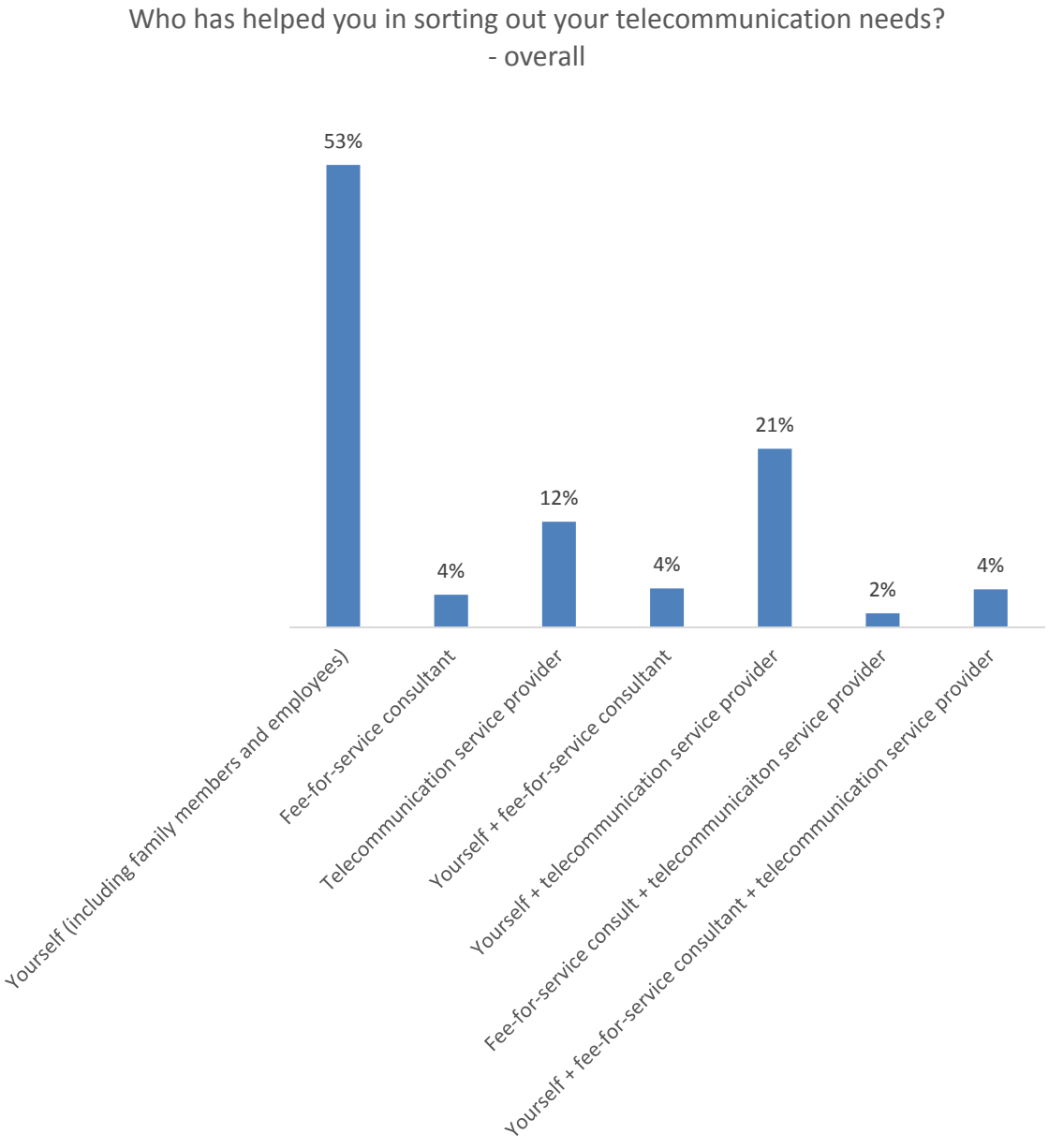


(Source: Zhang et al., 2017)

One-third of respondents reported that they knew nothing at all about the options available to connect devices on their farm. Half of respondents found they knew very little-to-moderate about these options; only 5% of respondents believe that they knew a lot about these options. In the 1-5 rating of knowledge, respondents from the cotton industry and aquaculture/pork industry groups appeared to know more about the options to connect devices to their farms, but this may simply be a consequence of more of them deploying these devices and learning on the go or through interactions with their service providers/consultants. Those sectors related to livestock industries tended to rank their knowledge lower. Interestingly sugarcane respondents rated their knowledge of options the lowest. There is quite possibly an education/training dimension evident here. The sugar workshop (Townsville) specifically singled out education and training as a significant requirement in meeting the evolving technology and connectivity needs of their industry.

Who has helped you in sorting out your telecommunication needs?

Approximately half of the respondents (53%) who have devices on their farms relied upon themselves to meet the installation and maintenance needs of their device networks. Approximately one-fifth (21%) used a combination of themselves and a telecommunication service provider to sort out their problems. The least quoted option was to involve a fee-for-service consultant to provide a solution.



(Source: Zhang et al., 2017)

The aquaculture, pork, cotton and sugarcane industries show the lowest likelihood of doing it themselves, relying upon third parties to provide and manage the solution. This is again reflective of the maturity of the connected device market, and in particular the service market in these sections as driven by irrigation management. In these industries, farm consultants, specifically agronomy related, often play a more active, wider role in managing the allied technologies associated with the clients and this may extend to connected devices that provide some, if not a significant proportion of information used to make management decisions.

Producer concerns about the NBN

Throughout the process of interviews and workshops, many producers and service providers repeatedly raised concerns about the NBN and these are summarised below.

Power

Producers using both fixed wireless and Sky Muster NBN were concerned about the reliability of their NBN communications in situations of a power outage, noting that NBN equipment located on the premises will not work during a power blackout. While it could be argued that producers face exactly the same power limitations as those on the various NBN 'wired' communications platforms, producers were quick to point out that the added issue of distance to/from 'help' adds a further level of risk to a failed communications scenario. Producer concerns regularly focussed on devices connected through their NBN connection such as medical alarms or monitored safety or security alarms.

Those users of NBN fixed wireless and Sky Muster connectivity acknowledged the advisories to consider (1) maintaining an 'alternative power option', (2) 'keeping a charged mobile phone' and/or (3) 'retaining an existing copper landline' for emergency communications (www.nbnco.com.au). However participating producers felt Option (2) may not be practicable if the farm is located any significant distance from mobile reception and Option (3) is predicated on whether landline will remain supported under any future amended USO.

It was also acknowledged that if one of the Sky Muster ground stations or a nearby fixed wireless NBN tower experiences power loss then neither form of connectivity will work irrespective of power availability at the premises. This is no different from existing landline telecommunications solutions.

Speed, capacity and 'shaping'

Producers expressed frustration with the reliability of their connection which, when questioned, boiled down to fluctuations in speed. Whilst not specifically an NBN issue (i.e. related to ADSL connections too), the problem was expressed by many with an NBN link in their farm offices. It transpired that users of ADSL connectivity, while in some cases experiencing lower speeds, knew what they were getting and were keen to 'hold on to it' from a reliability perspective. Many (> 50%) cited the NBN as 'not being as fast', or 'less reliable' (viz. speed) than their earlier landline (ADSL) connections.

Virtually all participants who subscribe to fixed wireless NBN reported reduced speeds over time; concluding this to be due to the filling of the subscriber base for each tower. Many questioned whether the carrying capacity of fixed wireless towers was being adequately configured for the number of subscribers.

Observation: Many producers report reduced speeds to fixed wireless NBN over time, presumably due to the filling of the subscriber base for each tower. Is the carrying capacity of fixed wireless towers adequately configured for the number of subscribers?

Another cause of dissatisfaction was around 'broadband shaping'; the lowering of the speed of an Internet connection once a subscriber has exceeded their monthly download limits. In the majority of overseas countries, home Internet connection plans are essentially unlimited, and while a subscriber may exceed a monthly limit, financial (sometimes significant) penalties may be incurred. This often triggers adverse (media reactions). From an ISP perspective, the alternative approach (which is favored in Australia) is to "shape" the connection which entails lowering the speed (often < 100 kbps); sufficient to service access to essentials, such as text-form emails. This usually applies until the next billing period (month) commences when the plan is 'restarted'. In many cases encountered in the workshops and follow-up discussions, the affected producer either under-estimated their farm management data use (and hence did not select an appropriate data plan), or simply selected a plan on the basis of what they felt they could afford and was appropriate, fully expecting that this may inevitably result in a shaped experience towards the end of the month (or

sooner). Many producers feel the cost of data access is expensive, and sometimes 'too expensive'. A summary of data costs (per Gbyte) is given in Table 19 (Graham, 2016):

Table 19. Data costs based on a survey of 199 rural broadband users in 2015 (extracted from Graham, 2016 and additional data provided from Zhang et al., 2017)

Connection	Proportion of users (%) Graham (2016) 2015 Survey	Monthly data cost	Cost per Gb	Proportion of users (%) Zhang et al. (2017) survey[20]
Cable/Fibre	2	613	$0.16	1
Fixed wireless	19	246	$0.36	16
Mobile network	**39**	**17**	**$6.47**	**55**
Landline	12	345	$0.27	30
Satellite	**28**	**26**	**$2.43**	**27**

Both the recent survey of Zhang et al. (2017) and Graham (2017; survey conducted in 2015) confirm the mobile network as the dominant means of internet connectivity on farms. Unfortunately the mobile network has, by far the largest broadband data costs (per Gb data), followed by Sky Muster.

Observation: Given the reliance producers have on mobile and satellite broadband data access, has data usage, and attendant business models been appropriately designed around on-farm users? Producers claim data costs are too high.

Fair use

The Sky Muster satellite has a Fair Use Policy (NBN, 2016) in place in order to help ensure fair access to services, and especially during peak-usage times (7 am – 1 am). Ultimately this is based on the capacity of Sky Muster. While the Fair Use Policy applies between NBN Co and the ISP, the ISP will usually have a separate fair use policy which applies to the user. The user must adhere to both the ISP and NBN Fair Use Policies, and while this sounds overly complicated, generally the ISP will offer data packages to ensure that the ISP data limits are exceeded and appropriate measures (such as shaping) are instituted to avoid further incursions into the NBN Fair Use Policy. Nevertheless, if a subscriber aims for a large data plan, and if in doing so the NBN Fair Usage Policy is breached, NBN will shape the access, restricting the speed of the satellite service to 256/256kbps until the service returns to compliance. Given the NBN thresholds are tested over a rolling 4 week period, on a per calendar day usage basis, the soonest this could occur would be the next calendar week of compliant behaviour. The user's ISP has no ability to remove this shaping.

At the same time, the ISP may shape the user on the basis of the monthly data plan. For example if a user's service has been shaped as a consequence of breaching the NBN Fair Use Policy, and they proceed to use up all of a monthly data plan, then their service may be further shaped by the ISP, for example down to 128/128 kbps. Given this would be based on a monthly plan, this shaping would then be removed at the beginning of the next monthly billing period.

Most ISPs offer their clients information on the impact of the different internet usage behaviour on data consumption, both for the purposes of avoiding ISP shaping but also NBN shaping (Table 20).

On 28 June 2017, NBN announced it will be doubling the maximum peak download allowance, from 75 Gbytes per month to 150 Gbytes per month, ostensibly on the basis that they have determined the network "is actually capable of delivering more than […] originally forecast." (ABC Rural, 2017). It was reported that "Each subscriber on the satellite service currently uses an average of about 27 Gbytes per month, a 12.5 per cent increase over the past six months." It is presumed that this increase in data allowance will flow through to amended ISP data package offerings and possibly even affect a reduction in data pricing. On this point it should be noted that it is unclear whether

[20] The Zhang et al. (2017) survey allowed respondents to select multiple modes of connectivity, hence % values do not add up to 100%

pricing (by NBN or ISPs) has ever been used as a means of discouraging data use (and hence encouraging compliance with Fair Use).

Table 20. An example calculation of typical broadband use ('average household') and the impact on shaping; both ISP and NBN (Data extracted from iiNet; https://iihelp.iinet.net.au/NBN_Satellite_Fair_Use_Policy_FAQ).

Online activity	Av % monthly data used for activity	Estimated data per hour for activity	Example of usage in a typical week	
			20 Gbyte monthly peak plan	40 Gbyte monthly peak plan
Web browsing and emails	**10%**	**0.09Gbytes/hour**	**5.5 hours/week**	**11 hours/week**
Standard High Definition (720p) video streaming (e.g. Netflix on 'Medium' quality setting)	**60%**	**1Gbytes/hour**	**3 hours/week**	**6 hours/week**
Low Definition (480p) video streaming (e.g. YouTube on 480p quality)	**17%**	**0.3Gbytes/hour**	**2.8 hours/week**	**5.6 hours/week**
Social media browsing and messaging (excludes video)	**7%**	**0.12Gbytes/hour**	**3 hours/week**	**6 hours/week**
Video calls (e.g. Skype)	**4%**	**0.5Gbytes/hour**	**24 minutes/week**	**48 minutes/week**

Observation: The data consumption behavior of producers is not known, or at least is assumed to be the same as 'average households'. Fair Use in relation to consumers of Satellite broadband must be based on the data usage (current and expected) of producers.

Accessing NBN on farms

In response to the higher-than-expected demand for NBN in rural and regional Australia, and to mitigate the risk of over-demand for broadband satellite services, extra resources were put into expanding NBN fixed wireless coverage. NBN's Sky Muster service experienced 'performance problems' over the late 2016-early 2017 period (Computerworld, 2017) and with growing concerns around capacity to deliver, NBN Co are also considering a third satellite, either in its own right or via a third-party provider.

Ultimately NBN access for all clients, including producers is locked into provision of a broadband service to a premises. Yet increasingly broadband access may be required anywhere on a farm, not just the farm office or homestead. Examples range from supporting 'data hungry' technologies such as remote vision systems, for accessing cloud-stored data while working in the field or while operating machinery, and for servicing the needs of worker communities (including families) accommodated across a single (large) farm.

Producers questioned whether their farms should be considered in the same light as urban premises when it comes to NBN connectivity. With only a single point of connection available, producers are faced with potentially significant internal communications infrastructure costs (and possibly data shaping) creating and maintaining multiple access points. Producers felt that multipoint NBN connectivity would be a big improvement to their current NBN connectivity options.

Observation: The current policy of providing NBN access to a single premises does not recognize the fact that large farms may require their access at different locations, often significant distances apart, either coincidentally or at different times.

Another issue raised was in relation to accessing NBN across farms. One solution is the notion of mobile Sky Muster satellite access. This refers to technology that has the ability to access Sky Muster satellite from a trailer- or vehicle-mounted receiver, parked anywhere on a farm (Figure 30). An unintended consequence of the 'Sky Muster utes' used by NBN Co around Australia to demonstrate Sky Muster 'in action' has been the creation of an appetite for mobile Sky Muster capability; and this is particularly relevant to producers on extensive farms.

(a)

(b)

(c)

Figure 30. (a) One of seven NBN Co's 'Sky Muster utes' set up to provide broadband 'on location'. Equipped with an automatically 'pointable' satellite dish and a Network Connection Device (NCD) to allow it to work in a given NBN satellite cell, the device not only creates a direct link but also generates a broadband hotspot around it. While this version of technology is expensive, consumer-grade, off-the-shelf, automatic (b) caravan TV satellite dishes, and (c) K_a band dishes for marine applications are available (Source: www.satplus.com.au (b) and www.satmarin.com (c)).

From a network operator perspective, managing capacity for mobile network access can be challenging, especially the mobile phone network where it is difficult to predict the usage of subscribers on the move in and out of cells. However this is not the case for farms, which are a fixed location, and where the mobile workforce is constrained to within a known area. In the case of Sky Muster access, the cell (beam; hence network connection device (NCD)) would remain the same for a given farm.

Compatibility issues with cloud-based farm management platforms and NBN Sky Muster

On a number of occasions producers reported an inability to access cloud based tools when attempting to log in using Sky Muster NBN. Importantly they did not experience the same problem when accessing the same sites using the NBN ISS service, fixed wireless NBN nor ADSL. One example

is the NRM Hub, a web-based farm management tool that combines geospatial mapping capability with time-series satellite images (30-years) for assessing and monitoring property infrastructure, land resources, ground cover and for managing livestock grazing (www.nrmhub.com.au) (Figure 31). NRM Hub currently has approximately 700 producer subscribers.

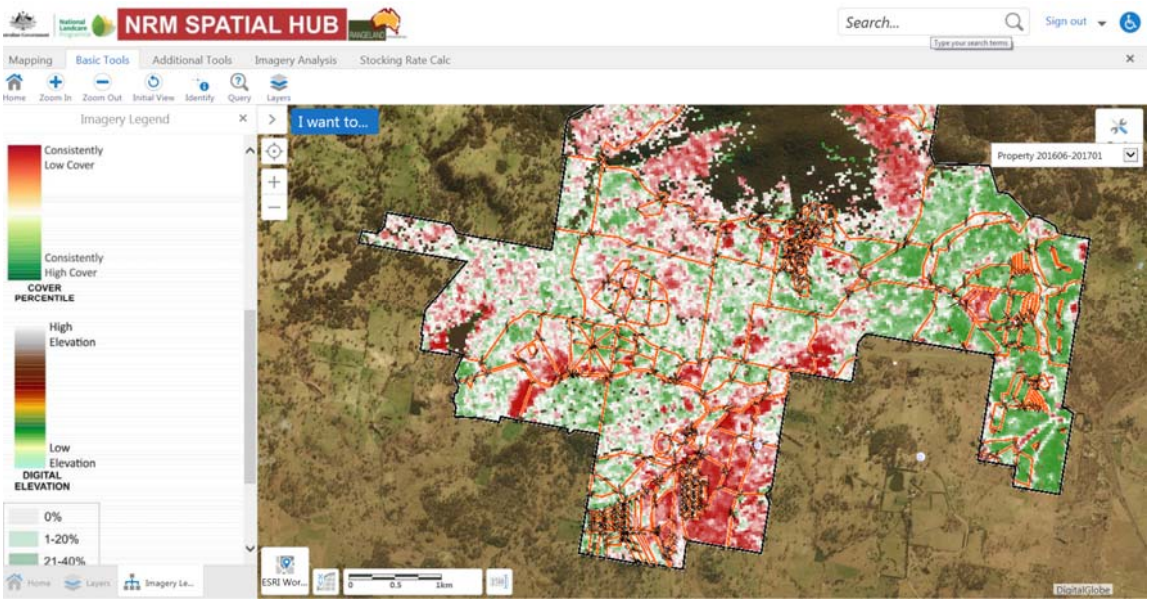


Figure 31. Example of NRM Spatial Hub showing land cover (pasture) stability (Source: UNE SMART Farm on http://map.nrmhub.com.au/hub/#).

In this case the problem was that the website's log-on/security software was unable to work with the Accelerator Software associated with the new NBN Sky Muster Satellite (ostensibly due to the sophisticated software, Accelerator and Optimisation protocols of NBN Sky Muster uses to help lessen the impact of latency and therefore improve Satellite customer experience). The solution to the problem was achieved by having the web service provider changing their web Site to HTTPS[21], in other words optimising their site to cater for NBN Sky Muster. The important lesson learned here was that the provider of this web service was unaware of the particular way that Sky Muster works and this was only solved following detailed (and extended) consultation between the web developers and the relevant technical personnel in NBN Co.

Observation: Developers of web services for Australian consumers accessing via Sky Muster need to understand the various means of optimising the service to suit the way Sky Muster operates. NBN Co must play a role in developing this material as it is out of the hands of ISPs.

[21] HTTPS, or HTTP Secure is a protocol for secure communication over a computer network. This particular website had a third party security provider that issues tokens to allow the registered end user to progress to the geospatial website and utilised HTTP. Sky Muster has "Acceleration" software which transparently accelerates unencrypted packets such as HTTP and increases efficiency by resending packets if it hasn't seen a response within a certain response window. The security provider perceives multiple requests for a logon as a fraudulent request and does not issue a token, hence the end users are unable to logon to the NRM website.

Challenges faced by second-tier telecommunication solutions providers

The last 2-3 years has seen the emergence of 'second tier' telecommunications service providers (examples included in the Case Study Section) seeking to deliver end-to-end services on farms. These providers, typically certified carriers in their own right, have access to large capacity transmission infrastructure such as dark fibre and regional points of presence from which to launch wireless connectivity. They are purchasing portions of spectrum and are seeking physical space on existing point-to-point transmission infrastructure. At the farm end they will have either an integral networking capability to provide ongoing point-to-point and point-to-multipoint connectivity across the farm, or will partner with local wide area network providers, and even with IoT providers to run connectivity literally into the sheds, troughs, tanks, machines etc.

Observation: Many of the producers contacted as part of this review indicated their interest in seeking solutions from second tier providers, citing a desire to 'avoid' the large network operators due to past or current frustrations with service provision. This is perhaps an unfortunate legacy of past years where interoperability and compatibility of 3rd-party hardware for on-farm connectivity and network solutions wasn't as established with external network operators as it is today. It is acknowledged that the major network operators are now focusing attention on rural and farm-ready solutions, but there is some rebuilding of trust to do.

In addition to offering the networking capability, many of these second tier providers act as ISPs and offer 'defining' data packages that include immunity from 'shaping', for example shaping under the NBN Fair Use Policy and competing CSP/ISP data agreements.

When asked about physical challenges in providing network services to farm clients, rather than talk about the limitations of line of sight (a major factor in point-to-point links), these second tier telecommunications providers cited access to physical infrastructure, e.g. telecommunications towers as the biggest challenge. For example, one provider described a scenario in the Riverina whereby accessing dark fibre to run connectivity out to a nearby farm required installing as dish on a particular tower (POP). However the tower in question did not have the mechanical scalability to hold the dish required for the onward Point-to-point link onto it. The fibre network could not be accessed unless the provider built an entirely new tower on which to mount the dish, or pay additional~ $125,000 for improving the strength of the original tower. In another scenario the producer had a private radio tower but, because they required a 3 m (100 kg) antenna (1.5 m deep), it would not have been capable of supporting the dish in a storm.

Providers expressed concerns that prices will go up; certainly as more and more users contest physical space on towers (a limited resource unless new ones are built at significantly extra cost). One provider observed that a mobile network operator that owns a tower can charge $10k just for a feasibility study to access that tower. The application fee itself then costs $4-5k, plus $900-1100 per month to rent space on tower. All of these charges are passed onto the client.

There is also the price of spectrum. The 11 GHz spectrum supports relatively wide channels and hence lots of data throughput. This spectrum is considered affordable. For example, to run a 11 GHz link from a particular farm in NW NSW to the nearby 3G tower costs $800-900 p.a. As more links go up then ultimately the available spectrum on that tower will become exhausted. In that case the alternative is to resort to the 8 GHz spectrum, with less capacity and a factor of 3-4x increase in license cost; i.e. $thousands p.a. Moreover, at the lower frequency, antenna size (and weight) also increases which places a greater physical burden on infrastructure, and antenna are more expensive (~$7000 per dish). Alternatively there is the 'public park' spectrum (5 GHz, 2.4 GHz, 900 MHz), but providers worry that it is difficult to guarantee clients freedom from congestion as more and more users use it.

Observation: Increasingly, on farm connectivity is being provided by second tier carriers offering local area network solutions. Those who have access to backhaul (e.g. dark fibre) capability and who have purchased relevant licences (e.g. spectrum to support point-to-point) are noting increasing difficulty in establishing the physical infrastructure due to structural limitations of existing towers. This could be alleviated by sharing dishes; e.g. using multi-spectrum dishes. Alternatively, there are some which may have physical access to towers, but lack of freely available spectrum. This could, conceivably be freed up were existing network operators to consider spectrally efficient means of operating links; e.g. spectrum pooling, or allow use of multi-directional antennas that operate on the same frequency. For example, a privately-owned, point-to-point link is rated at mW compared to the multi-Watt powered links utilized by major network operators in their point-to-point links.

Overall, when it comes to accessing spectrum and physical infrastructure for clients, the message received from second tier telecommunications provider was *"first in best dressed as costs may go up!"*

The majority of second-tier network operators consulted in this review agree that would-be clients' lack of knowledge of the basic concepts in telecommunications undermines their willingness (and their confidence) to accept solutions. Costs don't seem to be a barrier. Costs can range from $15-40k for infrastructure plus their first tranche of data, but many innovative producers generally "know their own business" and cite the value of even the simple things such internet access at workers quarters to be a major driver of seeking improved/alternative connectivity solutions. Producers cited already paying "thousands of dollars" in MNO fees per month during peak work periods (e.g. harvesting, planting) to keep their workers connected at their accommodation. Many producers are seeing the cost of connecting devices on their farms as 'realistic'.

Producer Case Studies

Case Study #F1- Livestock - Sundown Pastoral Company P/L

The Business

Business location: Sundown Valley, via Kingstown, NSW.

Key enterprise: Cattle grazing, specifically livestock finishing.

Property Size: aggregate size 17,200 ha (43,000 acres)

Rainfall: 750 mm average (spring dominant)

Date established: Sundown Valley Property purchase by Neil Statham 1964, and 4 adjacent properties (to complete Sundown Pastoral Company and Sundown Valley cattle property aggregate 1974).

Contact: Matthew Monk, General Manager.

Key activities and production capacity indicators:
Sundown Valley runs one of Australia's largest high-performance and pasture programs aimed at utilizing improved pastures to maximizing kilograms of beef per hectare. Its main operation is finishing cattle for Australian Agricultural Company (AACo), carrying 12,000-15,000 head dry cows/heifers/steers at any time, with a throughput of 30,000-35,000 head p.a. Generally aiming for 130 days on grass, finishing to 400-430 kg per head (based on animal specs).

Connectivity

External: Telstra 4G point-to-point data link from nearby 'Kingstown Knob' to Woolshed in located in centre of farm office/shed precinct. Point-to-point 3G connectivity to Butcher's Cattle yards. Radio over internet (RoIP) links admin officer in Parkes (NSW) to all properties for voice comms. Internal: 4G point-to-multipoint links from Woolshed (360º sector), out to Stockman's office, Chemical shed, and Main farm office (via relay link located on garden pump shed). UHF links from main pump shed to 4 header tanks (which service 1/3 of the farm) and level sensors used to auto-control tank refills.

Key technologies requiring or utilizing on-farm connectivity

The business relies heavily upon the Belvoir Animal Management System (http://belvor-it.com). All animal movements are recorded live onto the data management system. This includes induction onto the farm (utilising RFID readers on individual animals passing through the yards), various animal operations such as weighing, drenching-/needling and fecal egg counts (again in conjunction with RFID readers), movement as mobs from paddock to paddock and exit from the farm (via the yards) to the client post-finishing. The data base is remotely managed by a staff member located in Parkes (approximately 500 km away) and voice contact managed through a RoIP system.

Challenges and Opportunities

Belvoir 'trailers' are located at yards for data recording and gate control and to collect recorded data on board. Given all yards (with exception of Butcher's yards) do not have mobile reception. The data is downloaded at end of each data when back in mobile network connectivity (4G in office precinct or 3G at Butcher's yards). Ideally want to have Belvoir trailers working live via mobile network connectivity. "Data latency is important; any delays in viewing data form a day's work can have a serious impact on flow-on management decisions" (M. Monk, 2016).
Monitoring water storages (~180 trough tanks) is still done manually and leaks in pipes consume approximately $100 per hour in staff time. It's a costly and labour intensive operation. Currently Sundown are exploring radio links to tanks, and also remote means of trouble shooting pipes for leaks (e.g. based on section control).



Case Study #F2 – Grains - “Mudabie” via Mudamuckla, SA

(Source: Peter Kuhlmann)

The Business

Business location: “Mudabie” Mudamuckla, East of Ceduna SA

Key enterprise: Cereal cropping with some sheep

Property Size: “Mudabie”: 13,340 ha (arable 10,453 ha)
Leasing 2119 arable ha; all adjoining

Rainfall: 293 mm average (growing season rainfall of 216 mm)

Date established: The original property was share farmed and later purchased by Charles Kuhlmann (Grandfather) in 1911. Frank Kuhlmann (Father) did a large portion of the mallee scrub clearing and development. Peter Kuhlmann has been managing the property since 1981 and has intensified the cropping program.

Contact: Peter Kuhlmann

Key activities and production capacity indicators:
Cropping accounts for about 80% of the arable area with 8307 ha sown in 2016 mostly to wheat (5431 ha) with some barley and oats. The main soil type is a grey calcareous sandy loam with sandy rises (pH 8.6). Phosphoric acid is used as the phosphorus source and the variable soil type lends itself to no till farming and variable rate application of seed and fertiliser. Two permanent staff and casuals are employed for seeding and harvest. There is a large investment in cropping machinery to ensure timeliness of operations and over the large areas in this highly variable environment. The 5 year wheat average yield is 1.3 t/ha. A self-replacing merino flock of 1800 ewes and 400 older ewes mated to White Suffolk rams provide less than 10% of the business income which is much less risky than cropping.

(Peter was 2012 Australian Producer of the Year and is currently serving as a member of the GRDC Southern Panel).

(Source: Peter Kuhlmann)

Connectivity

External: Mobile phone- 3G (0-2 bars), Telstra 4G dongle (office) with Cel Fi reception boosters on sheds, Sky Muster satellite.

Internal: UHF radio (voice).

Key technologies requiring or utilizing on-farm connectivity

Satellite positioning technology (GNSS) is used for all spraying, seeding and harvesting in the form of auto steer technology. Add on benefits include the ability to inter row seed with a 2 cm accuracy, create yield and elevation maps and incorporate auto shut off functions. This data can be manipulated to create prescription maps for seed, phosphorus and nitrogen applications.

Reticulated water is very expensive and 6 leak detectors are connected to water meters. 2 units have electronic rain gauges attached. They send a 3G data message every hour on usage which can be viewed over the internet or via a daily SMS.

UHF radios are used at harvest time but mobile phones are the communication method of choice to speak with technicians, suppliers, contractors, staff and family.

Challenges and Opportunities

Being on the edge of the mobile phone tower range the reception is between 0 to 2 bars over most of the property which is frustrating with no service, missed calls and dropping out. Cel Fi reception boosters (now over $1,000 each) are in the 3 houses and shed to provide fair phone and internet options. A new telephone tower supported by the Federal Government is proposed on a neighboring property which would most likely fill in the black spots for phone reception on the property. The tower is an Optus tower and is useless to almost all local mobile phone owners who have Telstra phones and plans because of their previous better rural coverage. Paddock records are entered on an iPad and uploaded to the cloud when in internet range. The internet is becoming even more important for banking, emails, invoicing, quotes, information, weather and data sharing. A 4G Telstra dongle has been the main source of internet. “At peak times the rate that data can be accessed is at a speed reminiscent of 20 years ago”. To improve the reliability of the internet a Sky Muster satellite system has also been fitted. Both are expensive for data compared to urban plans.

Case Study #F3- Poultry - "Moana"

The Business

Business location: Oxley Highway via Tamworth (42 km)

Key enterprise: Poultry production (with cattle backgrounding on adjacent pivot-irrigated/rainfed pasture)

Property Size: 245 ha (1.1 km Peel River frontage), 8 sheds (23,000 m^2), 56,000 birds per shed (at capacity)

Rainfall: 609 mm average (267 mm November – February)

Date established: Farm bought 2006 as a greenfield site, first 3 of 8 sheds built June 2009 and fully completed in December that year.

Contact: Guy Hebblewhite, Managing Director.

Key activities and production capacity indicators:
Moana is an independent, intensive broiler growing operation comprising 8 tunnel ventilated sheds. Chickens are produced for Baiada (www.baiada.com.au) and are delivered to the farm as day old chicks. The desired processing age is determined by weight specifications, but is normally achieved between 5 to 8 weeks of age at which time the chickens are scheduled for delivery to the processing plant. Chickens are produced to meet a number of weight specifications; 32-34 days old (d.o.) (~ 1.9 kg eg for retail fast food); 42 d.o. (~2.5 kg); 49 d.o. (3.05 kg) and 55 d.o. (3.6 kg- eg for fillets, cubes, mince). At capacity, each shed contains 56,000 birds with a licence for the enterprise (8 sheds) to carry 450,000 birds at any time and the enterprise produces approximately 5.7 batches per year (2.4 million bird p.a.). Broiler production is to very tight time/weight specifications utilising feed provided by Biaida. Feed conversion ratio (fcr = feed intake/average daily weight gain) is another important performance metric and producers are rated relative to a 'pool' of other regional producers. In 2017, Moana achieved a fcr of 1.504, placing them at the top of the regional pool.

Connectivity

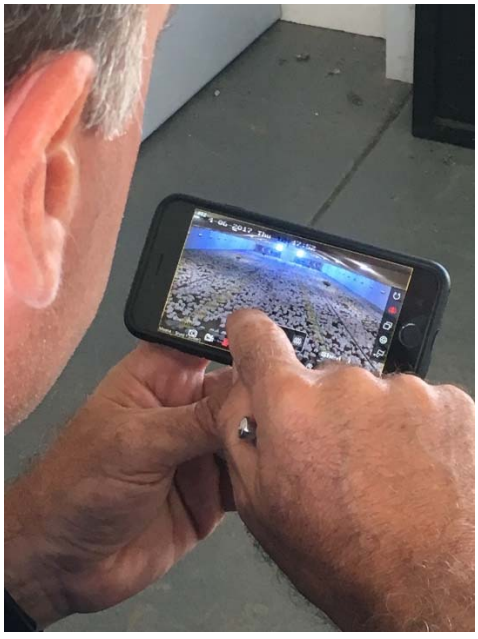
External: NBN Sky Muster (to farm house). Automatic weather station (supporting EPA compliance for environmental monitoring) is linked via cellular modem.
Internal: wifi router for internal connectivity within farmhouse, EDGE router and wireless link to connect to farm office (900 m away), with local wifi links from office out to chicken sheds to support a range of monitoring systems.

Key technologies requiring or utilizing on-farm connectivity

Broilers are produced to tight weight specifications in a production environment that requires close and detailed management of the in-shed physical environment (airflow, temperature and humidity) as well as control of food and water (to meet fcr targets). A significant in-shed sensor array has been established, including environmental monitoring and control, bird weight gain (weight scales where as many as 2,500 birds will voluntarily step onto the weighing platform each day- providing a high qualilty live weight data) and in-shed live vision (eg for monitoring population dynamics such as clumping which can be an early indicator of non-optimal climate control). All of this data monitoring and harware control is enabled through wireless links to the office, with many data sources (eg live vision) accessible remotely via smart phone.

Challenges and Opportunities

The farm is well set up with wireless links and external connectivity is considered reliable, with the exception that the Network Transfer Device (NTD) is prone to failing under electrical surges during thunderstorms (3 replaced in 3 months during 2016/17).The enterprise operates on 100 Gb/month data plan. In addition to routine monitoring of the in-shed production environment and external environs (e.g. for security), the use of vision is a key part of 'peace of mind' for the owner when off site allowing him to check operations and activities. The environmental sensors themselves can be very expensive, especially when customized for niche applications (e.g. monitoring the water 'formulation' for bird consumption). A key input into the enterprise is power ($200 k p.a. in gas and electricity alone) and the owner is keenly exploring other energy options such as bioenergy which would be a neat fit into the overall operation. This would likely require an additional external monitoring and control capability with further extension to the existing on-farm communications infrastructure.



Case Study #F4 – Sugar - "Pozzebon Farm"

(Source: Denis Pozzebon)

The Business

Business location: Mount Kelly, via Ayr, Queensland

Key enterprise: Sugarcane production

Property Size: 130 ha

Rainfall: 742 mm average (January – April dominant)

Date established: Purchased (father) 1957, current ownership since 1990.

Contact: Denis Pozzebon, Owner/Manager

Key activities and production capacity indicators:
Pozzebon Farm produces approximately 15,000 t sugarcane p.a., and is considered a small-medium operation for the region. Considered a leading grower in the industry, the farm runs on a minimum tillage planting system, using a ripper/single row billet planter at 1.55m spacing on formed beds. Irrigation management is facilitated by soil moisture probes monitoring electrical conductivity and temperature. Approximately 30 ha of the farm is fully automated with sensors and remote control of irrigation valves. A block specific nutrient plan incorporates a variable rate nutrient application system to optimize applied nutrients to plant growth demands and soil type; liquid fertilizer at planting and at ratoon the subsurface incorporation of a granular mix, usually with other liquid additives.

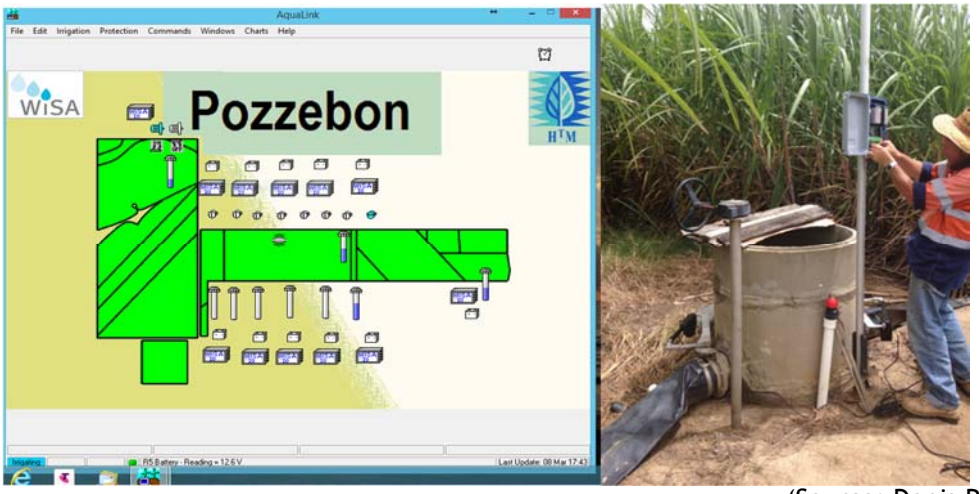
Connectivity

External: Mobile Network (partial), NBN Fixed Wireless
Internal: WISA Telemetry (AWS, soil moisture)

Key technologies requiring or utilizing on-farm connectivity

All machinery operates under RTK GNSS guidance (2-5 cm) utilizing initially a Trimble base station, but now with a privately owned base station (shared with 5 neighbours). The move to a private base station was necessary as partial shadowing of the Trimble base station (on a nearby hill) precluded reliable guidance in some areas of the farm.

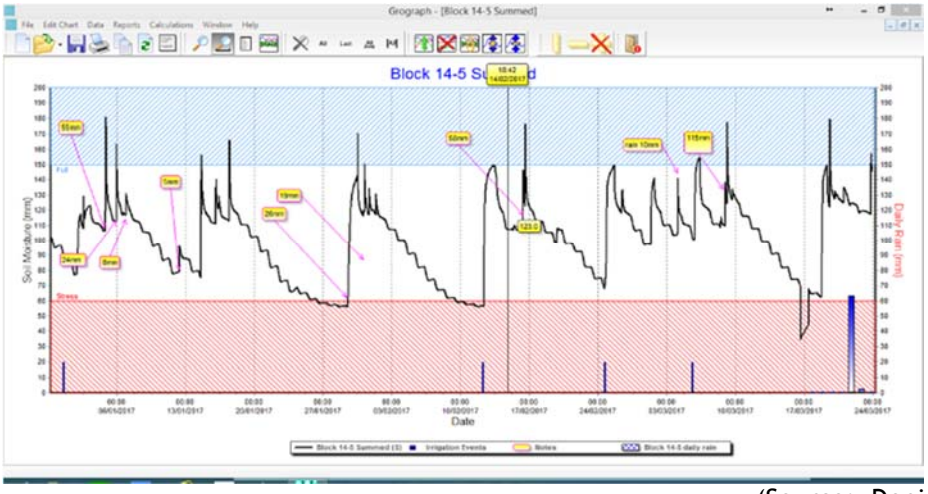
Approximately 30 ha of the farm is set up 'fully automated', utilsing a WiSA telemetry system (http://www.irrigatewisa.com.au/technology) which includes soil moisture probes and a weather station, the ability to remotely control a small number of valves and starting/stopping pumps.



(Source: Denis Pozzebon)

Challenges and Opportunities

Pozzebon Farm is keen to expand the existing automated footprint. As a lone farm operator (like ~60% of the farms in the Burdekin region), the automation provides significant labour and energy savings with significant environmental benefits through reduced runoff. The main irrigation period is November – February/March which can be a difficult time given school holidays and other competing demands on the owner's time (e.g. hosting field days). However, radio is considered very expensive for the size of the operation (~$2-4,000 per radio device) given up to 40 valves would need to be controlled over the whole farm. The owner is currently working on developing automated gate valves for his furrow system using water probes placed strategically in the paddock furrow which will feed back to shut off the pumps. Again more radio infrastructure is required. Ideally he seeks low-cost radio utilizing the 900 MHz spectrum. He considers radio is presently too expensive to support multiple links. Pozzebon Farms has good mobile coverage, which currently supports mobile phone use (voice) and Denis is exploring the mobile network enabled telemetry systems as an alternative to radio. The farm office is connected via NBN Fixed wireless. As an early subscriber to the nearby fixed wireless tower, Pozzebon Farms enjoyed 'good internet speeds', but owing to congestion of the tower as the subscriptions were progressively filled, NBN doesn't perform as fast as "it should be".



(Source: Denis Pozzebon)

Case Study #F5- Mixed farming - “Warialda” RB and TJ Wooldridge

The Business

Business location: “Warialda” Arthur River, WA; Church Lane Albany WA

Key enterprise: Mixed farming (sheep and cereal crops).

Property Size:
“Warialda”: 790 ha (arable 510 ha)
“Churchlane”: 200 ha (+ 45 ha additional lease),

Rainfall: “Warialda”: 430 mm average (winter dominant)
“Churchlane”: 850 mm average (10 month growing season)

Date established:
The original property “Warialda” was purchased as a bush block in 1958 by Brian Wooldridge (father). Current owners (Brad and Tracey Wooldridge) assumed ownership in 1995. They recently purchased a second farm (Church Lane farm, Albany).

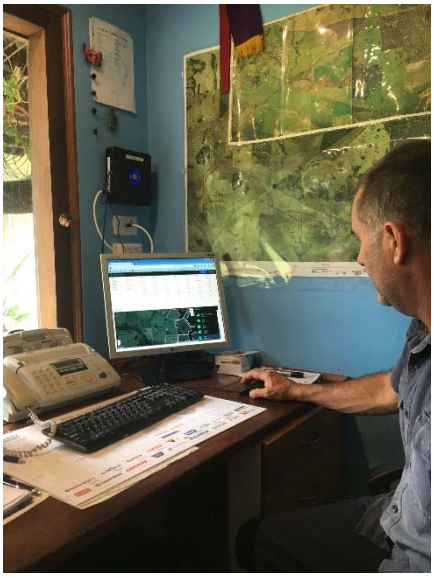
Contact: Brad and Tracy Wooldridge, Owners

Key activities and production capacity indicators:
“Warialda”: Farm divided 50:50 between sheep and crop production. Carrying capacity 1200 ewes, 1100 lambs p.a. (2016), indicative crop production (2016) 70 t barley, 350 t oat, 200 t canola, indicative pasture production 6 – 12 t/ha p.a. with 28 kg/ha/mm rainfall (winter growing).
“Churchlane”: all sheep (1100 ewes producing 1600 lambs (2016)), indicative pasture production 10 – 16 t/ha p.a., with potential to 24 t/ha p.a.

Connectivity

External: Mobile network, NBN Sky Muster
Internal: Nil

Key technologies requiring or utilizing on-farm connectivity



Churchlane is located 220 km from Warialda farm, hence reliant upon remote access monitoring tools. Operation is heavily reliant upon external internet connectivity (Sky Muster) at main house (Warialda) for daily internet usage (3 hours per day).

The farm is aiming for a water use efficiency of 28 kg dm/ha/mm of rainfall during growing season. This can only be achieved by deferment and rotational grazing with 50% crop. This requires accurate pasture growth rate measuring tools and Pastures from Space (PfS; https://pfs.landgate.wa.gov.au/) is a satellite image-based tool used to monitor the feed base on both farms. Considered innovative in many aspects of mixed farming practice, the farm hosts numerous technology, sheep and crop trials, collaborating with an extensive network of producers, researchers and ag business around Australia (the owner is also currently appointed as co-chair of the Rabobank WA Client Council). A number of these demonstration sites are equipped with soil moisture probes but all data is collected and stored in-situ. There is currently no device telemetry capability on the farm.

The owners recently purchased a second farm (Church Lane farm, Albany), and the choice of farm was largely informed through the use of PfS to identify long term seasonal growth trends in order to fill seasonal feed gap on their Arthur River property.

Challenges and Opportunities

Given the reliance on internet for all forms of farm business, and for regularly remotely monitoring the feed base on both farms, the speeds experienced through Sky Muster is variable and the owner has regularly explored numerous data management options with his ISP. In some instances the speeds of 'shaped data' plans has exceeded the 'unlimited plans'. The owner is keen to explore options of remote vision systems, in particular for visual monitoring of farm assets and fields. In 2015 it was "impossible to get clear Landsat (PfS) imagery of Churchlane farm for 5 months" and a terrestrial monitoring system would have filled the gap. The business is keen to deploy automatic weather stations and remotely connected soil moisture sensors across both farms but the owners are currently "unsure where to start". Mobile coverage is 'patchy' on Churchlane and so the owners are keen to explore options around radio connectivity, at least to a location on the farm where the mobile network is accessible. There is no on-farm telemetry based systems on either farm and the owners cite a lack of information on where to go and who to talk to get advice on radio telemetry and other options (e.g. mobile network connected AWS) as a key reason. Another keenly sought innovation is for a remote livestock monitoring system as livestock theft is a significant cause of loos in the district (for example 400 ewes stolen from leased land in 2012, with up to 700 ewes per farm reported in the district).

Case Study #F6 – Cotton - "Keytah"

The Business

Business location: 32 km West Moree NSW

Key enterprise: Cotton, Grains, pulses

Property Size: 25,042 Ha (incl. ~ 10,000 Ha irrigated, ~10,000 Ha dryland)

Rainfall: 584 mm average (269 mm November – February)

Date established: In 1984 Sundown Pastoral Co purchased Keytah, latter purchasing adjoining Cudgildool, and then in 1986 added Wathagar and Boorondarra stations.

Contact: David Statham, Owner

Key activities and production capacity indicators:
Keytah Station has a capacity to grow up to 150,000 bales of cotton or 140,000 Mt of grain per annum. In the 2016/17 season Keytah planted 4865 ha irrigated and 1443 ha dryland cotton, 2154 ha long fallow and 2952 ha short fallow wheat, 3033 ha chickpeas, 1187 ha faba beans, 2103 ha oats and 923 ha lab lab beans. Cotton yields range from 11-12 bales/ha (dryland cotton) through to 1-2 bales/ha dryland. Cotton is processed from field to bale, all on one site. Keytah's joint venture ownership with Wathagar Gin provides significant cost savings and efficiencies within the operation. The on-farm grain storage facility is capable of handling more than 50,000 t of grain/pulses per annum. Keytah is one of Australia's largest water license holders irrigating from the nearby Gwydir and Mehi Rivers.

Connectivity

External: Mobile network for office (4G tower in Moree located ~32 km away) and machine telematics (3G tower located ~ 9 km away)

Internal: UHF Radio (soil moisture probes, automatic weather stations, water level sensors etc), 3G (tower located ~ 9 km away; pickers, headers and tractors operating on JDLink™ and MyJohnDeere)

Key technologies requiring or utilizing on-farm connectivity

Considered one of Australia's leading innovators in precision agriculture for dryland and irrigated agriculture, Keytah is heavily reliant upon both static and mobile sensors for its operations including;
-50 soil moisture probes;
-11 pump sites where monitoring includes pump RPM, bearing temperature, prime/not prime status and fuel, and environmental data such as rain gauge, water level at pump intake and water storage level;
-2 automatic weather stations; and
-4 MACE meter monitors for monitoring river heights;
- 23 machines equipped with onboard telematics (John Deere) including 5 cotton pickers, 3 headers and 15 tractors.

Static sensors are linked via radio to a single, 3G gateway (farm office). The pump site diagnostics includes an essential alert capability which rings a sequence of mobile phone numbers (not SMS which is considered 'risky'). Machine telematics are connected via 3G network

Challenges and Opportunities

External connectivity is a primary challenge for this highly-innovative operation. Although Keytah is within visible line of sight to a mobile 3G tower (~ 9 km away), slow data speeds have necessitated installing a booster to access the 4G tower in Moree (~32 km away) for their offices. Machine telematics requires a 3G sim card per machine (~$4-500 p.a.) which equates to a significant annual data/machine service charge. Internet connectivity both across the farm landscape, to support the full capability of machine telematics and to facilitate staff access to live datasets, and within offices and the numerous living complexes is a significant challenge. From a purely lifestyle perspective Keytah management cite internet access for staff as a key decision point for them and their families deciding whether to live onsite or in Moree located 32 km away. Keytah are currently exploring farm wide network solutions with a number of service providers, including private network options to avoid what they consider are significant institutional impediments to them accessing the mobile network.

Farm and tower location rendered from Oztowers (Source: www.oztowers.com.au) and Google Earth. (N = NBNCo, T = Telstra, O = Optus, V = VHA). Distance marker = 8.3 km

Case Study #F7 – Horticulture (Avocados) - "Simpson Farms"

The Business

Business location: ~30 km south Bundaberg, Qld

Key enterprise: Avocados

Property Size: 3 properties- Goodwood, Goodwood West and Promisedland; 900 Ha orchards, employing 40 full-time staff and ~ 220 casual (during peak season)

Rainfall: 1024 mm (662 mm Nov – Mar)

Date established: 1969 when Ron and Fay Simpson started up a tomato and sugarcane operation near Bundaberg. Goodwood plantation established late 1980s (120 Ha); now Australia's largest producing avocado orchard.

Contact: Chad Simpson

Key activities and production capacity indicators:
Simpson Farms is Australia's largest producing avocado orchard, producing Hass, Shepard, Wurtz and Reed Avocados, as well as Calypso and Honey Gold Mangoes. The company also has an accredited packing facility on the original Goodwood plantation (4500 m^2). This packing facility is considered as one of Australia's leading avocado packing facility that includes computerized grading equipment, in-line sticker application, a sealed loading dock, and 566 m^2 of cold room space. The Goodwood shed also operates two flow wrap machines to prepare pre-pack avocados for the retail market. As a recognized industry leader, Simpson Farms is and has been involved in numerous R&D projects of national significance. These include; the long-term evaluation of rootstocks, fruit robustness evaluation for export market development, pruning and orchard management programs, the use of remote sensing tools for disease control, orchard health management, varietal evaluation, as well as fruit quality and yield forecasting. The company continually focuses is on improving efficiencies and effectiveness of operations with the evaluation of new technologies, systems and processes to ensure improvements in productivity and profitability.

(Source: Andrew Robson)

Connectivity

External: Mobile network and/or NBN fixed wireless for offices.

Internal: Mobile network for EnviroSCAN soil moisture system.

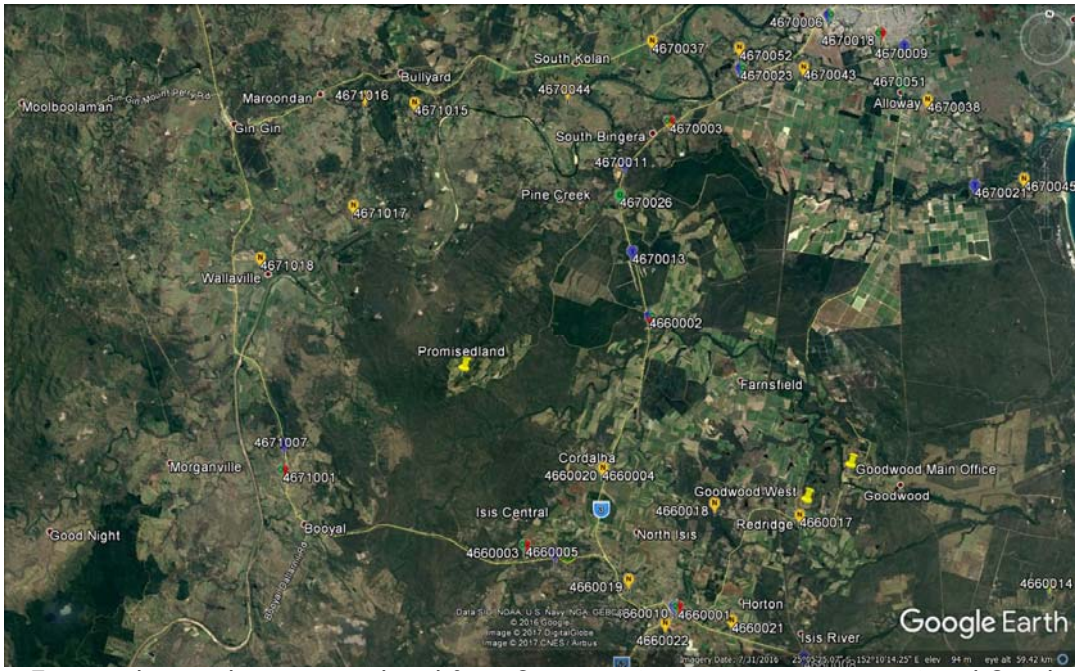
Key technologies requiring or utilizing on-farm connectivity

Simpson Farms are investigating large scale precision agriculture management, initially utilizing remote sensing (e.g. satellite imaging) products for identifying spatial variability in tree canopy vigour and relating this to potential yield quality, as well as tree health. Simpson Farms also operate an EnviroSCAN soil moisture probe system (www.sentek.com.au) and have also used dendrometers (devices for monitoring trunk development; www.phytech.com). Simpson farms have their main server database at their Goodwood office, although require access from the other offices located at Goodwood West (~ 4 km away) and Promisedland (25 km away).

Challenges and Opportunities

Initially, most of the large scale precision agriculture technologies that Simpson Farms are investigating utilize remote sensing (e.g. satellite imaging) products. Downloading remotely sensed imagery requires good internet connectivity (bandwidth) at the offices. Promisedland is literally surrounded by 14 mobile and NBN towers (along A1 Bruce Highway and Hwy 3, Bundaberg-Childers Road), the closet tower located ~ 10 km away. Goodwood Main office utilizes a dynamic mix of ADSL2 and NBN fixed wireless, and Goodwood West also uses NBN fixed wireless. Promisedland runs 3G and also has 2 directional yagi antennas as well as a cellfi booster but still continually struggle with connectivity.

Data speed at the offices and in the orchards remain poor. The EnviroSCAN soil moisture probe system (www.sentek.com.au) relies on cellular connection to relay information from the orchards back to the office. This is considered 'fairly reliable' as they are able to base probe communication 'towers' in those known cellular reception areas and the run cable to the probes. The dendrometers failed mainly due to poor in-situ cellular coverage. The remoteness of their offices and the ability to be able to connect back to the main server data base in the main office (and associated cloud-based management tools) remains a recurring challenge as this relies on good quality data (internet) coverage.



Farm and tower location rendered from Oztowers (www.oztowers.com.au) and Google Earth. (N = NBNCo, T = Telstra, O = Optus, V = VHA)

Case Study #F8 – Bligh Lee Farms

(Source: Darrin Lee)

The Business

Business location: 15 km northeast Mingenew, WA

Key enterprise: Wheat, barley, canola, lupins, oats and sheep

Property Size: 6,500 ha

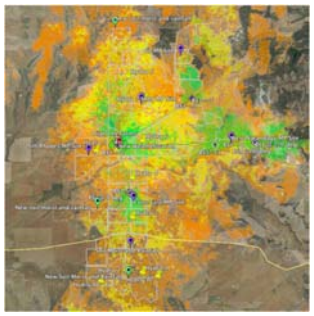
Rainfall: 297 mm, (160 mm May – Aug)

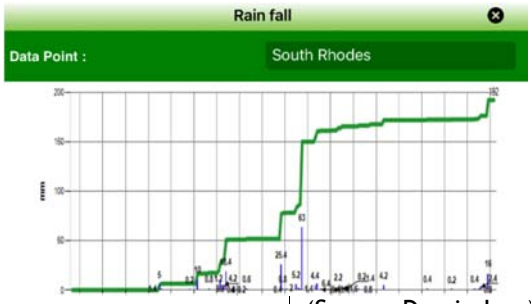
Date established: Darrin has been farming since 1998 (previously working in banking and finance). Works in family partnership with partner Steph Bligh-Lee and her brother Peter Bligh and his wife Lorraine.

Contact: Darrin Lee

Key activities and production capacity indicators:
The farm produces wheat, barley, canola, lupins, oats and runs approximately 3500 sheep (self-replacing Merinos and prime lambs). The 2016 cropping program was 2850 ha wheat, 350 ha barley, 410 ha albus lupins, 200 ha narrowleaf lupins, 345 ha oats and 245 ha canola. With a full moisture profile, capable of delivering 3 t/ha for wheat, compared to previous 5 year average of 1.87t/ha.

(Darrin is currently a GRDC Western panel member)





(Souce: Darrin Lee)

Connectivity

External: ADSL+2
Internal: WIFI (farm wide); 3 ~ 20 m tall WIFI towers sited via mobile radio strength testing from a 16 m broadcasting mast. Origo remote with CAN BUS compatibility on all vehicles (including machines), and sensor stations (e.g. weather stations)

Key technologies requiring or utilizing on-farm connectivity

Weather is critical to farm productivity and management. In 2013, a network of soil moisture probes (800 mm depth) and weather stations (including 9 rain gauges) were installed to monitor rainfall, available soil moisture, temperature and relative humidity throughout the seasons. Data generated from the device network can be accessed via mobile phone. Plant development, pests and weeds are tracked with other computer-based tools that use artificial intelligence combined with climate information to extrapolate development rates and projected available water. A web-based, app-accessible decision support software (Crop Manager) uses artificial intelligence to merge new data with historical data and can also link to regional data sets to enable informed crop planning, including variety, sowing time and fertiliser application. On board sensors on tractors and machinery remotely monitor fuel consumption and advise on predictive machinery maintenance, linking with service contractors for remote monitoring. An Origo Digital Agriculture Farm Server hosts the wifi network, Origo nodes (CANBUS connected) that provide connectivity (and interoperability) to all remote devices (and remote cameras) and sensors and data management (dashboard) capability. The Origo-designed dashboard allows remote access (via smarty phone) to collect real-time data from each machine (two headers, two airseeders, two sprayers, the road train, chaser bin), including running data (such as fuel level, service schedule, operator details) and agronomic information (spray rates, droplet size, crop yield, etc.); and monitor farm assets such as the 110t field bin for harvest management and stock water points for remote operation (turning pumps on/off).

Challenges and Opportunities

Connectivity is fundamental to his farming future. Data packages must be compatible with needs. 5 GB of satellite per month ($250)-sometimes the usage plan is exceeded. In 5-10 years, digital agriculture will be known as ‘farming’; in other words what is touted as the future is going to be today before we know it. Future proofing carrying capacity, ubiquitous connectivity coverage (without every farming having to personally invest what he has) and reliable data management are all key challenges.

Service provider case studies

Case Study #SP1- Agronomic services- Farmacist

The Business

Business location: Mackay and Home Hill Qld; www.farmacist.com.au

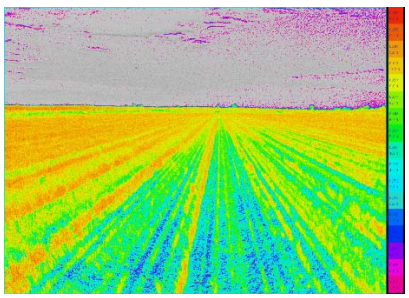
Key enterprise: Farmacist is an agronomic solutions provider based in Mackay and the Burdekin, North Queensland.

Date established: Providing agronomic and farm management services since 2011

Contact: John Markley (Managing Director**),** Rob Sluggett, Tony Crowley (Directors).

Size of Business: 20 employees; 7 full time, 6 part time (Mackay); 5 full time, 2 part time (Home Hill)

Key activities/Geographical footprint:
Farmacist provides agronomic services, geo-spatial data collection and research, development and extension in the sugarcane industry. In addition to providing commercial agronomic services, Farmacist is heavily engaged in conducting and/or facilitating funded research and development activities with over 320 clients involved in collaborative research projects. Services include analysis of soil, water and plant tissue, farm planning, irrigation scheduling tools and advice, soil mapping. Consultancy is provided on numerous crops including sugarcane, rice, legumes, horticulture and pasture with technical services provided around fertiliser box and spray rig calibrations, spatial data collection, satellite image-based yield mapping and in the design and conducting of on farm trials. Recent technology trials include testing the Japanese owned QZSS satellite navigation system as part of a multinational research team.



(Source: Farmacist)

Key technologies requiring or utilizing on-farm connectivity

Farmacist staff generate large quantities of field trial data, as well as data generated from their day-to-day precision agriculture service (soil surveys, crop monitoring, water quality monitoring). Staff are heavility reliant upon mobile network access when visiting client sites or uploading/downloading data. Significant use is being made of remotely sensed imagery, primarily satellite imagery, although the team are exploring the deployment of drones for tactical field scouting. In addition to maintaining the SQL platform and data server in their Mackay office, the bulk of the data is stored in the cloud. Transfering data to and from office servers, or accessing it when in the field, relies heavily upon the mobile network and, in the case of the office sites, use of landline (ADSL2) in the Burdekin and NBN fixed wireless in Mackay.

Challenges and Opportunities

The two offices are located 320 km apart. Operations are reliant upon, and hence sensitive to, internet access at the offices. With live data feeds from many sites coming into the office server/cloud, loss of internet connection, or a reduction in data speeds at the Mackay site substantially impacts, and sometimes renders inoperable, office operations. Farmacist staff report significant congestion on the nearby NBN fixed wireless tower with regular loss of connectivty. Ironically the move of the main office from Burdekin to Mackay was predicated on the availability of NBN fixed wireless to the site.

Farmacist staff experience adequate mobile network access when on client farms, and this is consistent with results of the phone survey.

Farmacist are working with Taggle (www.taggle.com.au) on a LPWAN network solution for the GDot soil moisture probes. Other tecnhology innovations include 'end of row sensors' which allow irrigators to switch off water as the water front approaches the end of the row. This will also require a LPWAN solution and once linked to a server will trigger alarm notifications for growers.

The use of centimetre-positioning GNSS for machine guidance is heavily reliant upon on-ground RTK-GPS base stations, or network basestations/network CORS. Radio congestion or line of sight is being observed in ground linked base stations, and use of network CORS is reliant upon mobile network connectivity. Farmacist have been coordinating a trial of a new satellite-only delivered ~cm positioning capability (QZSS) with the Cooperative Research Centre for Spatial Information (www.crcsi.com.au) and partners.

(Source: Farmacist)

Case Study #SP2- Supply chain and logstics management - AgTrix

The Business

Business location: Billinudgel NSW; www.agtrix.com

Key enterprise: Agtrix specializes in providing systems and services covering the entire agricultural supply chain from quantifying the crop through to optimizing the transport of the crop to the processor. Their suite includes systems to assist industries map their crop to forecast production and plan their operations, record grower inputs, manage and monitor the harvest progress, consign product to the field it was produced, and to visualize and manage the inbound transport. Many of their systems rely on real time communications such as harvester and vehicle tracking for traffic scheduling tools, supply of mill and delivery information relevant to harvest management, hazard recording and paddock identification and automated consignment verification. Agtrix also specializes in GIS and web platform systems with a mobile app that enables 'internet' access to farm data, vehicle locations, consignment events and tags/sensors.

Date established: Founded 1995

Contact: Robert Crossley (Founder and Director**)**

Size of Business: 10 staff

Key activities/Geographical footprint:
Agtrix provides spatially-enabled systems and services that optimise harvest management and supply chain efficiency to a significant proportion of the Australian sugar and rice industries, and agriculture and renewable energy industries in Africa, Europe and South East Asia.
The systems provided include:

1. Agtrix- FarmMap: Spatially-enabled mapping tools that allows industries to map and record crop location and attributes to better understand how much and where their crop is. This can be integrated with satellite interpretation or crop modeling analysis to improve forecasts or crop management with the aim to optimise supply chain, production and process planning.
2. Agtrix- CHOMP: Monitoring harvest progress through harvester tracking or deliveries to visualise where the remaining crop is located. This facilitates monitoring performance against predicted progress and estimated versus actual yield, with the aim to fine tune infrastructure, processing and marketing requirements.
3. Agtrix- Consignment: In-field consignment of deliveries to its source to provide visualisation of amount, location and character of incoming product, with the aim to provide traceability, capacity and transport planning and receivals optimisation. Real-time feedback to harvesters provides the opportunity to improve practices affecting product quality and efficiency.
4. Agtrix – FREDD: Real time monitoring and management of the inbound supply chain to optimise the supply and quality of agricultural product into the processing facility, with the aim of reducing and automating supply chain management decisions, increasing fleet utilisation, and reducing in-field and factory queues.
5. Agtrix- VisOps: Visualisation of the entire supply chain covering vehicle activity, factory performance, trip cycle analysis and harvesting performance, with the aim to benchmark against KPI and best practice, identify bottlenecks and areas to improve, and monitor outcomes of changes and trial strategies to form the basis of continuous improvement processes.

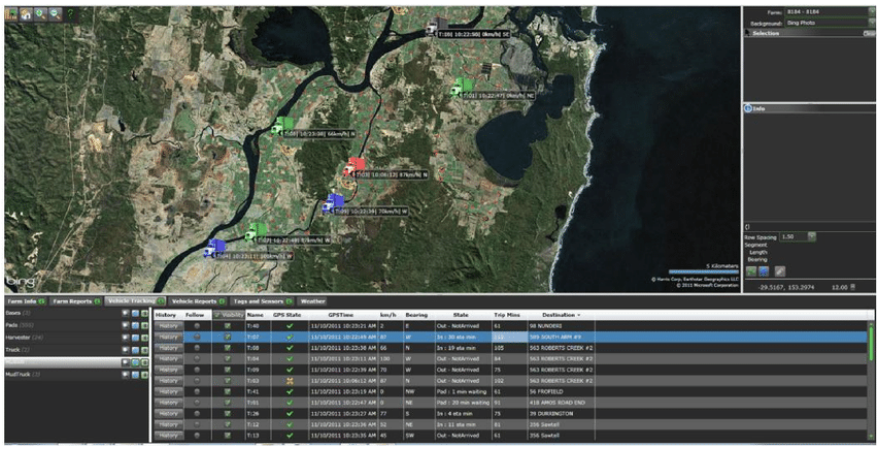
(Source: Rob Crossley Agtrix)

Key technologies requiring or utilizing on-farm connectivity

FREDD and Consignment work best when combined with real time exchange of information between the harvesting, transport and processing scctors of the supply chain. This communication currently relies on mobile networks, and utilises store-and-forward technology, meaning that when vehicles are outside of mobile range, the data is stored on board and transmitted once mobile connectivity has been established.

Truck and harvester GPS locations from Agtrix and various other tracking systems integrate with FREDD to provide estimated time of arrival information of those trucks back to the mill. Visualisation of this GPS information is through a map interface that allows receivals staff to see the truck fleet's location and activities in real time. FREDD monitors each trip, the status of the trip and ETA back to the processing factory to automate vehicle scheduling.

All Agtrix systems are interconnected to allow sharing of information across the various sectors. This communication takes place in real time between mobile phones, tablets, vehicle trackers and other internet connected IoT devices, which all currently rely on the mobile networks as a basis for data exchange.



(Source: Rob Crossley and extracted from Dines (2013))

Challenges and Opportunities

Agtrix utilises small data packets, and for the relatively mobile trucks on road systems to the mill mobile data connectivity (small packets) is not generally a significant issue. However harvesters frequently operate in remote areas with little or no mobile connectivity, delaying the delivery of important data, sometimes till the end of a harvesting day or operation. The supply chain is significantly impacted if real time availability of harvested product using Agtrix Consignment is not available. This can impact the scheduling of collections and visualisation of options for supply to the mill. Also for the scheduling system FREDD to optimise the supply chain, real time vehicle locations are required. Agtrix had initially utilised radio links to machines and trucks although this was abandoned in favour of the mobile network owing to difficulties in scheduling a considerable number of packet transmit/receives. Ultimately the mobile network was much easier to use.

Case Study #SP3- Network and sensor services- Taggle

The Business

Business location: Sydney NSW; www.taggle.com.au

Key enterprise: Taggle is a developer of Low Power Wide Area (LPWA) radio technology, focusing on low-cost, low-power, long range communications for many types of sensors and devices.

Date established: Founded 2007

Contact: Gordon Foyster (Co-founder and Chief Technology Officer Managing Director**), John Quinn (Managing Director)**.

Size of Business: 30 staff, 30 major clients

Key activities/Geographical footprint:
As a developer of Low Power Wide Area (LPWA) radio technology Taggle seeks to offer communications solutions compatible with existing and newly developed sensors. Taggle is a a market leader in automatic meter reading (AMR) and the first to deliver Low Power Wide Area Networks (LPWAN) to the water industry.

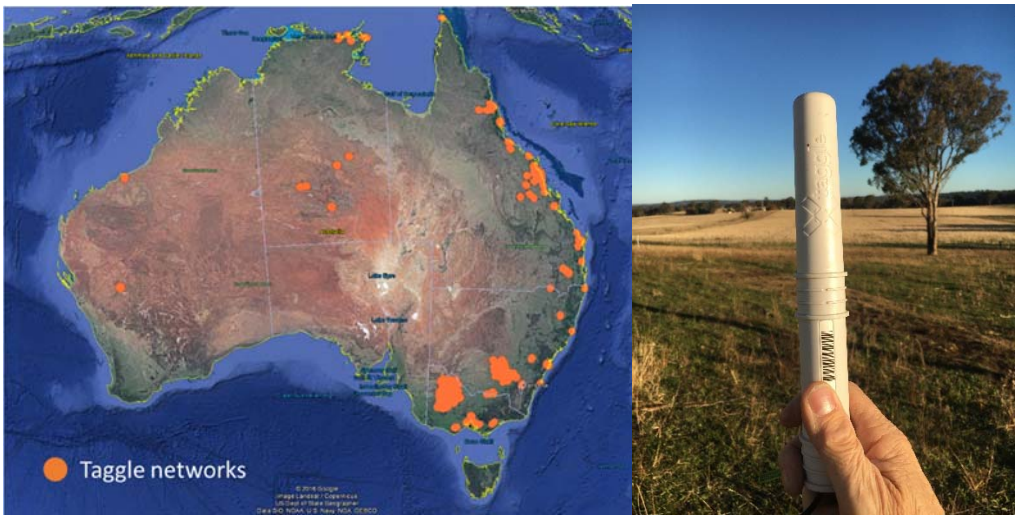
Taggle use radio technology to deploy Australia's only dedicated Machine to Machine (M2M) network enabling cost-effective data collection from thousands of devices across very wide urban and regional areas. Initially focused on utility-scale AMR, the Taggle network is used by a growing number of utilities to gather data for additional purposes such as leak detection, demand management, network optimisation and billing. Data can also be collected from other sources including electricity and gas meters, rain gauges, pressure sensors, liquid overflow, temperature and humidity sensors.

Taggle are in an intensive growth phase, building networks across Australia. As of March 2017 Taggle conservatively estimate their networks cover approximately 250,000 sq km. As new technology and standards for LPWAN emerge they are incorporated into existing and new networks.

(Source: Taggle)

Key technologies requiring or utilizing on-farm connectivity

Utilising the 915 MHz spectrum, Taggle radio networks consist of one or more highly sensitive radio receivers located strategically in an area and very low-cost battery powered transmitters fitted to end user devices such as water, gas or electricity meters, environmental sensors and security devices. Trials are underway to use the technology for a range of additional solutions including farm security and stock theft reduction, improved farm water use including soil moisture sensors and trough monitoring, environmental monitoring (rainfall, temperature and humidity), and wildlife monitoring. Some of the transmitters are capable of ranges up to 50 km (rural areas). Taggle owns, operates and maintains the wireless networks. Customers do not need to invest in or maintain the sophisticated radio equipment as Taggle manages the network, similar to a mobile phone network where the network operators provide the network and users purchase mobile phones to operate across the network.



(Source: Taggle and UNE SMART Farm)

Taggle utilize a range of transmitters to suit different solutions; for example those fitted to water meters transmit readings every hour which are picked up by one or more receivers and passed through to the end user via Taggle's data processing centre. The data can be ingested within a client's in-house system; for example clients receive hourly readings delivered daily in a variety of formats that is then used within their own systems. For those without appropriate software, Taggle offer a simple web-portal. The web interface shows both daily and hourly consumption data in a graphic format and provides the ability to download data for use in Excel or similar software.

Challenges and Opportunities

The use of low power transmitters (915 MHz) and sensitive receivers allows the large geographic scale deployment of sensors around hubs. For example Taggle worked with Goldenfields Water County Council (GWCC) (repsonsible for a region between Lachalan and Murrumbidgee Rivers in SW NSW) to install its Low Power Wide Area (LPWA) wireless sensor network to monitor water usage in the region. The wireless sensor network comprising 11,000 AMR transmitters and 35 receivers/gateways connected to the mobile network covers an area of approximately 22,500 square kilometres. Ultimately the scale of deployment is reliant upon locating the receivers such that they can be reached by transmitters (up to ~ 50 km transmit range) and yet be connected to the 'outside world', namely via the mobile network or, landline or NBN. Client access to data is likewise determined by their own local connectivity, for example to the Taggle-provided web interface.

Case Study #SP4- End to end telecommunications solutions – Field Solutions Group

The Business

Business location: 38/23 Narabang Way, Belrose NSW, www.fieldsolutions-group.com

Key enterprise: Field Solutions Group has 5 aspects to its business; development of business software systems, managed applications services such as online office suites and email services, assist businesses transition to the cloud, assist businesses with managing business and IT priorities by optimising their investments tecnhology architecture, and is also a licensed telecommunication carrier.

Date established: 2012

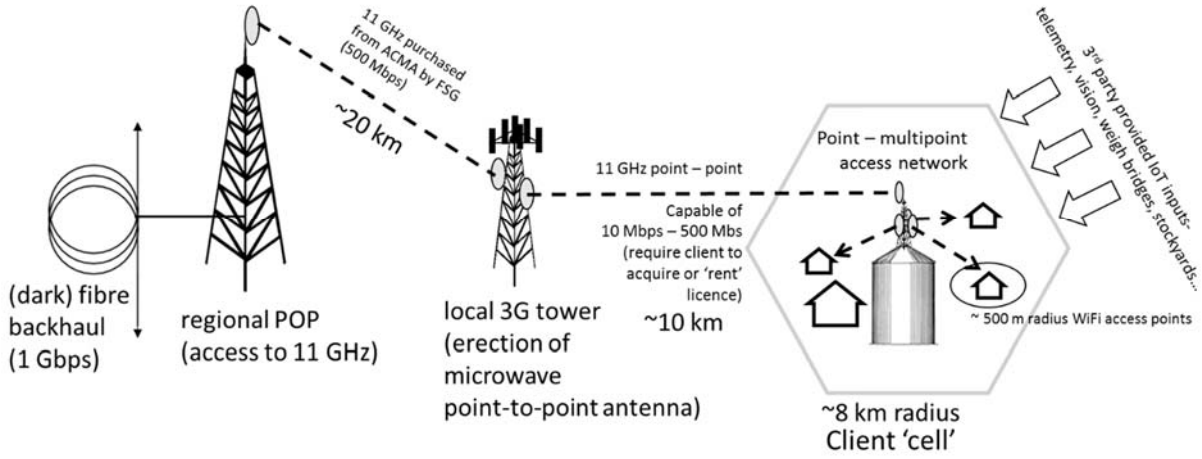
Contact: Andrew Roberts, CEO

Size of Business: 32 staff spanning software development, cloud hosting, IT and data transition management and telecommunications rollouts.

Key activities/Geographical footprint:
As a licensed Australian communications carrier, Field Solutions Group (FSG) partners with other Telcommunications Carriers to offer a private network that runs from Tasmania to Far North Queensland, and across to Perth. This is achieved by designing and delivering access solutions utilising connectivitiy options inlcuding lit and dark fibre, microwave (through lease or purchase of bandwidth at nearby telco point of presence (POP) sites), establishing ethernet links and WiFi cells, or via NBN (fibre and wireless) and satellite. Field Solutions have a focus on regional Australia, where they currently provide wholesale and retail products. Field Solutions can build software, establish private and public cloud hosting, design and deploy private networks and migrate existing products and software to the cloud; fully manage, monitor and optimise a client's cloud infrastructure and build disaster recovery scenarios. FSG is presently developing relationships with third party IoT solution providers to extend their telecommunications reach into the paddock. Examples of current rollout activities include northern and southern NSW, north Queensland and Tasmania.

Telecommunications solution on offer

As a licensed telecommunications carrier, and with staff experience covering WANs, backhaul telecommunications (including fibre rollout) and core infrastructure development and management, FSG is an exmaple of a business capable of offering full end-to-end solutions for producers. An example of a recent telecommunications solution developed for a large producer client (western NSW) is depicted below:



All aspects of the connectivity are included, including reserving of a portion of the 11 GHz beam (POP – local 3G tower), installation of the antenna on the 3G tower, establishing the point-to-point 11 GHz link to the client cell and establishing the point-to-multipoint connections to outlying buildings and regions within the farm. Point to multipoint access network is then designed for optimal speeds at each location; for example speeds are facilitated by time division multipoint access (TDMA) and if 360º coverage is required then the cell is divided into, say, 4 sectors- with, for example 100 Mbps capacity per sector (hence 400 Mbps capacity in full cell radius). The networks are built for low latency, hence supporting voice (e.g. VOIP) and video as well.

Challenges and Opportunities with clients

The majority of clients have little or no telecommunications background and so the team needs to have great 'retail engineering' skills. Surprisingly, cost is not a perceived barrier, even though solutions can range from $15-40k plus data, Usually innovative producers who are seeking solutions know their own business and the value of the connectivity to their business- both from enhancing the on-farm living experience of their workers, through to the value of accessing remote connectible devices.

Access to baseline telecommunications infrastructure can be as challenge. For example a nearby telecommunications tower may not have the mechanical scalability to support the additional installation of antennae and a new or strengthened tower may incur a ~$125,000 investment. The 11 GHz spectrum is affordable (< $1,000 p.a.) and supports lots of data throughput. However if this spectrum becomes fully utilized, for example with an increasing number of other parties also seeking to establish private links), then the lower frequency alternatives, for example 8 GHz have less capacity and significantly higher licence costs (~3-4 x). Antenna size also gets bigger, heavier (hence more tax on the infrastructure) and more expensive (e.g. ~$7,000). Solutions providers are not keen to rely upon the lower frequencies, such as the ISM Public Park bands because it is difficult to guarantee clients from interference and congestion.

The cost of accessing MNO infrastructure can be prohibitive; for example just feasibility studies required for tower access can cost tens of thousands of dollars, plus an application fee costs $4-5,000, plus infrastructure rental for that access can cost ~ $900-1100 per month. All of this must be translated onto the client.

Case Study #SP5- Farm telecommunications solutions – WI-SKY

The Business

Business location: 809 Gobarralong Rd, Coolac NSW 2727; www.wi-sky.com.au

Key enterprise: WI-SKY is a broadband provider building our own local networks and delivering fast internet to farmers and people in country areas who are unable to access other options.

Date established: 25 March 2015

Contact: Jock Graham

Size of Business: 4 staff.

Key activities/Geographical footprint:
WI-SKY is a carrier service provider (CSP) with a nominated carrier declaration (NCD) with Field Solutions Group (FSG) that builds and operates their own wireless internet service. Under the NCD, WI-SKY provides high speed broadband to rural users. The overall goal of the WI-SKY is to connect regional and remote properties to the nearest high speed access point available. WI-SKY operate 20 internet access towers across the Gundagai, Cootamundra and Tumut (NSW) shires and are continuing to extend this footprint and grow. In Qld Wi-SKY operate in the Richmond, North West Queensland shire and we will be rolling out connectivity solutions to Hughenden and Julia Creek (Qld).

(Source: Jock Graham WI-SKY)

Telecommunications solution on offer

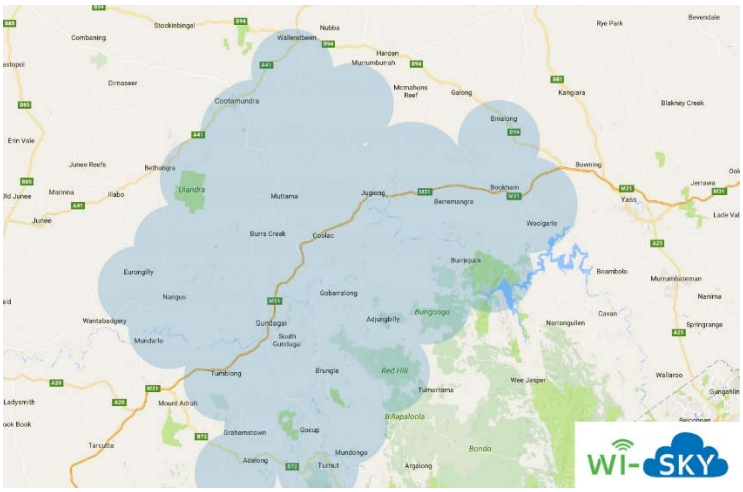
Wi-Sky specialises in customized rural network solutions which includes a dedicated rural communications network, private networks (home and business), NBN installations (ADSL, fixed wireless, fibre, satellite) as well as customized NBN Solutions. Wi-Sky development and testing of network equipment and tower locations was the first stage of their business plan, which occurred in

2015. This was the key phase to identify crucial locations for solar powered sites to reach the maximum number of rural clients and test the efficacy of the wireless technology in the undulating environment. Key developments in this phase were the Gobarralong, Mara, Adjungbilly tower sites that connect up to 40 users and provide a backhaul link to their fibre connection point. With these sites established the trial offered clients up to 50 km from Gundagai a high speed internet connection. The Gobarralong (NSW) site had been strategically located for this trial as a centre point of the network to allow the expansion to surrounding areas with direct line of sight from this advantageous position.

WI-SKY initially trialed a combination of ADSL2+ connections and aggregated them together to be the backhaul access it receives from a connection point in town. This initially aggregated 4 connections together and gave a potential speed of 80 Mbps download speed and 4 Mbps upload (20 Mpbs/1Mbps for each). Using this technique means aggregating existing connections, not utilising a fibre wholesale arrangement to reduce expenses. This setup was suitable in the start-up phase but as more clients were connected and utilised the service, more and more problems arose from using the ADSL aggregation technology. Wi-SKY is now utilising an Ethernet backhaul service from a utilities provider in Burra (near Gundagai) that connects directly to fibre (dark fibre) via their infrastructure. This enables WI-SKY to connect to their data centre with extremely low latency and symmetrical speed as well as provide much higher Internet speeds to the customer base. It also allows WI-SKY to grow their customer base with access to more bandwidth when required. The initial 100 Mb, uncontended speed connection provides the network with the ability to service many users without the restriction that ADSL aggregation had,

Challenges and Opportunities with clients

The target market is those rural and regional consumers that have poor Internet availability currently and a limited outlook for better connections going forward. NBN satellite services suffer from a typically high 'latency' issue and so terrestrial-broadband remains a major viable option for connecting those rural and regional customers. Due to likely congestion issues in the future, the NBN Sky Muster plans are already imposing 'significant' data download limits, with restrictions on the timing of data downloads to often inconvenient hours e.g. off-peak times (1am – 7am). Charges and/or shaping is usually applied to satellite broadband plans once users exceed their allocated monthly data limit. This offers an opportunity for Wi-Sky insofar as a key customer group are farming communities that are allocated by NBN as "satellite only customers" as they are unable to receive access to any fixed line or fixed wireless broadband service. (Wi-Sky service is not served via satellite and is not affected by these latency issues nor the exigencies of the Fair Use Policy as it currently stands).



(Source: WI-SKY)

Case Study #SP6- Farm telecommunications awareness- APA Sound

The Business

Business location: Cooma, NSW; www.apasound.com.au

Key enterprise: Over the past 30 years, provision of audio visual and IT services including live web streaming and recording of events throughout Australia. Service now includes provision of on-farm connectivity solutions and advice on optimizing connectivity.

Date established: Providing AV and IT services since 1977, and providing on-farm connectivity solutions since 1982.

Contact: Ian Ware, Managing Director/Owner.

Size of Business: 12 employees

Key activities/Geographical footprint:
APA Sound has its heritage in proivision of high quality AV and IT solutions for events. In recent years APA has also focussed on assisting farmers to establish reliable connectivity on farm and in all aspects of their operations, particularly around remote control, water points and video points (including video analytics), and with a focus on safety of life aspects. Their networks elying upon 915 MHz band for radio and the 2.4 GHz band for video feeds. Numerous information sheets have been prepared and education is a key part of APA's activities in this space.

(Source: Twitter- @APAsoundAV)

Challenges and Opportunities with clients

Over the past 8-9 years APA have been undertaking 'shared' R&D with producer clients into on farm oconectivity solutions. However education becomes a dominat aspect of undertaking this type of work. It's a clasic 'Catch .22'. "When meeting producers, we end up spending ¾ of our time taking them off 'scared'". Even the simple things like optimising mobile phone reception both in the home/office and in vehicles, understanding wifi and networking, and how the NBN works are all important to those seeking telecommunications solutions. Smart phones and tablets are generally the device of choice. If 3G/4G mobile coverage cannot provide internet access then extended networking and wireless communications systems are necessary to create this connectivity. Advice is provided on optimizing mobile phone reception both in the home/office and in vehicles, advising on selection of brand and model of smart phone which influence reception, selection of appropriate phone cradle and external antenna use of a Bluetooth headset.

In the home or office, phone reception can be optimized using a mobile phone repeater system. When it comes to choosing an internet connection for the home/office, producers are advised to choose the best internet connection available that meets current and likely future needs. Not all types of internet connections are available to all areas, the reliability and speed of the connection (not just the cost) should be considered when comparing options.

Setting up high speed wireless internet connection from a MNO tower is possible however the installation of this service will require a professional installer and negotiations with a MNO for the incoming signal to the transmitter. When selecting an ISP, consider coverage and customer service, not just the cost. When selecting a plan after choosing an ISP, producers need to compare home versus business plans, as services and costs can vary quite substantially between the two. It is important to consider how you intend to use the internet and how often you will access it; then compare connection speeds, download limits and pricing to select the best plan for you.

Regardless of which internet connection type and plan a client has chosen, the next step to optimizing connectivity is possibly sharing internet connection with other users and devices. It is important to optimize internet connectivity in the home/office through the use of antennas and networking

Extended networking over distances of more than 5km is best managed with either point-to-point or point-to-multipoint wireless networking solutions. These systems will allow producers to set up their own internet service in collaboration with a MNO tower, or to extend the internet connection across their property or into multiple properties. The cost of setting up internet infrastructure (for example creating a private internet connection or creating a property wide Wi-Fi network) may seem high, but producers need to consider the cost of being left behind and the long term savings that can be achieved through streamlining tasks and using automation, which will then allow for more time in the field and less time in the office. To reduce costs, producers are advised to consider forming their own group or community to extend an internet connection and better manage the initial cost of the infrastructure.

A particular concern that relates to safety of life work is around the reliability of the backhaul networks. Whilst rain and mist is associated with fade outs (e.g. 11 GHz) and reduced data transfer capability, smoke and ash is also of concern, especially for the smaller links. "Why not have a satellite dish on top of each tower as a 'backhaul backup'?" Backhaul links appear 'fragile and underbuilt' and backhaul links between mobile towers must be upgraded; for example by running fibre to each tower and thereby free up the 11 GHz spectrum (the microwave spectrum typically used for backhaul) for point-to-point links to farms.

Case Study #SP7- Carrier grade communications network solution for IoT on farms – National Narrowband Network (NNN)

The Business

Business location: Unit 10, 1 Talavera Road North Ryde, NSW 2113; www.nnnco.com.au

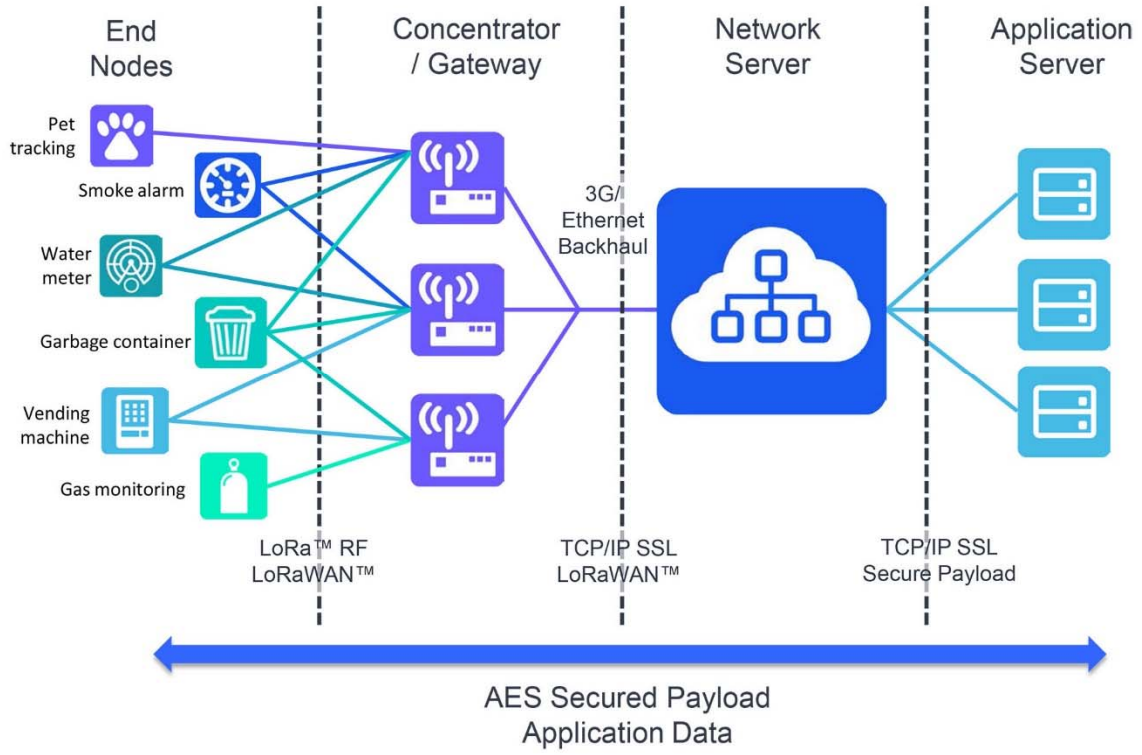
Key enterprise: NNN Co is an independent Australian carrier designed to provide IoT carrier grade network services for on-farm rural applications (narrow band). NNN Co is building its own network and seeks to offer secure data services from point of origin (on farm) through the gateway, backhaul, network operating centre and to the point of digest at open standard APIs.

Date established: 11 May 2015

Contact: Rob Zagarella, Founder & CEO

Size of Business: 15 staff.

Key activities/Geographical footprint:
NNN Co is building and operating a carrier grade network, supporting IoT (narrow band) applications on farms, with a particular focus on LoRaWAN. NNNCo was granted a carrier licence (ACMA) in January 2017; a vital step towards plans to build out open, shared IoT networks. NNN Co offers secure data services from point of origin (on farm) through the gateway, backhaul, network operating centre and to the point of digest at open standard APIs.



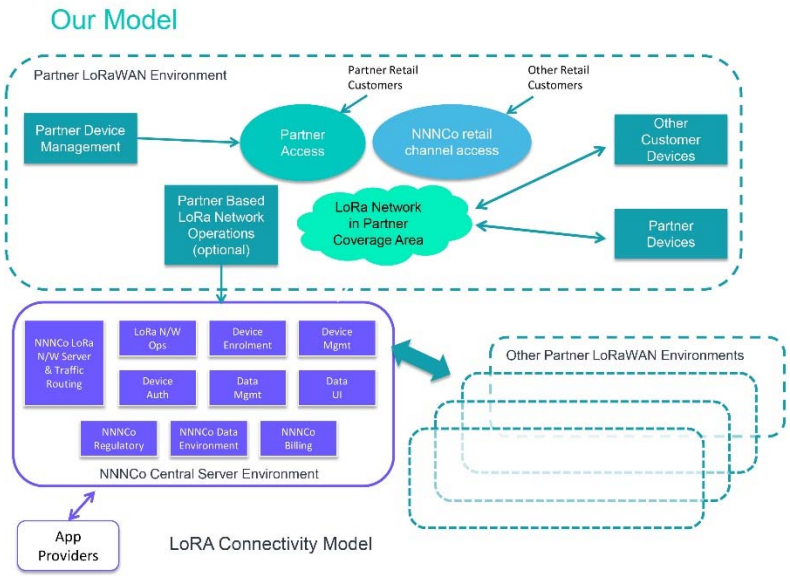
(Source: NNN Co)

Telecommunications solution on offer

NNN Co network development is a work in progress. NNNCo operates a collaborative model working with partners who have an interest in providing a LoRa network to an area. As a network owner, NNN Co seeks to offers a guaranteed level of service to producer clients. The NNN partners with providers of LPWAN/LoRaWAN technology essential for deployment on farm to support access to assets across large areas.

According to its published white paper (NNN Co, 2017) NNN LoRaWAN concentrators/gateways (NNN software), which can be shared between multiple users (farms), connect farm devices onto a guaranteed backhaul capability on the backhaul agnostic (e.g. 3G, 4G, NBN etc), NNN network, with an integral secure data transfer and management environment into the LoRaWAN network server. The cloud-based network server processes packets from multiple gateways, directing them to an application server. The secure provisioning available in the network server allows multiple service providers to create individual IoT offerings. The LoRaWAN network server controls data access and provides security and operational support. The network server sends packets to the appropriate NNN application server which handles the client application and presents only data that is relevant. The application servers (and open-standard APIs) support cloud based analytics and other user-defined tools. This helps users to monitor and track assets, cost savings and operational efficiency gains. Additionally, the user may set up rules to take action on specific events or a combination of events via a web-based application dashboard. There are highly-integrated application servers and dashboards available which make setting up and managing a LoRaWAN network fast. As most business owners and end users are looking for ease of use and reliable data that they can take action on, the IoT applications on smartphones and computers are designed to have easy configuration with a simple visual interface. These applications also offer integration with large Cloud service providers such as Amazon Web Services and Microsoft Azure.

In 2016, NNNCo began a demand management trial in Townsville with smart Demand Response Enabling Devices (DREDs) installed on hot water circuits for Ergon Energy. DRED provides a method to centrally control electricity demand by a remote device, and is of interest to utilities to limit resource consumption (eg power or water) by remote devices at critical peak load times. NNNCo was also successful in an Request of Proposal (RFP) to build a network across three water authorities in Victoria. This trial is currently in progress. In March 2017 NNNCo signed a contract with Actility to supply large-scale low-power wide area (LPWA) infrastructure and core network server functionality; a key component in develop a national IoT network at scale. NNNCo has contracted French company Actility to rollout a LoRaWAN network, claiming it will be “Australia’s first industrial IoT network.”



(Source: NNN Co)

Part 3 Opportunities

Universal Services Obligation (USO)

In acknowledgement of the critical importance of telecommunications for all Australians at their place of residence or where they conduct business, the Telecommunications (Consumer Protection and Services Standards) Act 1999 (Telecommunications Act 1999) allows the Minister to confer the primary responsibility of Universal Services Obligation (USO) (Telecommunications Act 1999 Section 9) onto a designated universal service provider[22]. In other words, the designated provider has responsibility for ensuring that "a standard telephone service (STS), payphones and prescribed carriage services are reasonably accessible to all Australians on an equitable basis, wherever they reside or carry on business." Furthermore, the USO should be fulfilled by the designee as economically as possible and that any losses involved in its provision should be shared among carriers. In the context of this review, the relevant component of the existing USO is the STS. For most people, the STS means a basic fixed line telephone used to speak with people in other locations. Carriage service providers supplying a STS are required to provide end-users with: local, national and international calls, 24 hour free access to emergency service numbers , a unique telephone number with a directory listing, unless the customer requests otherwise operator assisted services, directory assistance and itemised billing, including itemised local calls on request (ACMA 2016d). Telstra is currently the sole universal service provider and is obliged to provide an STS to anyone in Australia under the USO. Other telephone companies may also provide an STS; indeed the Act allows the Minister to declare two or more carriers as universal service providers, or regional service providers, with appropriately limited responsibilities (Jackson 2000).

It is noteworthy that the USO does not currently include provision for digital data services[23]. The Regional Telecommunications Review (2015) highlighted the fact that the current STS "is of rapidly declining relevance" given the increasing use of mobile phones and VOIP. But again this appears just in the context of voice communications. This assertion is not only equally applicable to data communications as well (as will be discussed in the following sections), but is indeed strengthened considerably by it. The Productivity Commission instituted a 12 month inquiry into the USO with the release of an 'Issues Paper' (Productivity Commission 2016a). Of particular relevance to producers were Commission recommendations that the Inquiry make recommendations on "whether particular sections of the Australian community have differing needs to which additional Government intervention should be directed e.g. low income, rural and regional" and "with regard […] to technological changes". Of particular note in the Issues paper is the fact that fixed line voice calls are declining and mobile calls are increasing, and of the growth on non-voice communications. In expanding on the telecommunications needs of regional users, the Issues Paper ('Box 5') focusses on mobile services "for communication and safety as they travel long distances and spend more time outdoors". No mention is made of the data telecommunications needs of producers. In terms of the outcomes of this review, only a draft report has been issued (Productivity Commission 2016b) pending release of a final report handed up to the Government on 28 April 2017. Importantly the Draft Report recommends phasing out of the existing USO "as soon as practicable" and reframe the objective to provide "a baseline broadband (including voice service) to all premises in Australia, having regard to its accessibility and affordability, once the NBN infrastructure is fully rolled out." The context of the findings and recommendations remain framed around voice services (albeit VOIP). There is no formal definition of the minimum bandwidth required to support such a service and it remains unclear whether a baseline broadband service capable of supporting VOIP will naturally service the complete 'spectrum' of data needs of producers. Some indicative values are listed in Table 21.

[22] In the context of telecommunications, a universal service provider (USP) is an entity capably of providing a baseline level of telecommunications service to every resident in a country.

[23] A Digital Data Service Obligation (DDSO) was established in 1999 under the Telecommunications (Consumer Protection and Service Standards) Act 1999, which along with the USO (STS and payphones) effectively provided a universal telecommunications service regime. Telstra was the declared Digital Data Service Provider (DDSP) up until late 2008. Ironically, owing to the substantial growth of demand for digital services, the increasing bandwidth involved (ie exceeding the original 64 kbps service requirements), and the expanding choice options for consumers of digital services, the DDSO was revoked in 2008 (DDSP Revocation 2008), effectively leaving the services regime devoid of a digital data component from late 2009 onwards.

Table 21. Minimum and recommended bandwidth for VOIP service (Source: Phone.com, 2017).

Number of Concurrent Calls	Minimum Required Bandwidth	Recommended speed
1	100 Kbps Up and Down	3 MBps Up and Down
3	300 Kbps Up and Down	3 MBps Up and Down
5	500 Kbps Up and Down	5 MBps Up and Down
10	1 MBps Up and Down	5-10 MBps Up and Down

The Draft Report assesses the service level provided by NBN infrastructure will be "more than adequate to meet a baseline level of broadband (including voice) service availability for the vast majority of premises across Australia" although this focusses on NBN's fixed-line and fixed wireless footprints. Based on the information provided in this present review, it would appear the level of service, namely 'speed' offered by fixed wireless and the satellite (precursor ISS and Sky Muster) is an ongoing cause of concern.

Observation: Producers consider 'access' to mean 'speed', as measured in bps. Baseline broadband access requires a notion of reliable 'speed'.

Another key draft recommendation of the USO Review was in relation to the Mobile Black Spot Program, namely that the MBSP should be targeted "[…] only to areas where funding is highly likely to yield significant additional coverage", while it also makes mention of revising infrastructure-sharing requirements to be consistent with the ACCC's findings in the ongoing Domestic Mobile Roaming Declaration Inquiry (ACCC, 2016b; ACCC, 2016c).

Domestic Mobile Roaming

With the recent release of the ACCC findings of domestic mobile roaming (ACCC, 2017), the key contributors to the decision not to declare domestic mobile roaming was built on the notion of competition, and largely on the basis of price of data/calls and the importance of incentives for MNOs to continue to invest in infrastructure development. The ACCC found that the benefits of any infrastructure advantage enjoyed by a particular MNO would be significantly reduced; namely reducing the benefits a MNO would experience from extending its network coverage beyond that of its rivals. For example, it can be argued that the current MBSP-supported expansion of mobile coverage in rural and regional Australia is largely driven by the value of this coverage to travelling urban customers. Under a declaration scenario, the ability of other MNOs to roam onto this new infrastructure effectively undermines the market advantage of the host MNO (for those urban clients). This would subsequently reduce the incentive for MNOs to invest in improved network coverage and upgrades in regional, rural and remote areas into the future. This of little relevance to producers when it comes to their need to see mobile coverage expanded on their farms outside of the collateral benefit accrued by MNOs erecting new towers for the benefits of urban clients. There is an opportunity and need for upgrading the existing mobile networks to improve capacity and reduce congestion experienced by producers, as is there a need to more closely consider the way infrastructure could be shared between MNOs as well as some form of oversight of the way backhaul is managed between competitors.

Observation: Mobile networks in rural and regional Australia have evolved to service the needs of primarily travelling urban clients. Were additional mobile network infrastructure to be established on the basis of servicing the needs, in-situ, of farmers, the economic benefits of domestic mobile roaming to network operators may be entirely different.

What we don't know about service, access and data speed

From a digital agriculture perspective, producers consider service and access to be synonymous with data speed, ultimately a byproduct of signal strength and the way the communications network is operated with respect to the location of the consumer. Put simply, producers want speed and volume.

But do we know exactly how much data Australian producers will generate from their farms, now and into the future? Do we know how much data they wish to access back at the point of decision making, namely the farm office or in the paddock/yards or their the shed? Do we know the nature of that data and hence what transmission speeds are appropriate, up and down, for that data? The answers are 'no', 'no' and 'no'.

All we presently have is a growing understanding of the type of data-generating activities farmers are interested in, both from the recent P2D farmer survey (Zhang et al., 2017) and other like surveys around the world looking at the adoption of aspects of precision agriculture and associated telecommunications technologies (for example Taylor et al., 2013; UNL 2015 (U.S.); Sunding et al., 2016 (Canada); AFI 2016; Wolfert et al., 2017). In terms of data access, the only measures at hand are around whether speeds and data volume (data plans) are adequate for use. For example in 2015 more than 60% of Victorian farmers surveyed considered access was too slow and more than 35% indicated that there was not enough data in their plan (Victorian Producers Federation, 2015).

Observation: There is no quantitative data available on the diurnal and seasonal demands for data (quantity and desired/required speeds of access) for farmers, specifically as it relates to the business of farming.

In April 2017 the Federal Government announced a new broadband performance monitoring program to be administered by the ACCC and involving 4,000 participants (ACCC Broadband, 2017). With the aim "to provide Australian consumers with accurate and independent information about broadband speeds" a Request for Tender to undertake the testing service was subsequently issued by the ACCC at the end of May 2017 with a call for volunteers issued on 19 June 2017. Presently the program will only cover fixed line broadband services, although most Australian farms will access broadband through fixed wireless NBN or Sky Muster satellites.

Observation: Broadband performance monitoring needs to be extended to include those modes of access to Australian farms, specifically with the aim of understanding broadband access experience related to the business and lifestyle of farmers.

Getting more out of our mobile networks for producers

Strategic planning- national and sector

The Ericsson Mobility Report (Ericsson, 2016) forecasts that globally, by 2018, the internet of things will exceed mobile phones in terms of connected devices, and that by 2022 data traffic via smart phones will be at ten times the level of 2016. Moreover, the ACMA 2015-16 Communications Report (ACMA 2016f) observed that data downloads over mobile handsets has experienced exponential growth over the last four years, from almost 10,000 Terabytes[24] of data in the June quarter 2012 to over 120,000 Terabytes for the same period in 2016. There is no reason why agriculture would not partake in this type of growth; indeed even surpass this growth rate given the fact that agriculture is considered a 'late bloomer' in the space. Mobile network data carrying capacity is a key aspect of the future, and indeed future-proofing for the telecommunications needs of our producers. The 2017 phone survey of 1000 producers identified the largest proportion (55%) of Australian producers utilized the mobile phone network to connect their business to the internet (Zhang et al., 2017). This is consistent with the findings of the GRDC Rural Communications Infrastructure Report (Graham, 2016); 52% reported in Victoria in 2015 (Victorian Producers Federation, 2015) and 30%

[24] 1 Terrabyte (Tbyte) = 1000 Gbytes

usage (NSW farmers) reported in 2014 (NSW Producers, 2014). The mobile phone network continues to play an important role in farm connectivity. A clear message gleaned from producers and service providers participating in the P2D workshops was that the mobile phone network is also considered 'by far' the easiest option for connecting devices on their farms.

The Draft Report of the Productivity Commission's Inquiry into Telecommunications Universal Services Obligation (Productivity Commission 2016b), Draft Recommendation 7.4 specifically refers to the Mobile Black Spot Programme 'target […] only to areas where funding is highly likely to yield significant additional coverage'. It is assumed that this means geographical coverage. The ACCC Domestic Mobile Roaming Inquiry Draft Decision (ACCC, 2017) acknowledges that mobile phone service providers compete nationally for market share and geographic coverage, and network coverage in regional areas is a key element on which they compete against other service providers. But what does regional coverage mean? The challenge faced by producers working on their farms is that this notion of regional coverage (outside of regional centres) is effectively coverage along transportation corridors in regional areas (Figure 32).

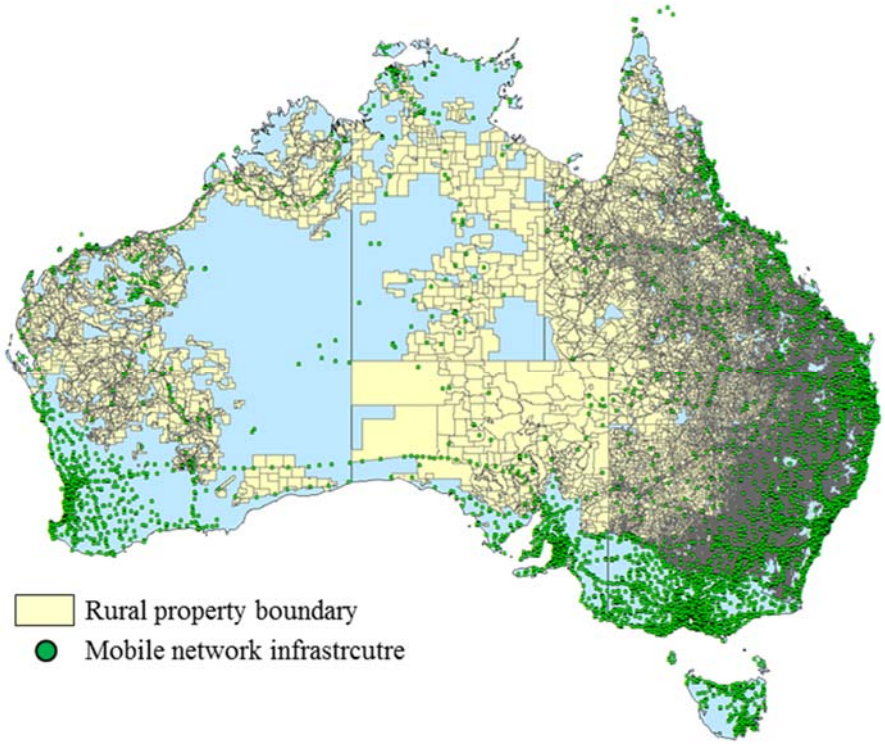


Figure 32. National map showing locations of network infrastructure (green circles) and freehold property boundaries (yellow polygons). Note missing property data for south WA, Victoria and Tasmania and properties < 10 Ha are excluded. Tower location data accessed from ACMA publicly-accessible database (http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Register-of-radiocommunications-licences/radiocomms-licence-data**), and property boundary data courtesy of Central West Local Land Services. This dataset includes 17,000 unique mobile infrastructure identifiers and 89,701 land holdings.**

If we are to understand the opportunities of utilizing the existing primary telecommunications networks of, say the four primary network operators; Telstra, NBNCo, VHA and Optus for on-farm connectivity it would be instructive to overlap the mobile network coverage layers with all farm boundaries in Australia. This would enable a quantitative understanding of, at a national and regional scale, and even at an industry level, the level and 'patchiness' of coverage experienced by producers. Such knowledge would provide a wealth of information for strategic planning around farm communications, not necessarily just to inform strategic expansion of mobile coverage as part of, say, the MBSP, but also to inform the market place seeking to develop and offer innovative (and compatible) network solutions for farmers to expand data coverage on their farms.

Observation: There is no single database of national mobile coverage (all network operators) available for analysis of farm coverage across Australia. Mobile coverage data, as opposed to publically-available data on tower locations, is generated by MNOs using proprietary assumptions, and available in such a form as to preclude rendering of digital data layers for further analysis

Moreover, if the interpretation of Draft Recommendation 7.4 of the PC's Inquiry into Telecommunications Universal Services Obligation (Productivity Commission 2016b) is indeed focusing on increasing geographical coverage then this could mean more powerful towers on high hills with larger cell coverage. This would likely be relatively more expensive (access, remote power, backhaul network links etc), but presumably more cost effective given the increased coverage. Large footprint sites can cause interference, with slight reductions in data speeds in existing coverage areas but this would need to be weighed up in light of 'coverage for all versus speed for a few' at a given location. If we take the national approach of a baseline signal coverage for all, the onus could then fall on the customer (producer), and the solutions marketplace, to bring the coverage 'down' to where it is needed; in the shed, the yards, machines etc.

Included in Figure 32 alongside the network infrastructure (green circles) for the four major network operators; Telstra, VHA, Optus and NBNCo, are freehold property boundaries (yellow polygons) greater than 10 Ha. Due to the difficulty in sourcing data, there is missing property data for southern WA, Victoria and Tasmania. Tower location data were accessed from ACMA publicly-accessible database (http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Register-of-radiocommunications-licences/radiocomms-licence-data), and property boundary data was provided courtesy of Central West (NSW) Local Land Services. This dataset includes 17,000 unique mobile infrastructure identifiers and 89,701 land holdings. When this limited property boundary dataset is intersected with infrastructure locations, it is possible to gain an indicative picture of the proximity of those farm boundaries to infrastructure (Figure 33).

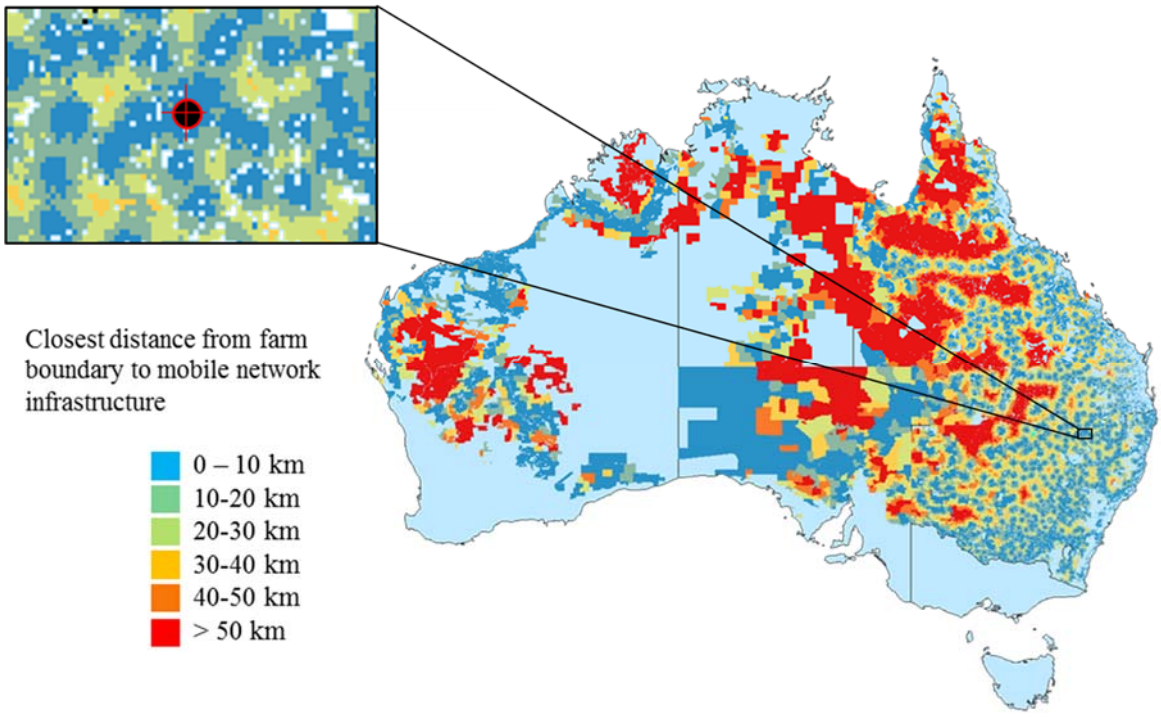


Figure 33. National map showing proximity of farm boundaries to network infrastructure. Note missing property data for south WA, Victoria and Tasmania and properties < 10 Ha are excluded. Inset: Indicative location (and property size) of a prominent W-NSW cotton farm located ~9 km from the closet tower and experiencing challenges in accessing mobile data. (Source: Derek Schneider, UNE PARG)

From such a dataset it can be calculated, for example, that 66.4% of these properties have infrastructure within 10 km of their property boundary, 95.8% within 30 km and 98.4% within 50 km

(Figure 34). This alone is useful information given a raft of emerging network technologies which are suited to certain distance ranges. It is accepted that distance to a given infrastructure (tower), is a key driver of access speed, but an analysis incorporating the host of additional other factors including tower frequency, topography (line of sight) and vegetation (obstruction), receiver performance (including external antenna), the dynamic capability of a cell tower to maintaining a link once established which is affected by current load and the way voice versus data is managed (e.g. 3G versus 4G or a combination) could be a powerful planning tool. Ultimately, while the data in Figures 32-34 serve to illustrate the potential of even simple datasets (and are included here for illustrative purposes only), it is evident that a publically-available, national dataset, incorporating pre-agreed metrics around tower performance that is independent of MNO's proprietary assumptions, would provide valuable information for a range of stakeholders (policy, R&D, service) working towards developing on-farm telecommunications into the future.

As the preliminary exploratory analysis of Figures 33 and 34 suggest, a considerable proportion of Australian farms are possibly 'within reach' of the terrestrial network. It may simply be a case of identifying the right solution to get the data from where it is accessible to where it is needed, and using consumer grade, off-the-shelf solutions suited to that distance and physical environment. Where not available then national and agriculture sector-based R&D agendas could be so informed, and so configured, to address remaining telecommunications technology gaps.

Observation: A national dataset comprising all farm property boundaries (no size restrictions), mobile network infrastructure locations with pre-agreed (MNO-agnostic) metrics around tower performance (including effect of number of voice/data users) and receiver characteristics, integrating nationally available datasets of ground cover (for obstructing vegetation), land-use (for industry type) and topography (visible line of sight) would provide valuable baseline information to inform the development of on-farm telecommunications into the future.

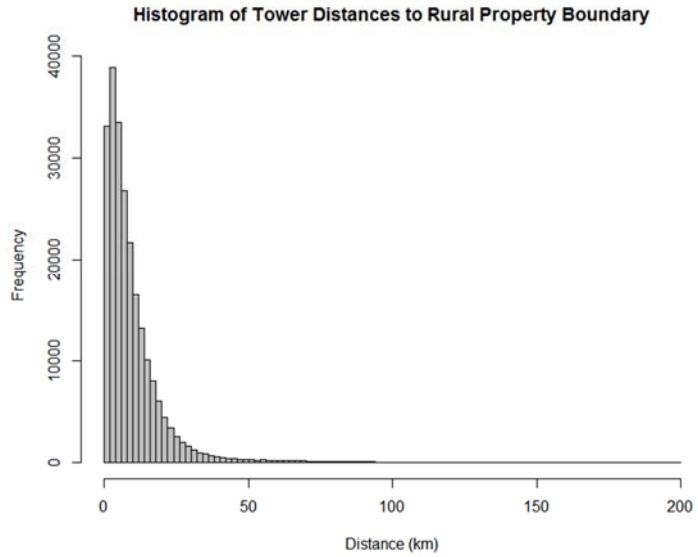


Figure 34. Generated histogram of mobile infrastructure distances from farm boundaries, as calculate using available data (missing property data for south WA, Victoria and Tasmania and properties < 10 Ha are excluded). (Source: Derek Schneider, UNE-PARG)

Planning ahead- producers

As mentioned earlier, it is difficult for mobile network operators to guarantee data speeds given that is inextricably linked to the amount of mobile users, and the type of use at any given time. What would be useful for producers seeking to utilize the network on farm for important data-related activities, such as downloading and installing firmware on machines, transferring bulk data to and from the cloud (e.g. during important operational events such as harvesting), accessing and analysis cloud-stored data, using the mobile network for machine guidance/telematics or recording livestock data (e.g. in the yard), and the like, is to be able to identify windows of opportunity when

the network is likely to support certain activities. Such information could be based on accumulating usage data from each cell, not unlike the diagnostics utilized when providing would-be shoppers with data to help them decide when to shop (Figure 35).

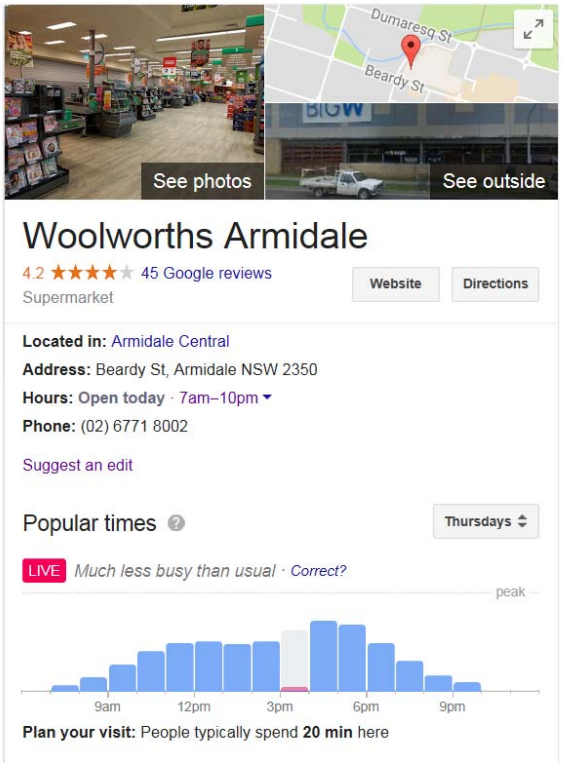


Figure 35. The result of a web search for 'Woolworths Armidale (NSW)', providing information useful for planning a visit (Source: https://www.google.com.au/search?).

Observation: Mobile network users, such as producers could benefit from indicators of traffic load in their local mobile cells as an aid for planning important data access activities on their farms.

Getting more out of our radio frequency spectrum

Throughout this review, many producers and service providers enquired about the spectrum and whether this would ultimately form an upper limit on the ability of our networks to cope with growth in demand.

Creating 'room' in the available spectrum is possible either by existing spectrum holders (for example mobile network operators) consolidating their holdings and making un-used portions available to the market place, or through a centralized process (i.e. ACMA) of undertaking a whole of spectrum review to improve efficiencies by reallocation of existing spectrum. The latter is complex, does not happen often and can be a long process. A summary of spectrum available (including those under consideration) for IoT applications and future mobile data use is given in Figure 36.

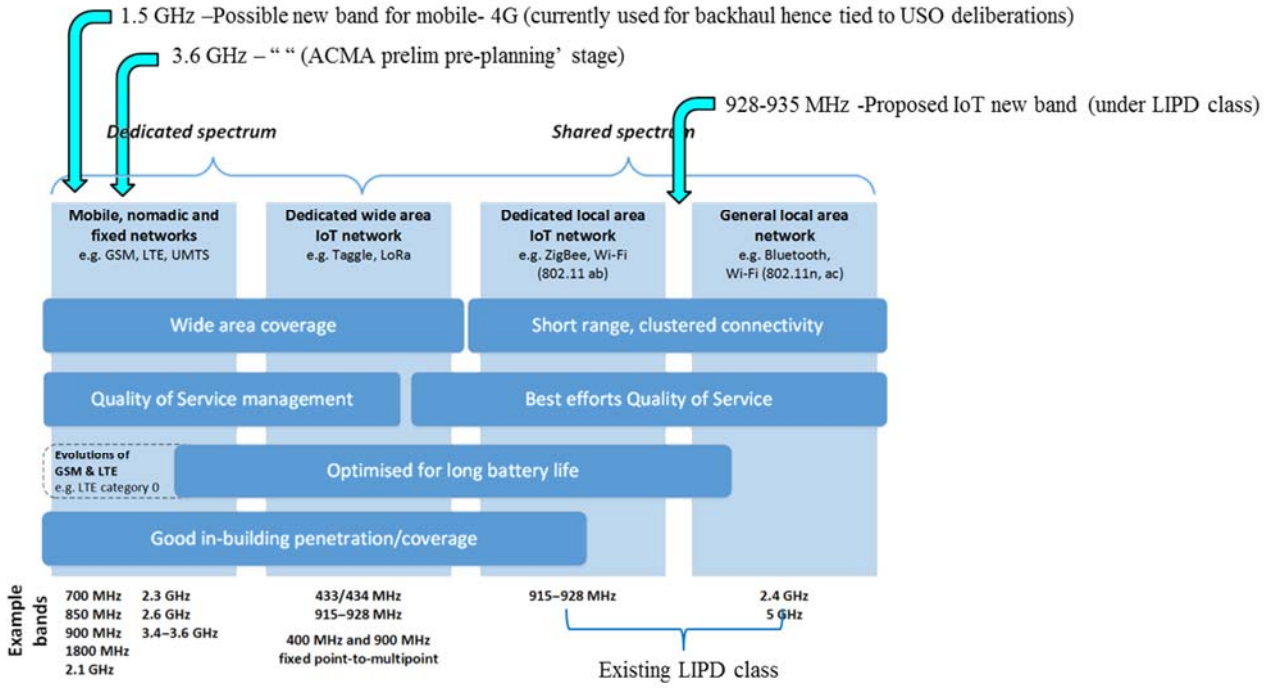


Figure 36. Schematic summary of existing and proposed/considered band allocations (blue arrows) (Diagram adapted from IOTA, 2016).

Mobile broadband network

The ACMA auction of the remaining portion of the 700 MHz spectrum (2 x 15 MHz blocks; 733-748 MHz and 788 – 803 MHz) concluded earlier this year and it is a band of particular importance to rural and regional Australia owing to the comparatively greater penetration/range afforded by the lower frequency. TPG Internet Pty Ltd secured 2 x 10 MHz effectively bringing a fourth MNO[25] into Australia which should bode well for competition. The licences for the 700 MHz band, including those sold in the original 2013 auction expire on 31 December 2029. At the time of writing TPG Internet has committed itself to rolling out a $2 Billion mobile network (TPG Internet, 2017).

A network operator can possess a nationwide license for a portion of spectrum, but it may not be fully utilized (or possibly not at all) in a particular geographical area. Mobile network operators are allowed to on-sell unused spectrum to third parties via secondary trading or allow access through a process known as 'third party authorisations'. A third party provider can negotiate with them to have access. There is nothing in the legislation that would prevent or discourage this process, and indeed the ACMA encourages it. One example recently appearing in the press is Vodafone which is currently exploring with Red WiFi the sharing of spectrum (Red Wifi, 2017).

The ACMA has developed a mobile broadband strategy and work plan (http://www.acma.gov.au/Industry/Spectrum/Spectrum-projects/Mobile-broadband/mobile-broadband-strategy-and-work-plan) to address the growth in demand for mobile broadband capacity. Part of this is looking at the 1.5 GHz and 3.6 GHz portions of the spectrum for considerations as additional spectrum for mobile broadband (MBB) services (ACMA 2016e). The 1.5 GHz spectrum is currently used for low capacity connections. For example Telstra uses it for digital radio concentrators in regional/remote areas as part of their USO. Depending upon the process of reconsidering the USO this portion of the spectrum may be freed up. Defence use portions of the 3.6 GHz band and some of the 3.6 GHz is currently used for point-point and point-multipoint connections in regional and remote Australia, for example by wireless Internet service providers. There are already in place international standards that support 4G in the 1.5 GHz and 3.6 GHz bands and the 3.6 GHz band is also being looked at, internationally, as a candidate for 5G

[25] At the time of writing, TPG Telecom P/L is Australia's second largest ISP and the largest MVNO.

deployment (Ericsson, 2016b). Following a round of public consultation the ACMA has now committed to progressing the investigation work on the 3.6 GHz band to a 'preliminary re-planning stage'.

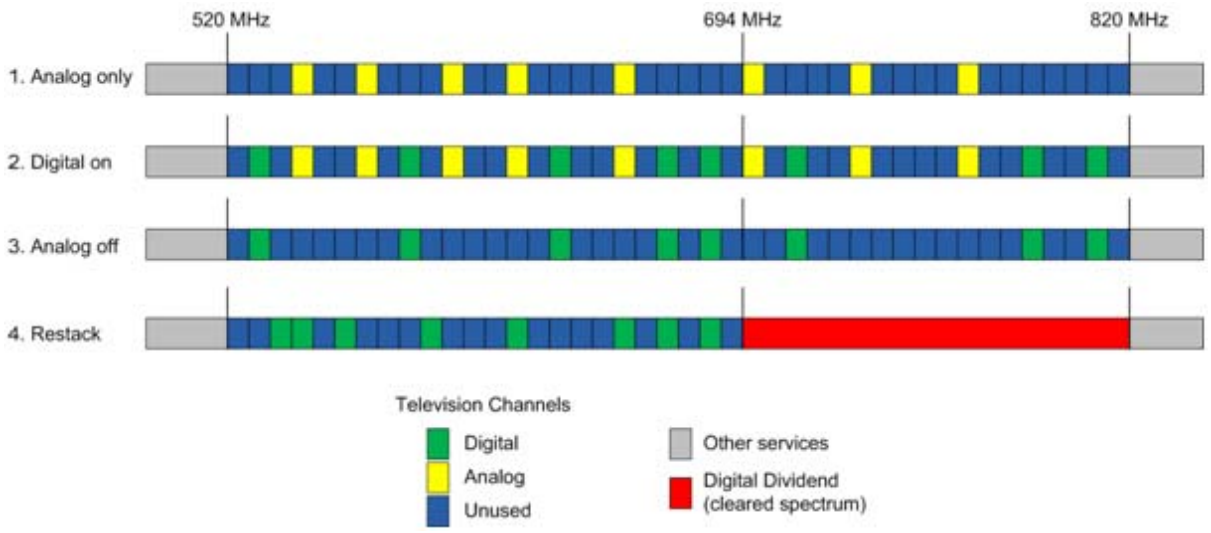
LORA WAN

Another important commitment of the ACMA's 803-960 MHz decision paper is access to a new segment of spectrum to support low power, low duty cycle communications suitable for some types of M2M communications such as smart infrastructure, metering and control; in other words in support of IoT. Whilst Australia currently allows access to the 915-928 MHz band using the public park approach (LIPD Class Licence), the ACMA, in collaboration with IoT Alliance Australia (https://www.iotaustralia.org.au/) is investigating the parameters for a new band in the 928 – 935 MHz range. Ultimately this will need to be included into the LIPD class licence and is expected to become available sometime in 2021. In the meantime, as portions of the spectrum are cleared in line with the implementations of the outcomes of the 803-960 MHz review, applicants (for an apparatus licence) may apply for access.

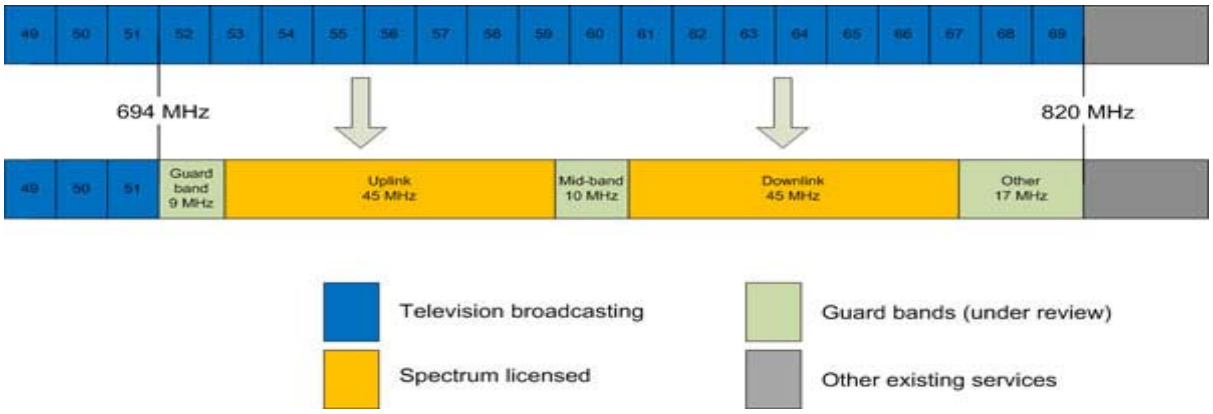
White space

White space refers to unused frequencies; generally 'gaps' between channels within a broader spectrum band. For example television channels operate on certain frequencies and small gaps (buffers) in the frequency bands are required to minimize interference between them. For example, in Australia analog television operated between 520 and 820 MHz (Figure 37 (a)'1.') with white space ('unused channels') available between them. This white space is typically utilised by LIPD class transmitters, so called 'symbiotic' white space devices (WSDs). Following the migration to digital channels (Figure 37 (a) '2.') and subsequent switching off of analogue channels (Figure A (a) '3'), the bands for digital television were reallocated (Figure 37 (a) '4. Restacked') within the reduced spectrum range of 520 – 694 MHz, clearing the 694-820 MHz range entirely. This reduced the white space immediately available to audio transmitters to within the 520 – 694 MHz range with users directed to switch off transmitters post January 2015. The creation of the 2 x 45 MHz blocks of spectrum in the Digital Dividend range includes a 'guard band' at either end, and a 10 MHz 'mid-band gap' band between them (Figure 37 (b)). The guard band at 694 – 703 MHz aims to prevent interference between the high power broadcasting services below 694 MHz and the mobile telecommunications networks deployed above 703 MHz. Because of its widespread geographic availability in Australia the 694-703 MHz guard band will likely be of interest to WSD developers. Ultimately the use of these three bands, what is potentially white space, is dependent on the outcomes of ACMA re-planning around the 803-960 MHz frequency band. The ACMA is currently considering proposals which may include providing a public safety mobile broadband (PSMB) capability in the 803–820 MHz part; the end guard band. In 2015 the ACMA released its 'Decision Paper' on the future of the 803-960 MHz band (ACMA 2015), which include the old 2G/GSM bands (890–915/935–960 MHz). The ACMA recognizes the need to reconfigure these two bands but it presently is unclear as to the nature and the process required. One option is to 'clear' the bands and put them to auction. The decision paper commits to planning for new spectrum for mobile broadband. A parallel, Productivity Commission Review into the PSMB (Productivity Commission, 2015) concluded that commercial mobile networks are the most efficient, effective and economical way of delivering a PSMB capability. Hence it is plausible that PSMB will be a key user of any reconfigured spectrum. At the same time Australia's public safety agencies (emergency services) have extensive POP and point-to-point link infrastructure throughout regional Australia which, should PSAs move to a LTE mobile communications framework, could then see this infrastructure augment 'civilian' mobile communications. This point was also flagged in the Regional Telecommunications Review (2015).

There is still scope for considering future 'commercial interests' in mobile broadband. It is possible that post-review the ACMA will investigate the feasibility of using the front guard band (694–703 MHz) and mid-band gap (748–758 MHz) for LIPD, i.e. wireless audio transmitter use. With the need to accommodate services displaced by the re-planning outcomes, it is possible that a portion of the 694–703 MHz guard band may be available for LIPD transmitters (ACMA 2017).



(a)



(b)

Figure 37. (a) Spectrum allocations under the migration from analogue to digital television and the white space bands allocated in the Digital Dividend band currently under consideration by the ACMA. (Source: http://www.acma.gov.au/Industry/Suppliers/Product-supply-and-compliance/Commonly-supplied-equipment/wireless-microphones).

It is worth mentioning that white space devices (WSD) actually fall into two classes. 'Symbiotic' WSDs include wireless microphones and biomedical telemetry monitors which are low power and short range. 'Invasive' WSDs, are higher power WSDs based on advanced technologies that are proposed to exploit white spaces on a much larger scale and in a more dynamic fashion (Freyens and Loney, 2011a). This can also include broadband wireless access services such as those advocated by the global WhiteSpace Alliance (www.whitespacealliance.org) and for long range environmental monitoring telemetry systems. A key aspect of the alliance is in the area of standards-based products and services; not unlike the global LoRAWAN Alliance, which includes interoperability specifications. Understanding the opportunities around both symbiotic and invasive WSDs in Australia, in light of the various reviews of spectrum underway is an important step, as advocated by Freyens and Loney (2011b). It is proposed that consideration be given to yet another digital dividend; 'Digital Dividend 2.0, this time involving the contracted digital television band (UHF spectrum 520 – 694 MHz). Freyens and Loney (2011b) assert that "intensive use" of the 520-694 MHz UHF spectrum by invasive WSDs may actually be to the long term benefit of both broadcasters and telecommunications operators. Similar to the recommended geographical analysis of mobile coverage relative to farms in Australia, any strategic planning of white space use in Australia would likewise be well served by the type of spatial and economic analysis published in the U.S. by Harrison et al. (2010) (Figure 38). This particular report was based on a 'semi-empirical

perspective', and used publically available databases of television transmitters, census data (from 2000), and standard wireless propagation and information capacity models. Similar datasets are available in Australia.

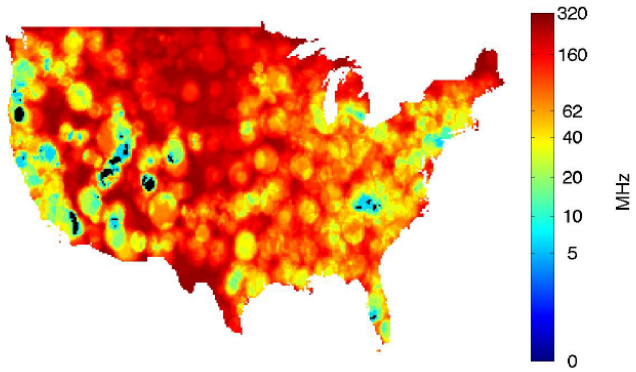


Figure 38. An example map of available white space channels in the United States based on tower locations and available channels to each tower (Source: Harrison et al., 2010).

Observation: Any consideration of opportunities of utilizing whitespace devices in rural and regional Australia would be informed by a spatial analysis of whitespace availability and potential demand.

A noteworthy innovation- NGARA

The CSIRO has been working on a spectrum-efficient broadband wireless technology 'NGARA' since 2009, initially field testing the concept in Smithton, Tasmania in 2011 (CSIRO 2011, 2012). Initially conceived to meet the fixed wireless broadband needs under the NBN, the NGARA 'system' comprises several telecommunications components: point-to-multipoint wireless access (within a 'cell'), point-to-multipoint backhaul (sometimes referred as "fronthaul"), point-to-point microwave and point-to-point 'E-band'[26] backhaul (Figure 39). The point-to-multipoint backhaul component of the 2012 and ongoing trials utilised a portion of the 3.4 GHz spectrum 'donated' by Optus (CSIRO 2012). Spectral efficiency (measured in bps/Hz) is achieved through two means; multiple user terminals (e.g. households, sheds etc.) with a single antenna and a central access point comprising multiple antennas (Figure 40). Within the NGARA 'cell' (Figure 39), the multipoint connections utilise orthogonal frequency division multiplexing (OFDM)[27] which allows multiple data streams to be transmitted in a single slice of spectrum (CSIRO 2011). A second means, which capitalises on the sparse nature of user terminals within the cell is a space division multiple access (SDMA) method called Multi-User MIMO (MU-MIMO). Effectively this means that users in different directions from the receiver can transmit on the same frequency. The 2011 trial demonstrated data rates of 12 Mbps 'up and down' (24 Mbps aggregate) for six simultaneous users in only a single 7 MHz (TV) channel, using two-way video streaming as the means of demonstration. This represented a spectral efficiency of 20 bps/Hz, compared to typical values ranging from 0.5 – 4 bps/Hz for a single digital TV channel. A second trial in 2012, demonstrated 50 Mbps symmetrical (i.e. 50 Mbps each way, or 100 Mbps aggregate) to 12 simultaneous users in only 28 MHz of spectrum, yielding a spectral efficiency of 40 bps/Hz (Figure 41). Subsequent efficiencies up to ~67 bps/Hz have been reported. By using frequency multiplexing techniques this system would be capable of providing 12 Mbps symmetric to a community of up to 1000 residences.

[26] E-band refers to 71-76 and 81-86 GHz bands which are used for ultra-high capacity point-to-point communications. The E-Band backhaul was specifically customized for low latency, high frequency trading.

[27] OFDM uses as a multi-carrier modulation method. Here a large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Orthogonal means 'at right angles'. In telecommunications this refers to two simultaneous signals that are both detectable. Hence orthogonality refers to detecting multiple data streams in the same channel and at the same time.

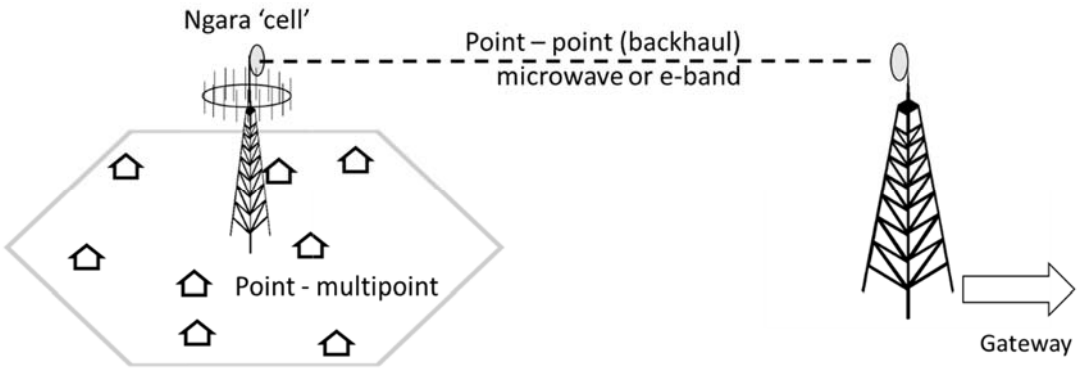


Figure 39. The basic telecommunications components of the NGARA system.

(a) (b)

Figure 40. (a) a UHF (641 MHz) user terminal (with directional Yagi antenna), in this case located in an open paddock 8.4 km from the receiver tower during the 2011 Smithton Tasmania trial (Photo extracted from CSIRO, 2011). (b) The heart of a NGARA 'cell' is the receiver tower, comprising multiple receiver antennas; this one used for the Macquarie University point-multipoint backhaul trial (3.4 GHz). (Source: https://www.csiro.au/en/Research/Technology/Telecommunications/NGARAMQtrial-2015.)

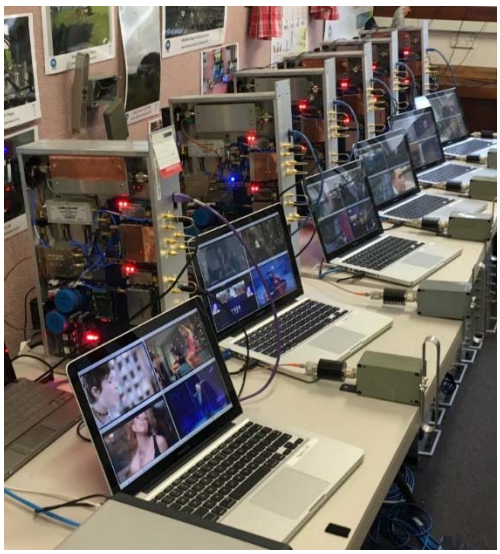


Figure 41. A group of 6 of the 12 laptop computers (the other 6 are out of sight), each streaming 4 high-definition videos via a NGARA point-multipoint link. (Photo taken at CSIRO Data61 research laboratories, Marsfield, Sydney with permission of D. Robertson).

Demonstrations of the completed integrated system consisting of the 50 Mbps symmetrical access and a 10Gbps Microwave Backhaul technology using a point to point link over 50 km (simulated) were conducted in 2012 (CSIRO 2012) and continue today.

Ultimately the NGARA system, both point-to-multipoint and point-to-point, has performance characteristics that are worth revisiting in light of potentially augmenting wireless networks currently servicing Australian producers. For example, NGARA does not exhibit the limitations experienced by mobile network clients on sector boundaries within a cell. NGARA has a greater data capacity for the same available spectral bands. In supporting point-to-multipoint links, and compared to a similar configuration involving 'single radio' microwave links, NGARA requires smaller (lighter) antennae (omni-directional antenna at the cell hub and Yagi antennae at the access points). The latency of a NGARA point-to-multipoint link is considerably less than satellite-direct links. In the case of point-to-point transmission links, the NGARA E-band link achieved the highest E-band transmission rate (5 Gbps), provided the longest E-band range (12 km, no rain) and produced unprecedented (low) latency. CSIRO have E-band designs capable of supporting up to 40 Gbps. NGARA point-to-point microwave transmission links, designed for the 30-50 km ranges are capable of providing multi-Gbps transmission rates at a cost comparable to the present ~300 Mbps (single channel) links. Through software-defined radio[28], a single NGARA radio uses all available channels, both adjacent and non-adjacent, with no performance compromises. Importantly, a single NGARA point-to-point link dish could replace a multitude of dishes operated by different network operators that are tailored to their fixed bands.

Observation: NGARA point-to-point technology could reduce the physical infrastructure demand on existing point-to-point transmission towers and provide more efficient use of available spectrum.

NGARA technology has the potential to augment existing and planned network expansion in rural and regional Australia, namely mobile networks, NBN fixed wireless and NBN Sky Muster. It is important to note that the underlying NGARA technologies are largely frequency independent. For example the Macquarie University point-to-multipoint backhaul system was a version of the point-to-multipoint access technology used in the earlier Smithton trial but at a higher frequency. In that case a NGARA user terminal was co-located with a Wi-Fi access point on the distributed end-user buildings and end users used standard Wi-Fi technology as a means of accessing the system. Ultimately NGARA offers an alternative, arguably a superior, network solution rather than a telecommunications solution.

Observation: NGARA point-to-multipoint technology could offer a 'spectrally-efficient' networking solution to complement existing telecommunications developments.

At present NGARA point-to-multipoint technologies lack a manufacturing partner (bearing in mind that NGARA has significant market opportunities overseas). The NGARA E-band backhaul technology has been licensed to Brisbane based EM Clarity Pty Ltd.

A selection of other emerging technologies that may make a difference to on-farm telecommunications

Tailor-made mobile cells

Australian mobile network operators are investing efforts into tailoring mobile cells, and in some cases handsets to extend coverage in rural areas. For example Telstra has rolled out high powered

[28] Software-defined radio (SDR) is a radio communication system where components traditionally implemented in hardware are implemented by means of software on an embedded system. SDR can to avoid the typical "limited spectrum" conditions of networks by dynamic selection of multiple channels, spread spectrum and ultra-wideband techniques that allow several transmitters to transmit in the same place on the same frequency with very little interference, and software defined antennas which adaptively "lock onto" a directional signal, so that receivers can better reject interference from other directions and hence detect fainter transmissions.

'Boomer Cells' (working on the low frequency 850 MHz band) providing extended range out to 200 km radius and 4G 'Small Cells' that provide localised coverage in selected small towns. Solar power mobile sites allow installations where power is not available and satellite backhauled micro-cells, that can be broken down into a 'few carry-bags' for helicopter transport, allow a capability to connect the most remote of locations during emergencies. Australian company ICS Industries has developed the 'cell on wheels' (COW) for deployment in emergencies and have a container and trailer based cell solutions for longer term network support (www.icsindustries.com.au).

Deployable networks for transient or moving targets

A large proportion of producers involved in this review identified the desirability of high capacity internet access while moving around their farms or to meet the demands of peak demand at fixed (although temporary) locations during certain operations. This could include cattle yard operations (for example 'marking'), harvesting or similar intensive field machinery operations and local field days. There are numerous innovations worldwide in the area of deployable or 'nomadic' networks. These are fully integrated, high capacity, portable wireless platforms. These typically include all components on a roll-on/roll-off configuration to support peak demand data traffic and even for establishing private LTE (mobile) networks (e.g. remote field camps) which seamlessly integrate into existing national LTE networks.

Virtual Fiber™ (Redline Communications, www.rdl.com) is an example of a portable wireless network capable of supporting video analytics. Innovations in multi-sector, auto-aligning antenna, effectively directional antenna) offer high capacity connectivity from a multi-sector base station (for example, located on a farm house or silo) to moving platforms (e.g. vehicles, farm machinery) within line of sight. These devices have no moving parts and the 'alignment' is achieved electronically by selectively energizing the required sector (Figure 42).

Figure 42. An example 'auto-align' MIMO terminal providing hijgh-capacity links to a central (line of sight) base station (Photo http://rdlcom.com/products/view/ras-elite**).**

Another example is FiberinMotion® Mobility (www.radwin.com) technology which offers 2-way up to 250 Mbps to moving platforms (cited up to speeds of 350 km/hr). Initially designed for providing video and data connectivity for rail, metro and ferry passengers, it is finding interest in agriculture for its ability to provide direct video access for security and for remote monitoring and control of heavy machinery (currently in use in mining). For moving vehicles it offers seamless hand-over across sectors (not unlike mobile phone handover when the handset moves from one cell to another). Again connectivity relies upon line of sight.

Voice communications over Internet and WiFi (VoWIFI)

Voice over Internet Protocol (VoIP) is the delivery of voice communications over the internet; effectively telephone calls. This well-known approach is facilitated by wired links between a telephone or computer and the gateway (the internet connection). Skype from a desktop computer is an early example of VoIP. Voice over wireless LAN (VoWLAN) is where the 'voice end' of the link is wireless (typically IEEE 802.11). VoWLAN is emerging as a viable option for areas with limited mobile coverage; and in particular voice over a Wi-Fi network to the gateway (VoWiFi) is gaining interest in Australian agriculture (The Land, 2017). In certain line of sight situations, Wi-Fi may provide connectivity over distances up to 5 km from the point of internet access. As expected, the data transmission speeds reduces with distance from the access point. With this in mind, VoWiFi is still an option for extended networks over distances from an internet access point (e.g. mobile,

fixed wireless, satellite or landline) potentially up to a few km away in line of sight conditions. As a means of extending mobile coverage on farms, voice over WLAN (including VoWiFi) is an alternative to mobile cell network picocells and femtocells, bearing in mind that VoWLAN uses a wireless internet network (typically IEEE 802.11) and the picocells and femtocells operate like a cellular network. Both Telstra and Optus are trialing VoWiFi to their mobile customers (Telstra Media 2016; IT News 2017) with a compatible device (certain models of Apple iPhone and Samsung Galaxy; 4G capable) and some form of supported fixed broadband service. With a VoWiFi product already offered in the U.K. (Vodafone UK, 2017), Vodafone have indicated they will follow suit in Australia (Computerworld, 2016)

Radio over internet (RoIP) is similar to VoIP but it augments radio communications rather than telephone calls. Ultimately RoIP is VoIP with 'push to talk' functionality afforded by radios, allowing 2-way radio communications over vast geographic areas or for linking disparate regions (for example providing coverage over multiple farms separated by distance). VoWLAN and RoIP (and ultimately RoWLAN/RoWiFi) relies upon a good internet connection from which to base the extended network. Again, this base could be located at the farm office or shed, utilizing Sky Muster, fixed wireless NBN or a bonded solution; even somewhere on a hill with a good mobile coverage. Bear in mind that in all cases a picocell or femtocell could also be set up; ultimately these are all alternatives.

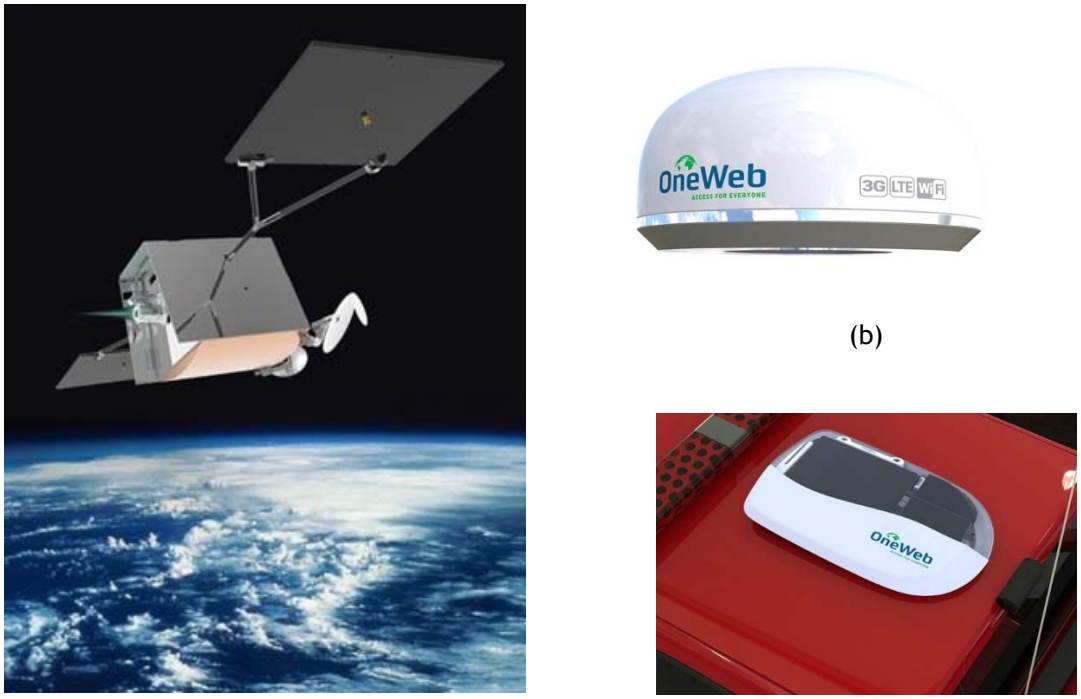
Narrow band-IoT on the mobile network

In recognition of the increasing reliance upon the mobile network to support IoT devices on farm, mobile network operators are developing network capabilities and services specifically aimed at supporting multitudes of small data packet devices. For example in 2016 Vodafone announced completion of a trial of their Narrowband Internet of Things (NB-IoT), a 4G technology aimed at Internet of Things (IoT) "by making it more efficient to connect products to the internet" (Vodafone 2016). Specifically-configured wireless access networks achieved coverage up to 30 km, a significant improvement on standard 4G services as well as the capability to penetrate obstructions such as double-brick walls. This bodes well for the cluttered environment encountered on farm landscapes. Moreover it was reported that the NB-IoT approach offers "increased scalability with up to 100,000 devices per cell and low cost of modem chipsets forecasted at less than $5." Notwithstanding the onward development of 5G, this type of innovation, which is effectively a LP Wide Area technology would significantly enhance 4G capability, while supporting the deployment of devices with extended battery life.

Observation: Mobile network innovations in narrowband communications will extend the capability of existing 4G networks, reducing, and ultimately augmenting the reliance upon 5G for supporting IoT on farms.

Low-cost LEO telecommunications satellites

The U.S. Federal Communications Commission recently approved the entrance into the telecommunications market of OneWeb (www.oneweb.world/), a company focused on mass production and deployment of telecommunications infrastructure including LEO satellites and web user terminals to facilitate internet access worldwide. Focusing on global communications coverage, OneWeb is on track to produce and launch a constellation of 648 LEO satellites. These will 'intelligently interlock' to provide seamless coverage and will provide significant reduction in latency compared to, for example, the Sky Muster NBN satellites. Mass-produced, small and low-cost user terminals, linked to the satellites will act as small cell terminals, compatible with LTE, 3G and Wi-Fi (Figure 43). Importantly, OneWeb does not aim to replace existing telecommunications networks. The system is being designed to extend these networks into rural areas. By offering what is known as layer 2 and layer 3 services, effectively supplementary network services, that can be used by any ISP or telecommunication provider to extend any network, partners effectively use the infrastructure with their current clients, devices and billing systems.



(a) (b) (c)

Figure 43. (a) Graphic of one of the proposed 648 LEO telecommunications satellites to be launched by U.S company OneWeb, (b) a user terminal for a building and (c) for a vehicle. Once linked to the LEO satellites, these act as a small cell, generating a 3G or LTE (and Wi-Fi) zone around it for an existing mobile network operator (Source: http://oneweb.world/#technology).

Increasing data speeds on copper- G.Fast and XG.fast

G.fast is a digital subscriber line (DSL) protocol standard for copper local loops shorter than 500 m, with performance targets between 150 Mbps and 1 Gbps, depending on loop length. G.fast uses time-division duplexing (TDD), as opposed to ADSL2 which uses frequency-division duplexing. Performance in G.fast systems is limited by crosstalk between multiple wire pairs (twisted pairs) in a single copper cable. In Australia, the FTTN will rely upon the existing copper network for the final stage of the connection into the premises. This last step is considered by opponents of the FFTN to potentially be a rate-determining step in achievable broadband speeds for the client. In 2015, Coomans et al. (2015) from Bell Labs, Alcatel-Lucent proposed XG.Fast, a 5th generation broadband (5GBB) technology capable of delivering 10 Gbps data rate over short twisted pair copper lines up to 130 m in length. In 2016 NBN reported delivering 8 Gbps (peak aggregate speeds) over 30 m and 5 Gbps over 70 m of twisted pair copper (NBN, 2016b). While this is still in an R&D phase, the potential to deliver broadband over existing copper infrastructure is highly relevant to rural premises, the majority of which have legacy copper connections. Admittedly, lengths of such connections are substantially greater than hundreds of metres but this innovation is nevertheless worth keeping an eye on.

High speed internet over powerlines

AT&T labs (U.S.) has developed a Radio Distributed Antenna System (RDAS) that utilizes existing powerlines. Transmitting on the 24-300 GHz frequency range (offering large bandwidth channels ~ 100 MHz), RDAS uses antennas made of low-cost plastic, along with inductive power devices which receive power from the adjacent powerlines without direct electrical connections (Figure 44) (AT&T, 2016). The RDAS will reconstruct signals that travel along or near the 'medium-voltage' wire, using the wire to guide the wave propagation (along visible line of light). It is important to note that the transmission of the signals does not occur inside the power wires as they aren't designed for (nor are capable of) transmitting at that frequency range. The power lines themselves act as a surface guide for the signal propagation through air either near ('Airwave mode') or adjacent ('Guided mode') to the wire, relying upon the so-called 'skin effect'. The concept is for the technology to be used in a mesh network design to hop along the power poles from a fibre

location (POP), until it reaches a pole closest to the end user's building. The RDAS may be then be able to transmit the signal from the terminating pole directing to an access point within sight of the terminating pole. The technology is claimed "to be able to support multi-Gbps wireless internet speeds". AT&T even propose the use of the technique for supporting 4G LTE or 5G mobile services, ostensibly by supporting the creation of a cell around a given end-point.

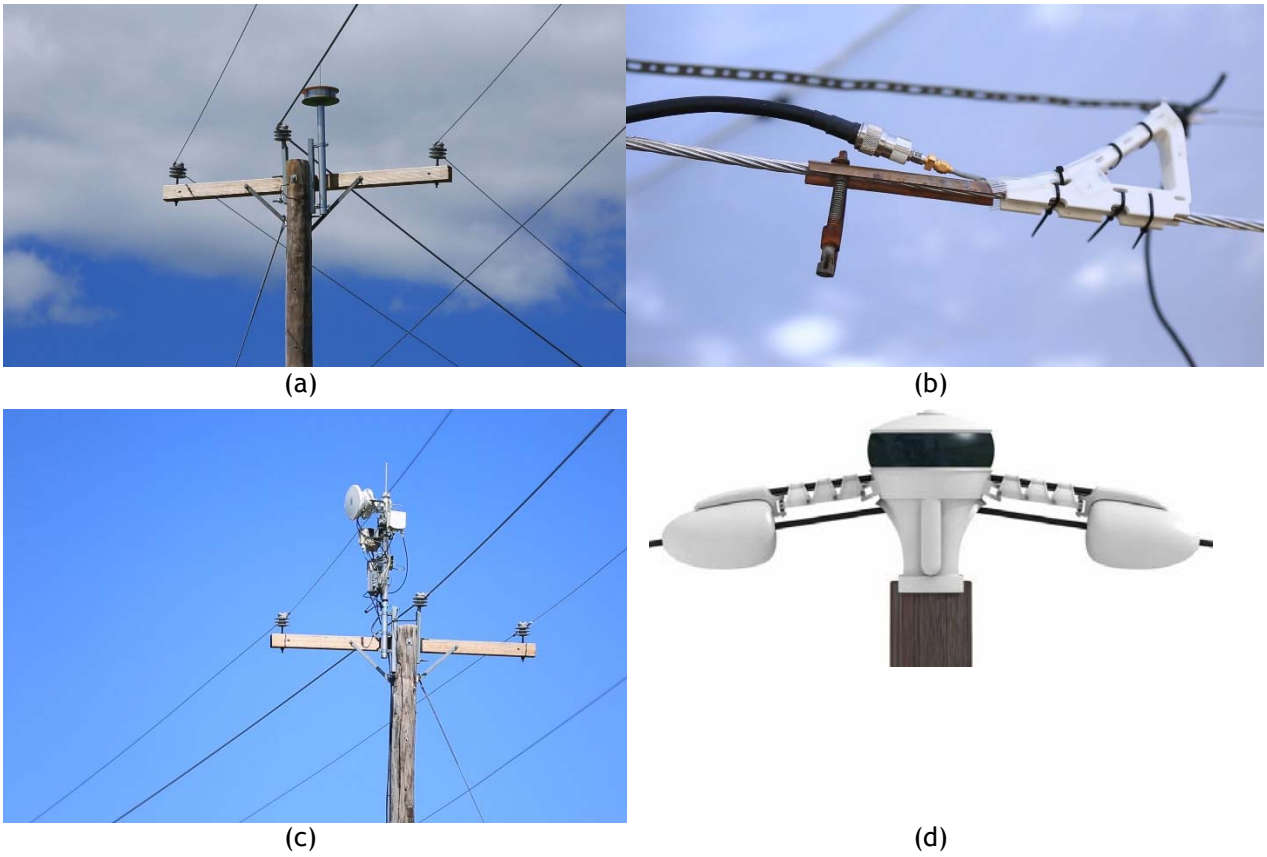


Figure 44. (a) AirGig Airwave mode transmitter, (b) guided mode transmitter, (c) internet access point and (d) a graphical representation of an AirGig network node mounted on a power line (Source: Images (a-c) AT&T (2016) and (d) www.thebroadcastbridge.com).

Remote internet access via high-altitude craft

Three high-altitude, non-satellite options are being considered as base stations supplying internet access to remote regions; one by Facebook, another by Google, and a third by Australian company Altitude Energy.

Facebook's Connectivity Lab (https://info.internet.org/en/story/connectivity-lab/) is working on solar powered, high altitude drones (Aquila Unmanned Aircraft), with a wingspan of 42 m, and designed to operate at an altitude of 60,000 ft. Communication is planned to be via IR laser. The unmanned, autonomous aircraft was launched on its first test flight on June 28th, 2016, in Arizona (Figure 45), and achieved 96 minutes flight, before crashing during landing.

Figure 45. The Aquila high altitude drone, destined to provide internet coverage to remote regions during its maiden test flight in 2016 (Source: Facebook).

Google's "Project Loon" (https://x.company/loon/) seeks to develop high altitude balloons carrying, in effect, solar powered cell towers. Designed to operate at altitudes 20 km, the balloons will operate as a constellation and in trials to date have achieved 190 days aloft. Machine learning and laser ranging will be used to position balloons to achieve desired coverage. A wireless internet signal is transmitted up to the nearest balloon from an on-ground telecommunications partner, relayed across the balloon network, and then sent back down in rural and remote areas. Each balloon has a coverage area of approximately 5000 sq km. Loon balloons navigate by moving up or down into different wind patterns travelling in different directions. A single balloon trial in 2016 achieved a loitering[29] time of 14 weeks, requiring more than 20,000 altitude adjustments. Inter-balloon communications facilitated by laser beams recently achieved 155 Mbps optical connection between two balloons more than 100 km apart. Numerous trials have been conducted during 2013 – 2016 (Figure 46) although little has been published outside of social media posts and newspaper articles.

Figure 46. A Project Loon balloon during testing in New Zealand in 2013 (Source: http://www.gsmnation.com/blog/2013/06/21/a-guide-to-project-loon/).

Altitude Energy is an Australian company that specializes in the use of tethered quad-rotorcraft platforms functioning as elevated mobile phone-towers or as generators of pollution-free electricity (www.altitudeenergy.com.au). These units are designed to remain aloft in the very powerful and persistent winds above Australia, while riding gyroplane-style (Figure 47) and simultaneously generating electricity for the transmission/receipt of data. In mobile phone-tower mode about 10 of these platforms, tethered at an altitude of approximately 6 km, would cover all regions of Australia in a direct line of sight. In the current IoT environment these platforms can stay aloft

[29] Loitering refers to maintain station in a single spot

unpowered from the ground for around 96% of the year. For the remaining 4% of the year electrical power can be supplied from the ground, via the electro-mechanical tether, to allow units to remain aloft as elementary helicopters.

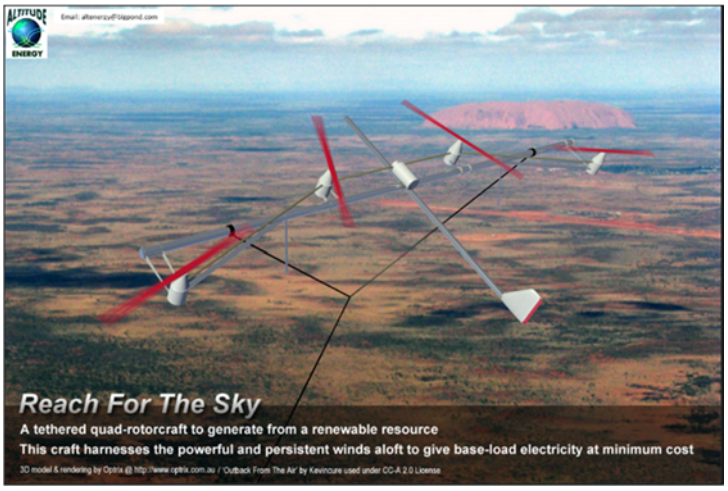


Figure 47. A graphic depicting the high-altitude, tethered quad-rotor platform that could serve as a mobile data communications platform (Source: Brian Roberts, Altitude Energy).

Mobiles without mobile networks- Serval

Serval, a project led by Flinders University is developing technology that allows mobile phones to communicate with each other through their Wi-Fi (and Bluetooth) interfaces, without the need of a mobile phone network (Simonite, 2013). The supporting app allows the user to make phone calls, send secure text messages and share files. The user is able to keep using their existing phone number on the mesh. The system relies upon open source, free software, is carrier independent, and automatically encrypts mesh phone calls and mesh text messages. Text messages and other data can be communicated using a store and forward system called 'Rhizome communication' over unlimited distances (via Wi-Fi routers) and without a stable live mesh connection between all participants (Figure 48). A "mesh extender" is also being developed which establishes a short range Serval mesh over Wi-Fi and joins it with other more distant meshes by linking to other mesh extenders over packet radio operating in the public park 915 MHz band.

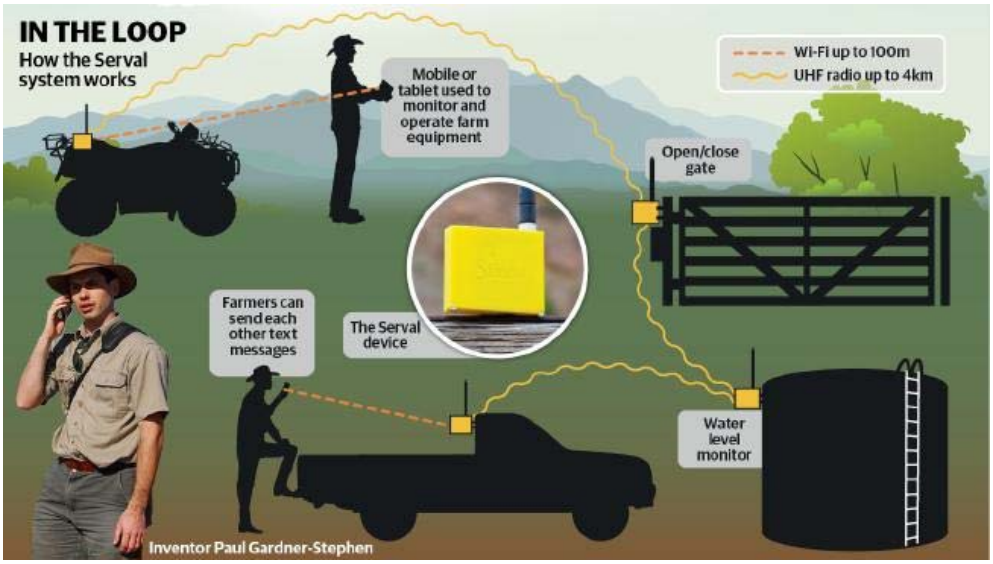


Figure 48. Schematic diagram of the Serval system showing the interaction between mobile phones (Wi-Fi) and UHF links to establish a mobile phone-mobile phone link (Source: http://www.weeklytimesnow.com.au/news/national/data-drought-mobile-power-without-tower/news-story/97865c651ec46867b4abbdb2273058ed**).**

Powering IoT sensors from the mobile network

Recently Australian researchers announced progress towards small sensor devices capable of extracting power from the mobile network, ostensibly extending battery life on those devices (Liu, 2016; Gizmodo, 2016). Although many years from realisation, the results (currently based on a desktop analysis) found it was “feasible” to use energy harvested from mobile phone base stations, with communication delays typically limited to less than a few hundred milliseconds.

Towards more energy efficient Wi-Fi

In order for Wi-Fi devices to communicate, two radio transmitters are required; one of at the plug-in device at the network end and the other at the roaming (or remote) device. The data information is then encoded on the transmitted carrier wave. Kellog et al. (2016) have demonstrated the use of passive Wi-Fi whereby the roaming device effectively communicates back to the plug-in device on the backscattered carrier wave rather than having to broadcast its own carrier. This method is already used in RFID tags where the signal is backscattered back to the dedicated 900 MHz RFID reader (for example for reading cattle ear tags). However backscatter as a basic communications mechanism has only been limited to RFID devices. In this recent work, Kellog et al (2016) duty cycled sensors that periodically transmit data using Bluetooth Low Energy and ZigBee protocols respectively. The researchers found that these devices which typically transmit data packets at a rate of 100 ms to 900 ms have a battery life of 3 months to 3 years, respectively (coin cell battery). They demonstrated that by replacing the BLE/ZigBee transmitters with an estimated power consumption 35 mW in ‘transmit mode’ with a passive Wi-Fi system consuming only 15 mW, it could extend the battery life in excess of 10 years. Whilst the devices in this work were tested in closed rooms (promoting backscatter) and over a limited range of <1 - ~ 8 m, this is nonetheless potentially applicable to ‘enclosed’ agricultural operations such as aquaculture, cattle feedlots and those reliant upon animal housing sheds such as poultry and pork.

New standards supporting Wi-Fi- HaLow

A new IEEE standard known as Wi-Fi HaLow (802.11ah), is being developed to extend the range of Wi-Fi connectivity, supporting extended signal range, power efficiency and scalability as typically required by rural Wi-Fi networks (IEEE, 2017b). HaLow will operate on the ISM 900 MHz frequency band as it has superior range and penetration capability compared to 2.4 and 5 GHz based systems. By utilizing 802.11ah access points, users will be able to extend the reach of their wireless signal with greater power efficiency. HaLow will also provide support for IoT applications as it is designed to work with relatively low cost battery powered sensors. With a minimum data rate of 150 Kbps, small, short-burst packets which result in limited power on-time for sensors increasing battery life and power efficiency. The 802.11ah standard will be a direct competitor to the open standard ZigBee technologies (utilizing IEEE 802.15.4) as well as the proprietary Z-wave protocol typically used for home automation.

Strategic Partnerships in the recent News

Coverage

There are many instances where strategic partnership between consumers of connectivity and/or a consumer and provider have been formed to share resources and costs. One recent example is Harrington Systems Electronics (HSE) (http://www.harringtonsystems.com.au/). HSE specializes in RFID and remote monitoring (including camera) systems for producers. The Harrington family also run Olga Downs Station, 50 km north of Richmond (Qld), which is also the base of the HSE business. Facing limited and unreliable connectivity, HSE established a 46 km-long wireless link (Figure 49) and teamed up with the Richmond Shire Council to share the costs of connecting into the optical fibre cable running from Townsville through to Mount Isa (ABC Rural 2016). For the Richmond Shire Council, the Harrington's internet service provides an alternative to the existing sole network operator, and the new internet tower (Figure 50) will be set to connect a group of other cattle stations in the Richmond area.

Figure 49. The wireless tower set up by HSE in partnership with Richmond Shire Council to provide internet access to nearby cattle stations. (Source: ABC Rural, 2016)

Spectrum

Red Wifi (www.redwifi.com.au) is an independent telecommunications service carrier and focusses on delivering fast internet to rural clients; if necessary working on all components from backhaul through to access points, bonding and cloud services including web hosting. Red Wifi are currently in negotiations with Vodafone around sharing some unused spectrum (Red Wifi, 2017) and plans are currently underway to move to a 'proof of concept' stage.

Additional Information

Telecommunications Industry Ombudsman

The Telecommunications Industry Ombudsman (TIO) is an independent dispute resolution body for small business and residential consumers in Australia who have unresolved complaints about their telephone or internet services. The TIO can investigate breaches of the Telecommunications Consumer Protections Code (http://www.acma.gov.au/Industry/Telco/Reconnecting-the-customer/TCP-code/the-tcp-code-telecommunications-consumer-protections-code-acma), an industry code developed by the peak industry body, Communications Alliance (http://www.commsalliance.com.au/) and registered with the Australian Communications and Media Authority (ACMA). The code sets minimum standards for telecommunications providers in their interactions with customers. This includes standards for advertising services, contracts, billing, sales techniques and redress mechanisms.

Observation: Although the TIO receives a large proportion of complaints around service quality, the TIO does not have the power to influence the way network operators manage their networks

Relevant Peak Bodies

Australian Communications Consumer Action Network (www.accan.org.au)

The Australian Communications Consumer Action Network (ACCAN) primarily seeks to represent consumers on communications issues including 'telecommunications, broadband and emerging new services'. A key component of ACCAN's activities is in keeping consumers abreast of key issues allowing them to make better choices on products and services. Membership is drawn from policy makers, government and industry.

Communications Alliance (www.commsalliance.com.au)

The Communications Alliance provides a forum for the Australian communications industry to contribute to policy development and debate. Membership of Communications Alliance is drawn from a wide cross-section of the communications industry, including service providers, vendors, consultants and suppliers as well as business and consumer groups. Through a 'Works Program' members contribute to the future direction of the industry and participate in governing its operation. Recent examples relevant to on-farm telecommunications includes assumption of responsibility for the Industry Codes and core responsibilities of the Internet Industry Association (IIA), VoIP information packages and customer guides (particularly relevant to at-home/office broadband capability) and a range of activities relating to the transition over to the NBN (http://www.commsalliance.com.au/Activities/)

Regional, Rural and Remote Communications Coalition (www.accan.org.au/rrrc-coalition)

The Regional, Rural and Remote Communications Coalition (RRRCC) is a Coalition of advocacy groups including National Producers Federation, Country Women's Association (NSW), Australian Communications Consumer Action Network (ACCAN), AgForce Queensland and the Isolated Children's Parents' Association. The RRRCC was formed in 2016 to provide a coordinated 'voice' for consumers and small businesses (including producers) around telecommunications, ostensibly to ensure 'reliable and quality' telecommunications service'. The arguments are framed around tackling the 'data drought'. The Coalition are working towards achieving five 'fundamental outcomes', centred around 'equitable connectivity' for regional and remote consumers (RRRC Web release, 2016):

1. A universal service obligation that is technology neutral and provides access to both voice and data;

2. Customer service guarantees and reliability measures to underpin the provision of voice and data services and deliver more accountability from providers and nbn;
3. Long term public funding for open access mobile network expansion in rural and regional Australia;
4. Fair and equitable access to Sky Muster satellite services for those with a genuine need for the service, and access which reflects the residential, educational and business needs of rural and regional Australia; and,
5. Fully resourced capacity building programs that build digital ability, and provide learning and effective problem solving support for regional, rural and remote businesses and consumers.

Internet of things Alliance Australia- IoTAA (www.iot.org.au)

The IOT Alliance Australia (IoTAA) is the primary IoT body in Australia. Hosted by the University of Technology Sydney (UTS), IoTAA was created in 2015 as part of Communications Alliance (www.commsalliance.com.au) and in 2016 became a separate not-for-profit entity.

The IoTAA comprises members from IoT service providers, vendors, consultants and suppliers, business, universities and consumer groups. As a peak body IoTAA seeks to accelerate IoT innovation and adoption by: Activating and supporting collaboration across industry, government, research and communities; Promoting enabling, evidence-based policy and regulation; and Identifying strategic opportunities for economic growth and social benefit (www.iot.org.au). With particular relevance to on-farm telecommunications opportunities, and through its 'Workstream 4', IoTAA is working with the ACMA to develop and maintain a framework for considering IoT spectrum needs, maintain active IoT spectrum community information flows and provide policy and regulatory advice to government on IoT spectrum (http://www.iot.org.au/workstreams/).

References

ABC Rural (2016) Media: “High speed internet for Queensland's Richmond graziers”. http://www.abc.net.au/news/rural/2016-12-21/high-speed-internet-for-richmond-graziers/8134462?section=technology. Accessed June 2017.

ABC Rural (2017) Media: “NBN to double Sky Muster download limits in bid to end rural 'data drought'”. http://www.abc.net.au/news/2017-06-27/rural-nbn-users-told-to-expect-plans-with-higher-data-caps/8655718. Accessed June 2017.

ACCAN (2015) “Regional Telecommunications Review 2015; Submission by the Australian Communications Consumer Action Network 15 July 2015”. http://consumerlaw.gov.au/files/2016/07/Australian_Communications_Consumer_Action_Network.pdf. Accessed November 2016.

ACCC (2016a) “Competition in the Australian telecommunications sector. Price changes for telecommunications services in Australia. (February 2016)”. 123 pages. https://www.accc.gov.au/system/files/ACCC%20Telecommunications%20reports%202014%E2%80%9315_Div%2011%20and%2012_web_FA.pdf. Accessed June 2017.

ACCC (2016b) “Domestic mobile roaming declaration inquiry. Draft decision”. (Australian Competition and Consumer Commission) May 2017. 91 pages. http://www.accc.gov.au/system/files/D16%20145458%20%20MACE%20-%20MR%20Declaration%20Inquiry%20-%20Discussion%20paper%20-%20AMENDED%20PUBLISHED%20VERSION%20-%2027%20October%202016.pdf. Accessed January 2017.

ACCC (2016c) “What you need to know: How the ACCC’s domestic mobile roaming inquiry affect you. A guide for consumers (Australian Competition and Consumer Commission) October 2016”. 2 pages. http://www.accc.gov.au/system/files/D16%20145458%20%20MACE%20-%20MR%20Declaration%20Inquiry%20-%20Discussion%20paper%20-%20AMENDED%20PUBLISHED%20VERSION%20-%2027%20October%202016.pdf. Accessed January 2017.

ACCC (2017) Domestic mobile roaming declaration inquiry. Discussion Paper. (Australian Competition and Consumer Commission) October 2016. 51 pages. https://www.accc.gov.au/system/files/Domestic%20mobile%20roaming%20inquiry%20draft%20decision%20May%202017.pdf. Accessed June 2017.

ACCC Broadband (2017) “Broadband performance monitoring & reporting program” https://www.accc.gov.au/regulated-infrastructure/communications/monitoring-reporting/broadband-performance-monitoring-reporting-program. Accessed June 2017.

ACMA (2007) “Communications Infrastructure and Services Availability in Australia 2006–07”, (Australian Communications and Media Authority: Commonwealth of Australia), ISBN 0 642 78353 5, 40 pages.

ACMA (2015) “The ACMA’s long-term strategy for the 803–960 MHz band. Decision paper NOVEMBER 2015” (Commonwealth of Australia: Australian Communications and Media Authority). 49 pages. http://www.acma.gov.au/theACMA/review-of-the-803-960-mhz-band. Accessed April 2017.

ACMA (2016) http://www.acma.gov.au/Industry/Telco/Carriers-and-service-providers/Licensing/carriers-carriage-providers-licensing-i-acma. Accessed November 2016.

ACMA (2016b), http://acma.gov.au/Citizen/Internet/Internet-services/Wireless-local-area-networks/wireless-lans-in-the-24-ghz-band-faqs, Accessed November 2016.

ACMA (2016c) http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Class-licences/shortrange-spreadspectrum-devices-fact-sheet, Accessed November 2016.

ACMA (2016d) http://acma.gov.au/Industry/Telco/Carriers-and-service-providers/Universal-service-obligation/uso-services-universal-service-obligation-acma, Accessed December 2016.

ACMA (2016e) "Future use of the 1.5 GHz and 3.6 GHz bands. Initial investigation of the 1427–1518 MHz and 3575–3700 MHz bands for mobile broadband services" Discussion paper October 2016 (Commonwealth of Australia: Australian Communications and Media Authority). 64 pages. http://www.acma.gov.au/theACMA/future-use-of-the-1_5-ghz-and-3_6-ghz-bands. Accessed April 2017.

ACMA (2016f) "Communications Report 2015-2016" November 2016 (Commonwealth of Australia: Australian Communications and Media Authority). 154 pages. http://www.acma.gov.au/~/media/Research%20and%20Analysis/Report/pdf/ACMA%20Communications%20report%202015-16%20pdf.pdf. Accessed April 2017.

ACMA (2017) "Applicant information package: 700 MHz spectrum—unsold lots auction". http://www.acma.gov.au/Industry/Spectrum/Spectrum-projects/700-MHz-band/applicant-information-package-700-mhz-spectrum-unsold-lots-auction. Accessed April 2017.

ACMA (2017b) "Sold! ACMA completes high-value spectrum auction". Media Release. http://www.acma.gov.au/theACMA/Newsroom/Newsroom/Media-releases/sold-acma-completes-high-value-spectrum-auction. Accessed April 2017.

AFI (Australian Farm Institute) (2016) "The implications of Digital Agriculture and Big Data for Australian Agriculture" (Australian Farm Institute) ISBN 978-1-921808-38-8. 84 pages.

AGDCA (2016) Mobile Black Spot Program, https://www.communications.gov.au/what-we-do/phone/mobile-services-and-coverage/mobile-black-spot-program, Accessed December 2016.

Ag Excellence Alliance (2014) "Smart Phone Apps for Smart Farmers V2". (Ag Excellence Alliance Incorporated). https://bzav2en1q03dckdk2kr1c412-wpengine.netdna-ssl.com/wp-content/uploads/2014/11/Smartphone-Apps-for-Smart-Farmers-v21.pdf. 229 pages. Accessed June 2017.

Agriculture Technology Survey (2015) "Agriculture technology micro-survey results 2015", (GrainGrowers) http://www.graingrowers.com.au/policy/micro-surveys. Accessed December 2016.

Air-stream Wireless (2016) "Strategic Plan". http://www.air-stream.org.au/about. Accessed November 2016.

AT&T (2016) Media Release: "AT&T Labs' Project AirGig Nears First Field Trials for Ultra-Fast Wireless Broadband Over Power Lines". http://about.att.com/newsroom/att_to_test_delivering_multi_gigabit_wireless_internet_speeds_using_power_lines.html. Accessed June 2017.

Australian Fisheries Management Authority (2017) "Electronic Monitoring Program". http://www.afma.gov.au/monitoring-enforcement/electronic-monitoring-program/. Accessed June 2017.

Australian Producers (2017) "The National Producers' Federation (NFF) and the Rural Doctors Association of Australia (RDAA) today called for a five-star safety rating system to be applied to quad bikes. Media Release. https://producers.org.au/content/nff/en/news-updates/nff-news/producers-and-doctors-call-for-quad-bike-five-star-safety-rating-system-27032017.html. Accessed March 2017.

Australian Radiofrequency Spectrum Plan (2013) "Australian Radiofrequency Spectrum Plan 2013- including General Information", Commonwealth of Australia (Australian Communications and Media Authority) 2013. 209 pages.

Bland Shire Council (2015) “Submission to 2015 Regional Telecommunications Review”. https://www.communications.gov.au/sites/g/files/net301/f/Bland%20Shire%20Council%20-%20Public%20Submission%20RTIRC%202015.pdf. Accessed January 2017.

Bughin, J., Chui, M. & Manyika, J. (2015) “An executive’s guide to the Internet of Things”. McKinsey Quarterly (McKinsey and Co).

Carvalho de Gouveia, F., & Magedanz, T. (2009) “Quality of service on telecommunications networks”. In “Telecommunications Systems and Technologies” Volume 2. (Editor: Paolo Bellavistaaytexas) (Encyclopedia of Life Support systems EOLSS). 412 pages

Channelnews (2017) “Sky Muster Problems: NBN Co considers plan for third satellite”. https://www.channelnews.com.au/sky-muster-problems-nbn-co-considers-plan-for-third-satellite/. Accessed June 2017.

Commonwealth of Australia (2009) “Phoning home– inquiry into agricultural innovation”, House of Representatives Standing Committee on Committee on Communications Report. (Commonwealth of Australia). ISBN 978 0 642 79166 5 (Printed version), ISBN 978 0 642 79167 2 (HTML version) (HTML version), Chapter 2: 18 pages.

Commonwealth of Australia (2016) “Smart farming – inquiry into agricultural innovation”, House of Representatives Standing Committee on Agriculture and Industry Report. (Commonwealth of Australia). ISBN 978-1-74366-514-5 (Printed version), ISBN 978-1-74366-515-2 (HTML version), 138 pages.

Computerworld (2016) https://www.computerworld.com.au/article/597329/vodafone-launch-voice-over-wifi-shortly-ceo-says/. Accessed June 2017.

Computerworld (2017) https://www.computerworld.com.au/article/618530/nbn-rolls-147-fixes-sky-muster-service/. Accessed June 2017.

Coomans, W., Moraes, R.B., Hooghe, K., Duque, A., Galaro, J., Timmers, M., van Wijngaarden, A.J., Guenach, M. and Maes, J. (2015) “XG-FAST: the 5th generation broadband”. IEEE Communications Magazine, 53(12), pp.83-88.

CSIRO (2011) “CSIRO NGARA Wireless broadband access. Field trial, Smithton, Tasmania- technical results” (CSIRO Australia), 8 pages.

CSIRO (2012) “CSIRO NGARA Rural Wireless Broadband Program, CSIRO ICT Centre Final General Report to the Science and Industry Endowment Fund March 2012” (CSIRO ICT Centre). 46 pages. http://www.sief.org.au/Documents/RP/NGARAFinalGeneralReport.pdf. Accessed May 2017.

DDSP Revocation (2008) https://www.legislation.gov.au/Details/F2008L04701/Explanatory%20Statement/Text. Accessed December 2016.

Dines, G., Henderson, C. and McRae, S. (2013) “Sugarcane harvest and transport management: A proven whole-of-systems approach that delivers least cost and maximum productivity”. International Sugar Journal 115(1376):550-554.

Dohler, M. (2016) “Feature Issue on 5G”. Transactions on Emerging Telecommunications Technologies, 27: 1150–1151.

Eckelmann, C. (2017) Personal communications and http://wysps.net.au/. Accessed February 2017.

Ericsson (2016) “Ericsson Mobility Report- On the pulse of the networked society, June 2016”. https://www.ericsson.com/res/docs/2016/ericsson-mobility-report-2016.pdf. Accessed April 2017.

Ericsson (2016b) “Future use of the 1.5GHz and 3.6GHz bands- ACMA-Dec 2016”. Submission to ACMA Consultation on Future use of 1.5 GHz and 3.6 GHz bands.

http://www.acma.gov.au/~/media/Spectrum%20Transformation%20and%20Government/Issue%20for%20comment/IFC%2025%202016/Ericsson%20Australia%20-%20submission%20pdf.pdf. Accessed April 2017.

Evans, D. (2011) "The Internet of Things. How the next evolution of the internet is changing everything". Cisco Internet Business Solutions Group (IBSG) White Paper, 11 pages. http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf. Accessed October 2016.

Freyens, B.P. & Loney, M. (2011a) "Projecting Regulatory Requirements for UHF White Space," in Wireless Networks in the TV White Space: Concepts, Techniques and Applications". R. A. Saeed and S. J. Shellhammer (Eds), (Taylor & Francis/CRC Press), 509 pages.

Freyens, B. & Loney, M. (2011b) "Opportunities for white space usage in Australia". In Proceedings of the 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE 2011), 28 February - 3 March 2011, doi: 10.1109/WIRELESSVITAE.2011.5940841. Accessed June 2017.

Fusion Broadband (2017) "Bonded Hybrid". http://fusionbroadband.com.au/newfbbsite/wp-content/uploads/2016/09/Fusion-Bonded-Hybrid-Service-Guide.pdf. Accessed May 2017.

GSMA (2017) "International roaming explained". http://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Africa-International-roaming-explained-English.pdf. Accessed January 2017.

Gizmodo (2016) "Australian breakthrough: Harvesting renewable energy from mobile base stations. Media Release: www.gizmodo.com.au/2016/07/australian-breakthrough-harvesting-renewable-energy-from-mobile-base-stations/#4Mxvgv5T8HZUrIww.99. Accessed June 2017.

Graham, J. (2016) "Rural Communications Infrastructure- Options to improve rural connectivity and harness opportunities that this creates", Nuffield Scholarship Report (GRDC Australia), 38 pages.

Harrison, K., Mishra, S.M. & Sahai, A. (2010) "How much white-space capacity is there?" In Proceedings of the IEEE Symposium on New Frontiers in Dynamic Spectrum 2010. Pages 1-10.

Heires, K. (2015) "The rebirth of mesh networks". Risk Management. 62 (8): 38-43.

IEEE (2017)
http://standards.ieee.org/findstds/standard/wired_and_wireless_communications_all.html. Accessed January 2017.

IEEE (2017b) "Official IEEE 802.11 Working Group project timelines- 2017-05-15". http://www.ieee802.org/11/Reports/802.11_Timelines.htm. Accessed June 2017.

International Direct Dial (2017). http://www.idd.com.au/mobile-providers.php. Accessed January 2017.

IOTA (2016) "Spectrum available for IoT" (Work Stream 4 of the Internet of Things Alliance Australia). http://www.iot.org.au/resources/. Accessed May 2017.

IT News (2017) https://www.itnews.com.au/news/optus-pushes-ahead-with-voice-over-wi-fi-448881). Accessed June 2017.

Jackson (2000)
http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Publications_Archive/archive/uso. Accessed December 2016.

Kaur, J. P., Kaur, R., & Mann, G. S. (2016) "Performance Analysis of ZigBee Mesh Networks Under Nodes Failure". In Proceedings of the International Conference on Recent Cognizance in Wireless Communication & Image Processing (Springer India). 589-598.

Kellogg, B., Talla V., Gollakota, S. & Smith, J.R. (2016) "Passive Wi-Fi: Bringing Low Power to Wi-Fi Transmissions". Published online (University of Washington) http://passivewifi.cs.washington.edu/files/passive_wifi.pdf. Accessed May 2017

Lamb, D. (2013) "Game changer: The role of broadband connectivity in Australian farms and why we need to get this right". Papers/2013/02/Game-changer- The-role-of-broadband-connectivity-in-Australian Agriculture. http://www.grdc.com.au/Research-and-Development/GRDCUpdate. Accessed November 2015.

Lamb, D.W. (2015) "Agricultural Innovation Submission 11, Smart farming – inquiry into agricultural innovation", House of Representatives Standing Committee on Agriculture and Industry. 12 pages http://www.aph.gov.au/Parliamentary_Business/Committees/House/Agriculture_and_Industry/Agricultural_innovation/Submissions. Accessed January 2017.

Liu, W., Zhou, X., Durrani, S., Mehrpouyan, H., & Blostein, S. D. (2016) "Energy harvesting wireless sensor networks: Delay analysis considering energy costs of sensing and transmission". IEEE Transactions on Wireless Communications, 15(7): 4635-4650.

LORA Alliance (2017) https://www.lora-alliance.org/What-Is-LoRa/Technology. Accessed May 2017.

MBSP1 (2014) "Mobile Black Spot Programme, Round 1 Guidelines Version 1.1", (Commonwealth of Australia), 37 pages. https://www.communications.gov.au/documents/mobile-black-spot-programme-round-1-guidelines. Accessed February 2017.

MBSP2 (2016) "Mobile Black Spot Programme, Round 2 Guidelines Version 1.1" (Commonwealth of Australia), 39 pages. https://www.communications.gov.au/documents/mobile-black-spot-programme-round-2-guidelines. Accessed February 2017.

McCown (2002) "Changing systems for supporting producers' decision: problems, paradigms and prospects", Agricultural Systems, 74: 179-220.

MobileNetworkGuide (2016) http://www.mobilenetworkguide.com.au/mobile_phone_networks.html. Accessed December 2016.

NBN (2010) "National broadband network implementation study". (Department of Broadband, Communications and the Digital Economy, Canberra, A.C.T). 534 pages. http://nla.gov.au/nla.arc-119989. Accessed June 2017.

NBN (2016) "Fair Use Policy", 7 pages. http://www.nbnco.com.au/content/dam/nbnco2/documents/sfaa-wba2-product-catalogue-fair-use-policy_20160407.pdf. Accessed June 2017.

NBN (2016b) Media Release: "nbn delivers 8Gbps over copper lines on XG.FAST trial". http://www.nbnco.com.au/corporate-information/media-centre/media-releases/nbn-delivers-8Gbps-over-copper-lines-on-XGFAST-trial.html. Accessed June 2017.

NNN Co (2017) "LoRa Technology: Ecosystem,Applications and Benefits" Whitepaper. https://www.nnnco.com.au/wp-content/uploads/2017/05/LoRa_technology_Whitepaper.pdf. Accessed June 2017.

NSW Producers (2014) "Telecommunications Survey Results July 2014", 10 pages. https://www.nswproducers.org.au/__data/assets/pdf_file/0006/37761/Survey-Report-Final.pdf. Accessed January 2017.

Noor, N. M., & Zulkifli, C. Z. (2016) "Using embedded active RFID and wireless mesh networks in agriculture". Electronics World. 122(1961): 34-37.

Ojha, T., Misra, S., & Raghuwanshi, N. S. (2015) "Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges". Computers and Electronics in Agriculture. 118: 66-84.

Optus (2016) Submission in response to ACCC "Discussion Paper Domestic Mobile Roaming Declaration Inquiry" (Public Version) November 2016. 30 pages. http://www.accc.gov.au/system/files/Optus_0.PDF. Accessed January 2017.

Optus (2017) http://www.optus.com.au/shop/mobile/network/coverage. Accessed January 2017.

Phone.com (2017) "How Much Bandwidth Do I Need for VOIP?" https://www.phone.com/2014/10/18/much-bandwidth-need-voip/. Accessed May 2017.

Pradhan, N. L., & Wood, J. (2012) "Broadcasting video over the Cellular network and the Internet". In Proceedings of the Annual Technical Conference & Exhibition, SMPTE 2012. (Society of Motion Picture and Television Engineers). 1-6.

Productivity Commission (1999) "International Benchmarking of Australian Telecommunications Services", Research Report, AusInfo, Melbourne, March. (Commonwealth of Australia 1999) ISBN 0 646 33589 8, 361 pages.

Productivity Commission (2015) "Public Safety Mobile Broadband", Research Report, Commonwealth of Australia 2015) ISBN 978-74037-579-5, 407 pages.

Productivity Commission (2016a) "Telecommunications Universal Service Obligation, Productivity Commission Issues Paper June 2016". 30 pages. http://www.pc.gov.au/inquiries/completed/telecommunications/issues/telecommunications-issues.pdf. Accessed May 2017.

Productivity Commission (2016b) "Telecommunications Universal Service Obligation, Productivity Commission Draft Report November 2016". 28 pages. http://www.pc.gov.au/inquiries/completed/telecommunications/draft/telecommunications-draft-overview.pdf. Accessed May 2017.

QuadWatch (2016) "Safe Work Australia ATV fatalities". http://www.safeworkaustralia.gov.au/sites/swa/whs-information/agriculture/quad-watch/pages/quad-bike-fatalities. Accessed December 2016.

Regional Telecommunications Review (2015) Commonwealth of Australia, 66 pages.

Red Wifi (2017) Media "Big telco makes Red WiFi an offer". https://www.chinchillanews.com.au/news/big-telco-makes-red-wifi-an-offer/3140178/. Accessed February 2017.

Roberts, K. and McIntosh, G. (2012) "Use of mobile devices in extension and agricultural production- a case study" Proceedings of the 16th Australian Agronomy Conference (The Regional Institute Online Publishing). http://www.regional.org.au/au/asa/2012/precision-agriculture/8224_robertsk.htm. Accessed May 2017.

RRRC Web release (2016) "New Coalition formed to end the data drought" http://www.producers.org.au/content/nff/en/news-updates/nff-news/data-drought-coalition-launch-301116.html. Accessed December 2016.

Salim, R, Mamun, S.A.K. & Hassan, K., (2015) "Role of communication technologies in broadacre agriculture in Australia: an empirical analysis using panel data", Australian Journal of Agricultural and Resource Economics, 59, pp. 1–22.

Shephard, S (2011) CISCO Blog http://blogs.cisco.com/cle/the-most-complex-machine-ever-built. Accessed January 2017.

Simonite, T. (2013) “Build Your Own Internet with Mobile Mesh Networking” MIT Technology Review. https://www.technologyreview.com/s/516571/build-your-own-internet-with-mobile-mesh-networking/. Accessed June 2017.

SPRFMO (2015) “Australia’s electronic monitoring program”. Proceedings of the 3rd Meeting of the Scientific Committee, South Pacific Regional Fisheries Management Organisation, Port Vila, Vanuatu 28 September - 3 October 2015. Paper SC-03-30. 29 pages.

StartupAUS (2016) “Powering Growth: Realising the potential of AgTech for Australia”. 68 pages. https://startupaus.org/resources/agtech/. Accessed November 2016.

Sunding, D., Rogers, M. & Coleman, B. (2016) “The Farmer and the Data:
How Wireless Technology is Transforming Water Use in Agriculture”. (The Brattle Group Inc.). 36 pages.

Taylor, K., Lamb, D.W., Griffiths, C., Falzon, G., Lefort, L., Gaire, R., Compton, M., Trotter, M. & Wark, T. (2013) “Farming the Web of Things”, IEEE Intelligent Systems (ISSN 1541-1672), 28 (6): 12-19.

Telstra (2016) “Response to the ACCC’s Discussion Paper on the declaration of a wholesale domestic mobile roaming service”, Submitted to “Discussion Paper Domestic Mobile Roaming Declaration Inquiry” (Public Version) November 2016. 130 pages.
http://www.accc.gov.au/system/files/Telstra%20main%20submission1_0.PDF. Accessed January 2017.

Telstra Media (2016) Media Release: https://www.telstra.com.au/coverage-networks/mobile-technology. Accessed June 2017.

Telstra (2017). https://www.telstra.com.au/coverage-networks/our-coverage. Accessed January 2017.

Telstra Exchange (2016) https://exchange.telstra.com.au/2016/09/20/reimagining-future-5g-first-live-trial-australia/. Accessed December 2016.

Telecommunications (Act 1999).
http://www.austlii.edu.au/au/legis/cth/consol_act/tpassa1999620/. Accessed December 2016.

The Land (2017) “Controlling the Farm”. Supplement March 2017, Article “Better Connectivity key for maximizing on-farm progress”, 8.

The Things Network (2017) “LoRaWAN” https://www.thethingsnetwork.org/wiki/LoRaWAN/Home. Accessed May 2017.

TPG Internet (2017) Media: www.theaustralian.com.au/business/technology/tpg-telecom-pays-13bn-in-spectrum-auction/news-story/072b7f7885b8c4b2991601f9458496d3. Accessed May 2017.

Tucker, R. (2017) “The Tragedy of the NBN”. Australian Journal of Telecommunications and the Digital Economy, 5(1), 116.

UberSignal (2017) “Field test mode: What it is and how to enable it on your phone”.
http://www.ubersignal.com/field-test-mode. Accessed May 2017.

UNL (2015) “Precision Agriculture Usage and Big Agriculture Data”, Cornhusker Economics, University of Nebraska-Lincoln Extension, May 27, 2015. 3 pages.

Vellidis, G., Garrick, V., Pocknee, S., Perry, C., Kvien, C. & Tucker M. (2007) “How wireless will change agriculture”. In: Stafford, J.V. (Ed.), Precision Agriculture ‘07 – Proceedings of the Sixth European Conference on Precision Agriculture (6ECPA), Skiathos, Greece, pp. 57-67.

VHA (2017) (http://maps.vodafone.com.au/VHAMap/apps/public-vf. Accessed January 2017.

Victorian Producers Federation (2015) “Submission to 2015 Regional Telecommunications Review”. https://www.communications.gov.au/sites/g/files/net301/f/Victorian%20Producers%20Federation%20-%20Public%20Submission%20RTIRC%202015_1.pdf. Accessed January 2017.

Vodafone (2016) http://www.vodafone.com.au/media/gears-up-internet-of-things/. Accessed October 2016.

Vodafone UK (2017) https://www.vodafone.co.uk/explore/network/network-improvements/wi-fi-calling/. Accessed June 2017.

Ware, I. (2014) “The technology opportunities for the farming business what are you missing out on”. GRDC Update Papers 12 August 2014. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/The-technology-opportunities-for-the-farming-business-what-are-you-missing-out-on. Accessed May 2017.

Wolfert, S., Ge, L., Verdouw, C. & Bogaardt, M-C (2017) “Big data in Smart Farming- a review”. Agricultural Systems. 153: 69-80.

Zarco-Tejada, P.J., Hubbard, N. & Loudjani, P. (2014) “Precision agriculture: An opportunity for EU producers- potential support with the CAP 2014-2020. (European Union: Brussells). Policy Department B: Structural and Cohesion Policies, European Parliament. ISBN 978-92-823-5575-6. 50 pages.

Zhang A, Baker I, Jakku E and Llewellyn R (2017) “Accelerating precision agriculture to decision agriculture: The needs and drivers for the present and future. A cross-industries producer survey for the Rural R&D for Profit ‘Precision to Decision’ (P2D) project”. EP17593
CSIRO, Australia.

Zhu, W., Luo, C., Wang, J., & Li, S. (2011) “Multimedia cloud computing”. IEEE Signal Processing Magazine, 28(3): 59-69.

Zigbee (2017).http://www.zigbee.org/. Accessed February 2017.

A local producer's perspective on solving connectivity problems: A 'direct line' utilising an electric fence connection from the farmhouse 'straight into' a nearby telecommunication exchange. (Photograph composed and provided, in humour, by a producer who wishes to remain anonymous).

Citation:

Lamb, D. W. (2017) Accelerating precision agriculture to decision agriculture: A review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia, University of New England and Cotton Research and Development Corporation, Australia.

ISBN: 978-1-921597-74-9 (Hard Copy) 978-1-921597-75-6 (Electronic)

ACCELERATING PRECISION AGRICULTURE TO DECISION AGRICULTURE - P2D PROJECT RESEARCH PARTNERS

PROJECT LED BY

Australian Government

Cotton Research and Development Corporation