“Getting Connected”
Technical Assessment

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Appendix 2

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1 Getting connected

Feedlots are data and information rich environments, with many potential 'moving parts' (Figure 1-1). From a day to day management perspective, the feedlot office is typically the primary interface between the outside world, of cloud-based services and internet-based decision support tools and repositories, and the data generating environment of the many moving parts of the feedlot itself.

Connectivity is the key. Here we mean telecommunications connectivity, which takes two forms: voice connectivity, namely making and receiving phones calls, and data connectivity, taken to mean exchanging data in its many forms. One has to consider the many sources of data from within a feedlot to understand the many forms of data that we are referring to here. Data can include information such as weights taken from a weighbridge, live vision (or still images) transmitted from a camera located on a weighbridge or in induction sheds or pens, weather measurements (temperature, humidity, wind etc) from an automatic weather station, remote monitoring systems on feedlot machinery, control data from an irrigator, water levels in storages and pump pressure, weight and tag data from an induction shed, and bunk call data at the mill and in the feed truck. Some of the data is manipulated into information using cloud-based servers and other data is made accessible via internet (www) access. Of course, the ultimate link in the chain is feedlot staff, mostly on-the-go, who need to stay in touch with each other and with their operation, both upstream and downstream, and who are relying upon the many pieces of information that these connected data sources provide.

Not all of these data sources are in digital form. Paper records still play an important, if not dominant, role in the Australian feedlot industry (Figure 1-2), reflecting a combination of propensity, appetite and confidence of feedlot operators to move into a digital age. In many cases, paper records are simply the only option, as connectivity, that all important roadway of moving digital data around, is simply not available.

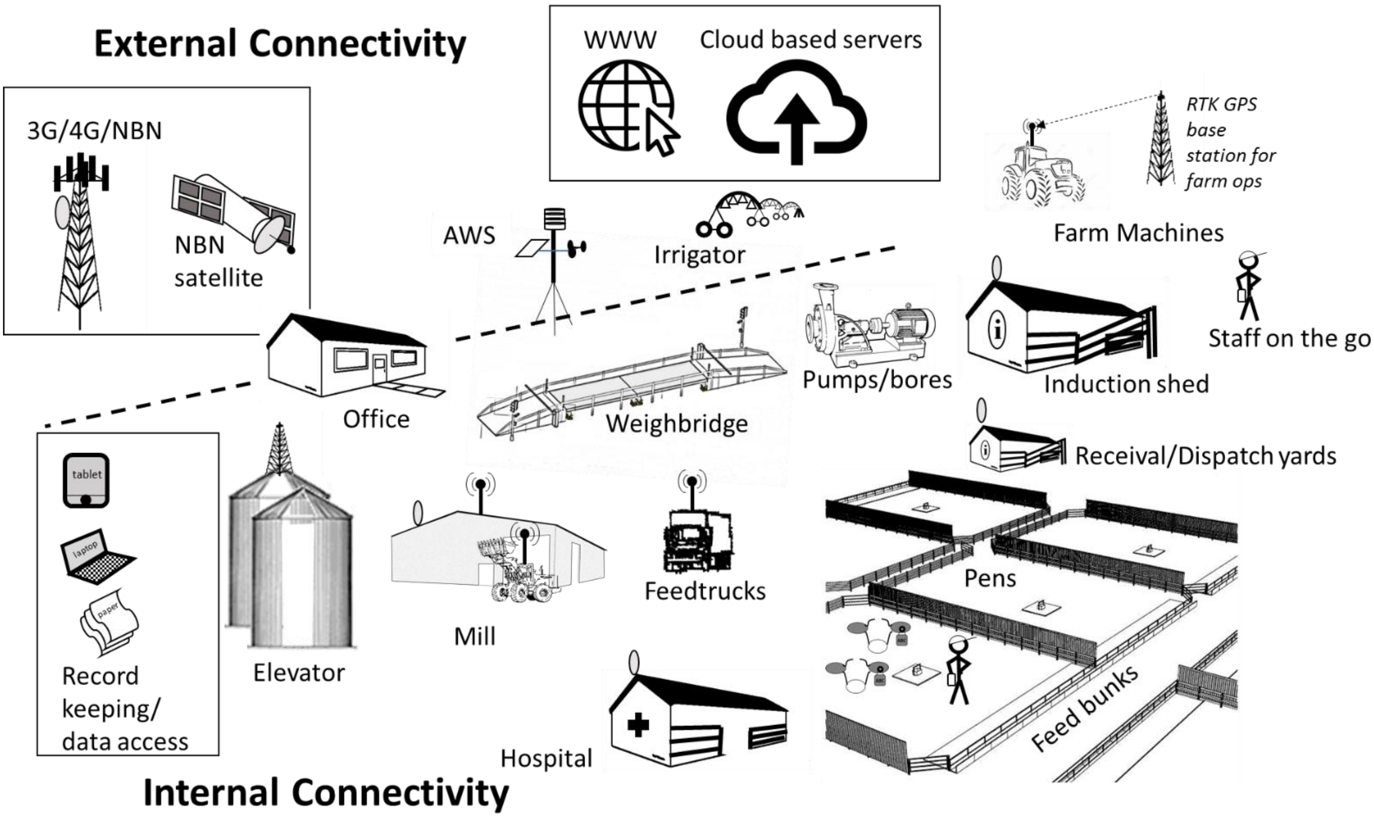


Figure 1-1. ***Some of the many data/information sources and consumers in a feedlot environment***

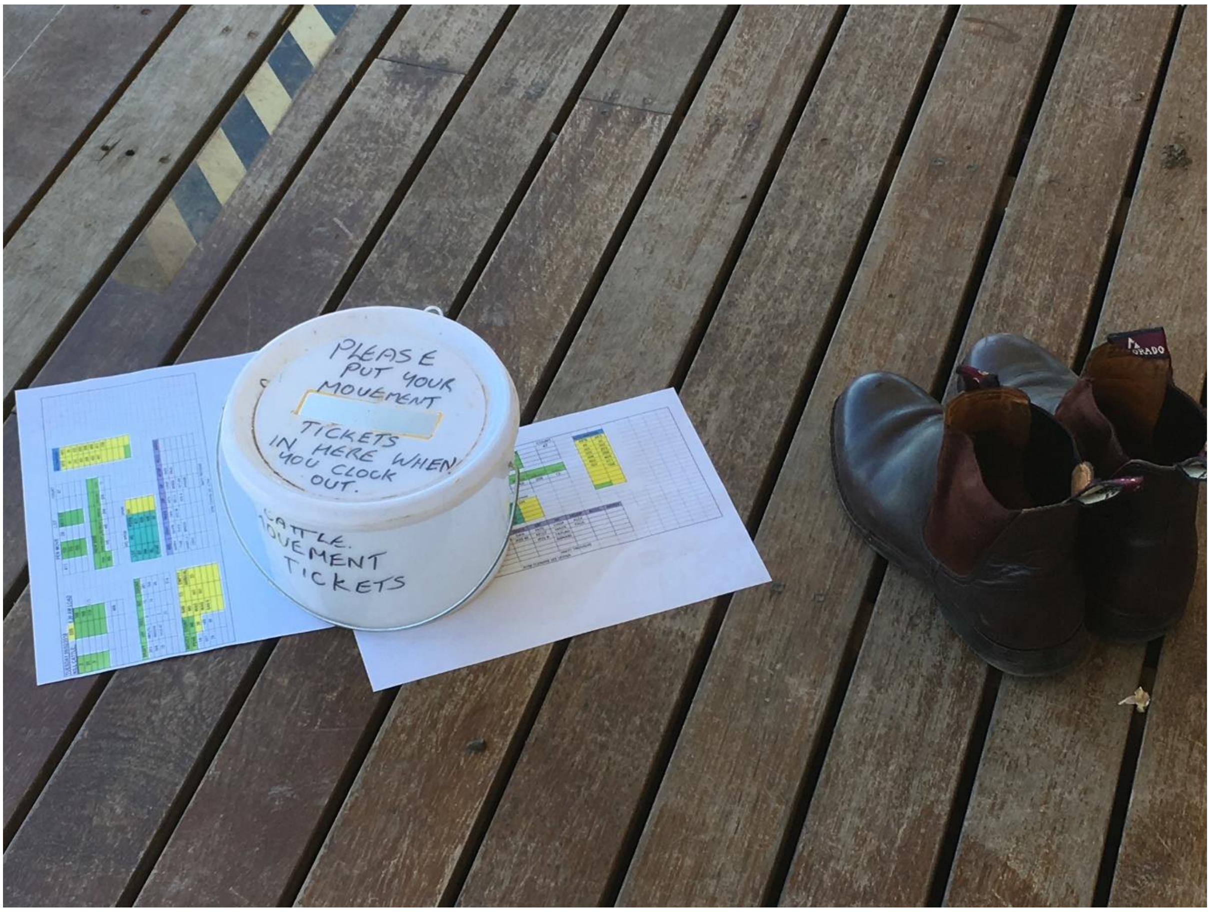


Figure 1-2. ***Paper records play an important, and currently dominant, role in the operations of many Australian feedlots.***

For the purposes of understanding and discussing connectivity, as it relates to Australian feedlots, we will consider separately 'external' and 'internal' connectivity. In this document, external connectivity refers to connecting people and devices directly to the outside world. Note the emphasis on 'directly'; in other words, involving a single link. This could include using the mobile phone for example from inside the feedlot, or a device that transmits data directly to the 'cloud' (again, say via a mobile phone link). Internal connectivity is taken to mean connectivity links that exist inside the feedlot, and where relevant, the associated farm precinct. This may involve one or two steps. Ultimately the device, or person that is connected internally, may end up connected (externally) to the outside world. However, in many cases the internal connectivity utilises different link technology to that utilised by devices (externally) linked directly to the outside world.

1.1 Data - bits, packets and bytes

Just as atoms are the fundamental building blocks of all matter (including us), data also has a basic building block - the bit. This smallest unit of data is a binary digit (bit is short for 'binary digit') which is either a 'one' (1) or a 'zero' (0). A data packet is the smallest data package (a combination of 1's and 0's) that is conveyed, from one location to the next, via a network. The packet conveys the basic information which may include identification, status of connection and structure of message (contained in the packet). A data packet may range in size from only a few bits through to 64,000 bits (64 kbits) depending on the information to be conveyed and the type of network it is to be conveyed along. A group of 8 bits is typically utilised as a single unit, known as a byte where 1 byte = 8 bits. Typically, computers use a byte, that is a string of 8 bits, to represent a character such as a letter, number or symbol.

1.2 Moving data and data speeds

Moving data (and associated information) around is based on two primary factors. The first is how much data is needed to be conveyed, as measured in bits or bytes (we will focus on bits from hereon in). This is, more or less, referring to the richness of the information conveyed. The second, which is the one that ultimately affects our experience as movers of data (especially as consumers of data and information) is how fast that data/information is conveyed. Here we are talking about data transmission rates, which are considered in terms of bits per second (bps). To give an example of the meaning of speeds, a typical voice call on a mobile phone would transmit the digital form of your conversation to and from your handset at between 8 and 64 kbps (i.e. 8,000 - 64,000 bits per second, here 'k' = kilo = 1,000). A digital TV streaming a movie from an internet site may deliver upward of 83 kbps (lowest video quality) to as much as 833 kbps (i.e. 0.83 Mbps where 1 Mega = 1,000 kilo). At the other end of the scale are devices that periodically (i.e. not 'live' every second) generate (and hence seek to move around) only small segments of data. A typical example is an automatic weather station in a feedlot, which may seek deliver only a few kilobits of data (e.g. temperature, humidity, wind speed) every 15 minutes or so.

The movement and consumption of data is a lot like using our cars; when you operate your car, you can pay an initial premium for how fast it goes (i.e. at purchase), but when you are operating it, you are not paying for how fast you drive it (unless you cop a speeding fine of course). Ultimately you pay for the fuel that you pump into it. This is the accumulated effect of the speed/performance over time. The same applies for data. You pay a component of a premium that is tied to how fast you move data around, but principally, users pay for how much data (i.e. bits) is consumed, over a fixed time period such as a month. This is the notion of data charges, which will be discussed later.

Different types of networks offer different transmission speed capabilities, which will be revealed as we look closely at the sorts of connectivity options available.

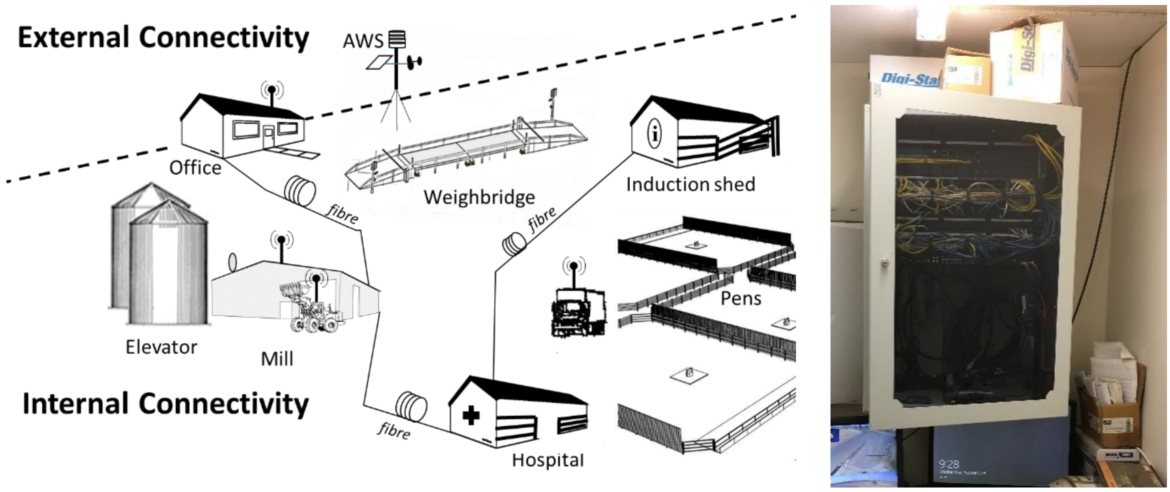
2 Internal connectivity - Communicating with devices inside feedlots

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. In the context of feedlots today, we are talking about connecting devices internally within the feedlot environment. There are a number of possible communications pathways to and from remotely connectible devices. The pathways used are 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 panning/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).

2.1 Fibre connectivity

In terms of carrying capacity, that is data speeds, and a range of other technical considerations, including immunity from electromagnetic interference (e.g. from electric fences and overhead power lines) and lightning damage, the ultimate means of transporting data is the optical fibre. Unlike electrical cables, namely copper wires, optical fibres convey data in the form of light pulses

('1' is on, '0' is off). By using light pulses, it is possible to convey considerable amounts of data at considerable speeds. Moreover, while all transmitted signals (optical and electrical) lose signal strength with increasing transmission distance, optical fibres have better than an order of magnitude lower attenuation rate with distance than copper. For example, over a distance of 100 m, an electrical signal in a copper wire can fall as much as ~90% compared to an optical signal may experience only a ~5% reduction in signal strength. It is for this reason that optical fibres constitute the ground-based (terrestrial) backbone of telecommunications worldwide. Optical fibres are not just used for external connectivity (e.g. for connecting homes via our national broadband network and for connecting regions, countries and continents). Fibres can also be installed underground as part of internal network connectivity, to form the future-proof (owing to the carrying capacity and speeds) backbone of feedlots. Bearing in mind the current and emerging data needs of feedlots, and in particular the focus on key operational locations within the feedlot such as the office, mill, pens, induction sheds and hospitals, some feedlot operators are already installing fibre loops as the main data haul conduits within their operations (Figure 2-1).



(a) (b)

Figure 2-1. ***(a) An example schematic of a fibre loop installed in an Australian feedlot and (b) inside the feedlot office sits a network service cabinet; the heart of an internal fibre loop within the feedlot precinct.***

2.2 Wired connectivity

The lowest cost solution, generally suited to distances up to 50 - 100 m, is via direct wire (co-axial) 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 at 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).

(a) (b)

Figure 2-2. ***An example of (a) an automatic weather station and (b) office vision from a weighbridge camera, both connected directly into an adjacent feedlot office via cable.***

Nowadays, this option is used in only the simplest (and shortest) of connections, for example, a nearby weather station or weighbridge camera (Figure 2-2). The vast majority of devices and sensors dispersed around a feedlot precinct are connected using entirely wireless means except, of course, where linked through an internal feedlot fibre loop.

2.3 On-farm radio networks – LANs, WLANs and WANs

When we refer to wireless telemetry, we are talking about radio networks. 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 an internal telecommunications network, which includes nodes and communications links between them. While we are still talking about data and transmission speeds, radio networks have a much broader lexicon of terms and physical concepts. The following discussion clarifies some of the complexity around radio networks. The first step is to look deeper into the basic elements of a network.

Networks can have different geometrical/spatial constructs and these are summarised in Figure 2-3. A 'node' is where the sensor/device resides. Effectively, nodes are connection end-points 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). The information ultimately finds its way to the point at which a connection is made to the outside world. The link to the outside world is known as 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 (Lamb, 2017 and references therein). '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. 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 in later sections.

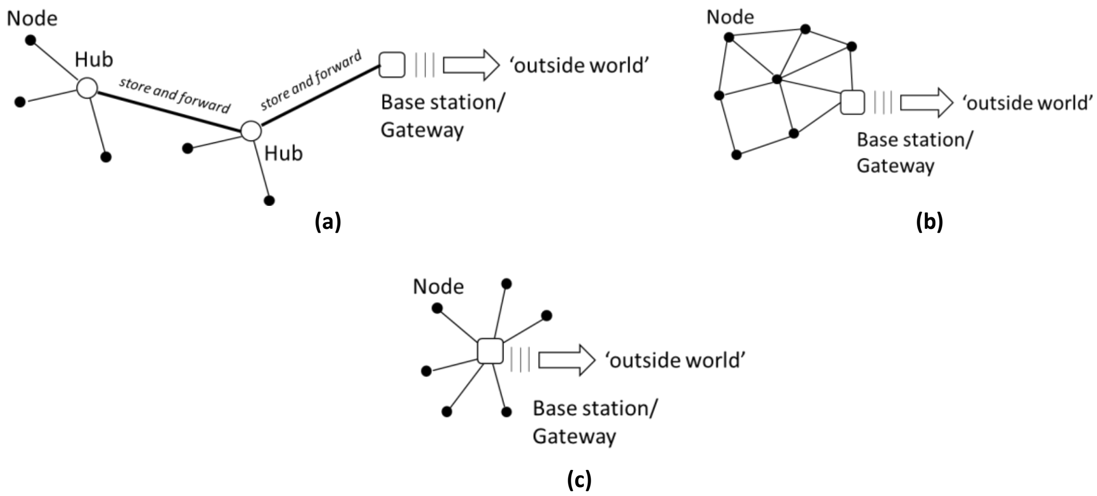


Figure 2-3. ***A basic network diagram as relates to (a) 'store and forward', (b) 'mesh', and (c) star farm sensor networks (Extracted from Lamb, 2017).***

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 the now ubiquitous 'Wi-Fi' brand name. 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 in their feedlots when talking about feedlot wide networks. Unless they are talking only about in and around the office or other buildings/sheds '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.

2.3.1 Radio transmission and antennas

The transmission range of wireless sensor nodes varies considerably. 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[1], 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 (ie, 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 is also 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.

[1] Wavelength is always inversely related to frequency; i.e. higher wavelength means lower frequency.

The frequencies at which 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 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.

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 Australian Communications and Media Authority (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 2016). An excellent discussion of currently available spectrum with respect to Internet of Things (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 (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[2]). Antenna are divided into two basic classes - omni-directional and directional. Three commonly used antenna designs are depicted in Figure 2-4.

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

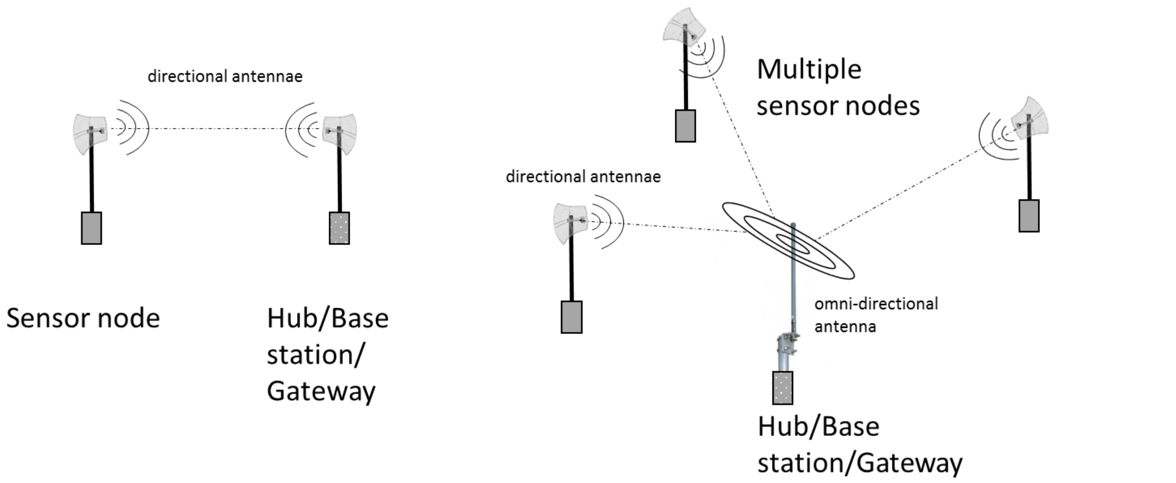
(a) (b) (c) (d)

Figure 2-4. ***Four common types of antenna (a) Omnidirectional ('Omni') and directional; (b) & (c) Parabolic grid or dish (or semi-parabolic grid/dish) in two common forms and (d) Yagi (Source: (a) http://maxcomm.co.za; (b) http://www.l-com.com; (c) www.ubiquiti.com and (d) https://www.scmsinc.com).***

An omni-directional antenna (Figure 2-4a) radiates, or collects, radiofrequency energy from all directions equally on a plane. The strength/sensitivity is highest at right 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 2-4b, c & d) are examples of directional antennae.

High 'gain' antennae are required to cover long distances. The gain of a reflector type antenna, such as a parabolic grid or dish (Figure 2-4b, c) 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 2-5a). 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 2-5b).



(a) **(b)**

Figure 2-5. ***A basic wireless sensor network (WSN) indicating use of different antenna types used in (a) point-to-point and (b) point-to-multipoint links (Extracted from Lamb, 2017).***

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[3]. 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 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[4] '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

2.3.2 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. Some of the basic terms often used in discussions of radio networks are defined and discussed below.

There are two types of signal transmission- analogue and digital. Analogue transmission involves the use of a continuous signal and is particularly suited to short range transmission (where repeaters are not required), and in particular voice communications (e.g. CB/UHF radios). The information is

[3] Wavelength is always inversely related to frequency; i.e. higher wavelength means lower frequency.
[4] Known as the first Fresnel zone

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 analogue signal such as a phone call or a video signal, digitized into a bit-stream using some form of analogue-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) is the 'transmission speed' introduced earlier. This is, again, 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, the higher the upper limit of the modulation frequency available 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 wireless 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. The popular Wi-Fi uses a set of pre-defined frequencies (channels) within its allocated portion of the 2.4 GHz spectrum. Frequency, or 'Channel hopping' is one means of avoiding interference between multiple Wi-Fi networks, for example in a feedlot environment.

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.

2.3.3 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 2016). 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 (ACMA, 2016). Higher field strengths are allowed because spread-spectrum systems are:

- less likely to interfere with other systems compared to single-frequency transmitters,
- more immune to interference from (or causing interference to) other systems, and
- 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).

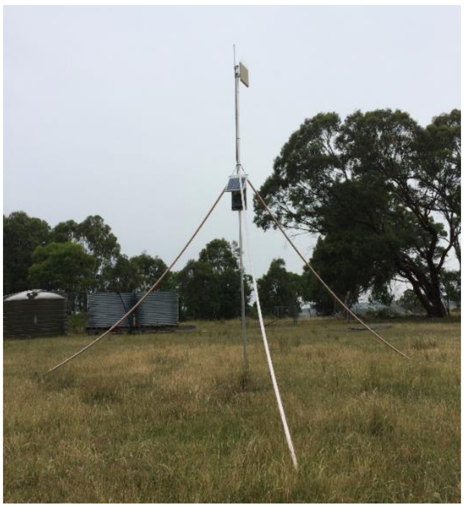
In summary, over long-distance links, several factors contribute to the radio link performance. It is not the purpose of this review to recommend designs. Even though the open-air (free- space) loss at 915 MHz is lower than at 2.4 GHz for purely physics reason, when you consider the typical antenna gains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

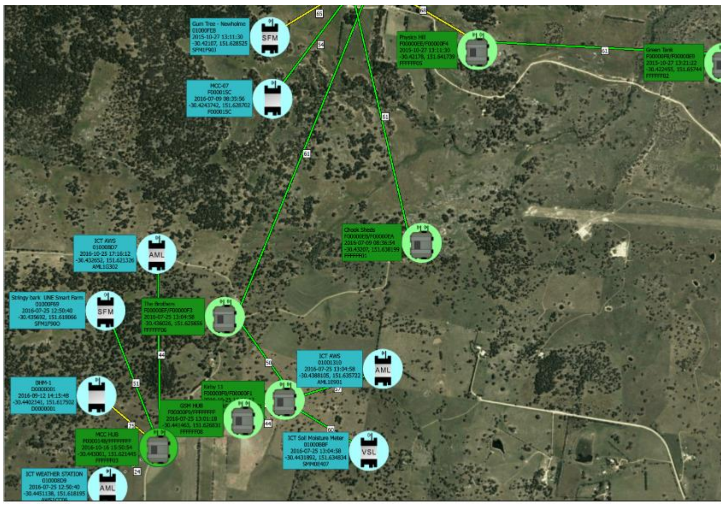
Users of the two key frequency bands and in particular the 2.4 GHZ band, are experiencing increasing levels of interference because so many devices around us use the same band. The unregulated 'public park' concept applied to this band renders responsibility of managing interference on the user. The 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.

2.3.4 Store and forward telemetry

Store and forward telemetry systems are useful where large distances are involved. Intermediary hubs act as repeaters (Figure 2-3a). 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 2-6) 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.





(a) (b)

Figure 2-6 ***(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) (Extracted from Lamb, 2017)***

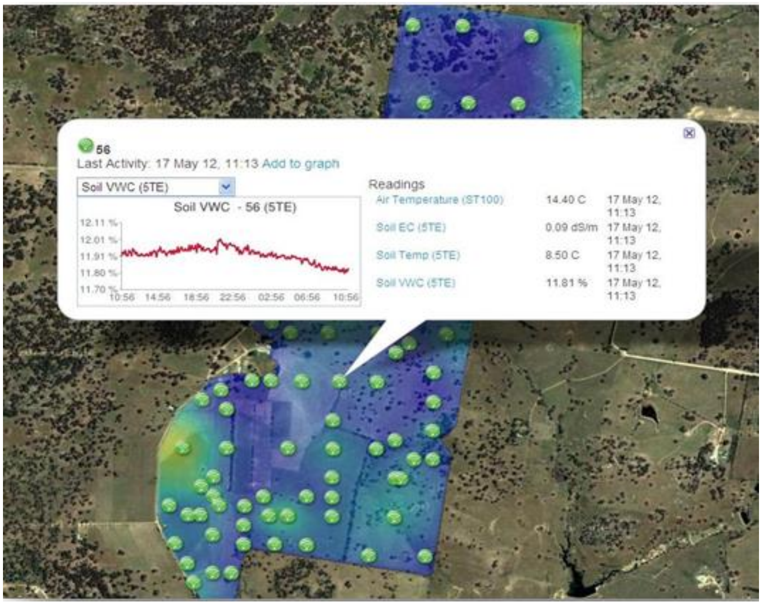
2.3.5 Mesh networks

Like the other network architectures, mesh networks are finding increasing use on farms. The use of the ZigBee radio standard (IEEE 802.15.4) which facilitates a 'self-healing' capability is particularly desirable given the harsh environmental conditions in which many sensor 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 each 'hop' in communicating data from a given sensor to the gateway (Figure 2-3b) 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 2-7). 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 2-8) 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 2-7 ***(a) 3 nodes (circled) of a (b) 100-node self-healing mesh network and user interface, (c) mesh gateway receiver and mobile network modem (Extracted from Lamb, 2017).***

*Figure 2-8****. An example of a low-cost Wi-Fi node capable of forwarding internet access as deployed in a community WYSPS mesh network (Extracted from Lamb, 2017).***

2.3.6 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 2-3c). 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
- only small packets of information, such as from soil moisture probes, device sensors (e.g. pumps, gates and weather stations) are required (Figure 2-9).

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 2-9. (**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) (Extracted from Lamb, 2017).***

2.3.7 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 2-10 a, b). Thinxtra partners with developers around the world to develop solutions (Figure 2-10 c, d). Example devices include irrigation flow sensors, soil sensors and wearable livestock monitoring devices.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 2-10. ***IoT device development kits relevant to feedlots (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 relevant third party-developed devices; (c) wearable animal devices from Spanish company Digit Animal, (d) remote worker sensor Thixtra Xpress (Source: https://www.thinxtra.com/portfolio-item/lone-worker-monitoring/), (e) Silo level sensor developed by French partner GreenCitizen (Source: http://www.greencityzen.fr/en/produits-en/hummbox-level-connected-ultrasonic-level-sensor/) and (f) Tank or storage level sensor. All examples are fully compatible with the SigFox data management system.***

2.3.8 Point-to-point links within feedlots

Point-to-point links between feedlot offices and key operations locations such as induction sheds, yard/pens and mills is an important wireless connectivity option for managers wishing to run key software platforms including Digi-Star and Elynx platforms (discussed below) on location where the platform is located on servers either in the nearby feedlot office or (via an external connection point on the feedlot, for example the office) on a server located at headquarters in another region/location entirely. Such internal point-to-point links utilise directional antenna and rely upon Wi-Fi frequencies (2.4 GHz) or, in some cases the higher frequency (hence higher bandwidth) Wi-Fi-'n' frequency (5 GHz) (Figure 2-11).

(a) (b)

*Figure 2-11. **Examples of a point to point link between (a) an induction shed and (b) feedlot office. The induction shed has a parabolic dish and the feedlot office uses a Yagi to facilitate the link.***

Typical speeds between a wireless router (for example located in the Office where external connectivity is linked) and client devices at the end of a Wi-Fi link depends very much on the nature of the link technology. The physical layer (PHY) rate is the maximum speed that data can move across a wireless link between a wireless client and a wireless router. User activities like file transfer and web content browsing happen at the application layer. The rate obtained at the application layer will be much lower than the physical layer rate. For example, a typical link rate of 300 Mbps usually corresponds to 50 to 90 Mbps speed on applications layer. In other words, this is the realisable speed (from a user perspective) through the link.

Examples of the platforms that rely on point-to-point links include Elynx and Digi-Star platforms. Elynx is a software and information technology service providing a suite of products including:

- StockaID (individual animal identification and management software program design to record numerous parameters via readers or manual input),
- FY 3000 (a suite of projects including Feedlot 3000, which is an integrated management system that imports data from the StockaID program and exports financial data to financial accounting software programs), and
- Bunk Management System (a simple commodity and feedbunk management system to manage animal movements on a lot or pen basis).

Digi-Star is a brand of weight management software to manage feed mixes. It includes Beef Tracker, which is a Windows ® based feed management software system that works in conjunction with the scales on a feed mixer truck and allows management and collection of feed batching and delivery weight data.

3 External connectivity

3.1 Telecommunications Networks

As with any other subscriber, feedlots will access one or both of two types of telecommunications networks; fixed and/or mobile. 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, such as the office. 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. Some feedlot offices, while obviously at a fixed location, may access the network via a mobile network (for example using a mobile booster antenna on the office roof - discussed later), which is then accessed via desk-top phones (giving all the appearance of a landline though it is actually utilising the mobile network).

In its simplest form (Figure 3-1), fixed networks consist of multiple local access networks, linked together by a transmission 'backhaul' 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 operators.

'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 3-2). Backhaul networks carry voice and data transmissions. 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 as well as retailers of the service to subscribers. Quality of service refers to the performance of the network, in particular as experienced by users of the network (Lamb, 2017)

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 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).

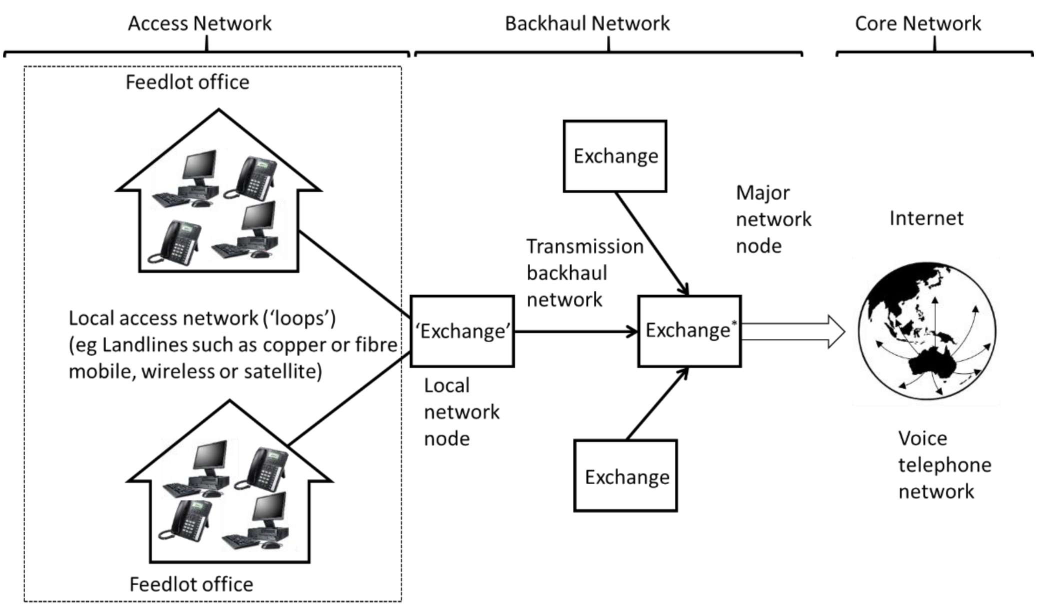


Figure 3-1. ***Schematic diagram of a basic network structure (Extracted from Lamb, 2017).***

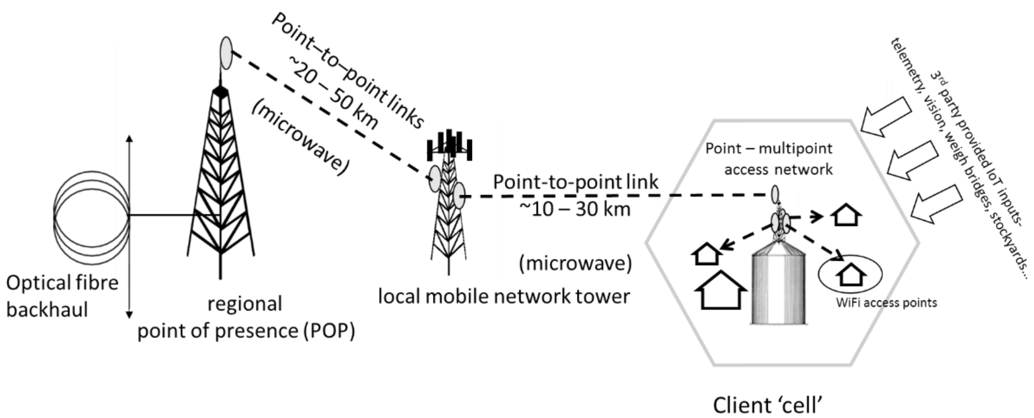


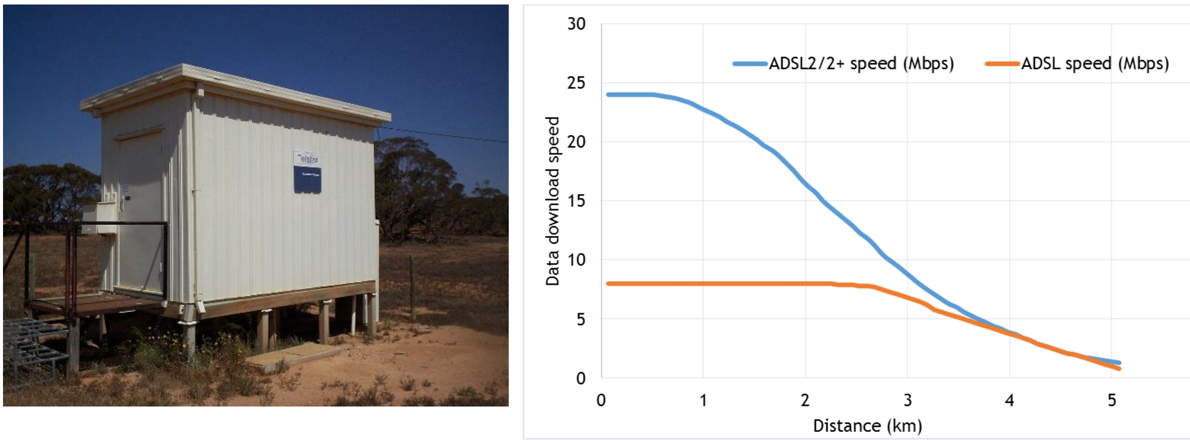
Figure 3-2. ***An alternative view of networks, especially relevant to some feedlots (discussed later) (Extracted from Lamb, 2017).***

A mobile network is one where the last link is wireless. Generally, a mobile network is accepted to describe a mobile phone network. However, it equally applies to any form of wireless network including 'radio' (as used for telemetry purposes) and Wi-Fi. A typical example of a network structure as relates to telecommunications in rural and regional Australia is given in Figure 3-2. 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, 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 carriage service providers (CSP's) are reaching out through backbone networks in to the feedlots offering services that include the within-feedlot data transmission technologies and infrastructure. These are so-called 'second tier' providers (Lamb, 2017b) and such 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 (in this case then '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 these second tier feedlot telecommunications service providers which are also 'carriers'. These carriers lease access and then provide fully-managed services (including backhaul) to clients. Second tier service providers are discussed in more detail in Section 4 and examples of the connectivity offered by these second tier providers are discussed in the feedlot case studies.

3.2 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 3-3).



(a) (b)

Figure 3-3. ***(a) A typical local exchange a seen in rural Australia (Source: Longhair, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=3934601) (b) 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.

3.3 Communicating through the mobile phone network

Increasingly, feedlot staff (both offices and on the go) and office computers are connected to the outside world via the mobile phone network, for example via 'mobile broadband' (Figure 3-4).

(a)

(b)

*Figure 3-4. **(a) An example of a dual mobile booster located on the roof of a feedlot office, and (b) the internal router boxes used to (internally) link office desktops. Note the mobile link is facilitated by a Yagi antenna. A second Yagi (directly beneath the first) is used for the point-to-point link (Wi-Fi) to an Induction shed***

When we talk about mobile phone connectivity in feedlots, 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 feedlot staff may access the internet (for example to access web-based decision support systems like that related to pumps/irrigators, commodity prices, auctions, heat loading/weather etc), mobile data connectivity is also a vehicle through which operators can connect devices from inside the feedlot.

It is acknowledged that the mobile phone network is one of the most sophisticated technologies in existence today. Users see the QoE side of the equation, i.e. it is or isn't up to scratch in terms of their needs. The network performance challenges experienced are but a hint of the significant technical and operational challenges faced by network operators literally every second of the day.

3.3.1 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 (this word actually has a specific meaning as discussed later). Of course, 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. 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 3-5).

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 (i.e. channel carrying capacity). Note that increasing the channel frequency is one way of increasing bandwidth, but this then reduces range (coverage). This is an important point to note when we hear of new mobile technology such as 5G (revisited later). 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.

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. However, in the case of an isolated base station, this is not possible; 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 3-5).

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 (femtocells not indicated in Figure 3-5) 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. A microcell may exist in a remote area (and hence even near a feedlot) to fill in a small gap in coverage, for example along a major roadway or to service a small village. They are also carrier specific. Small cells do have carrying limits, typically ~10-20 access points.

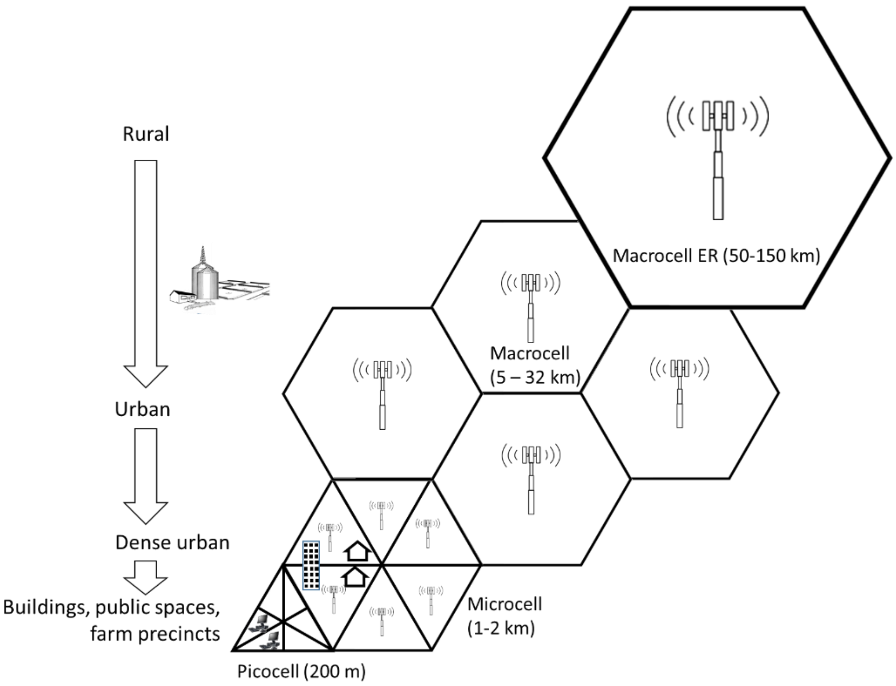


*Figure 3-5. **Basic mobile cell types. Indicative cell radius (in km) included (Adapted from MobileNetworkGuide 2016) (Extracted from Lamb, 2017)..***

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. The current mobile frequency bands in Australia are listed in Table 3-1.

*Table 3-1. **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 3-2). Before interpreting the 'G's in Table 3-1 and Table 3-2, 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 retrospective after 2G was introduced). From the early years, 2G/GSM was on the 900 MHz/1800 MHz band. 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 in 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 3-2 are all technical enhancements emanating from the innovative use of data 'packets'. Note that UMTS Data sub class refers to downlink only. Often referred to as 3G$^+$, these offer progressive improvements in transmission speeds and reductions in latency. Latency 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. 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.

*Table 3-2. **Typical Mobile data speeds in Australia (Source: MobileNetworkGuide, 2016) (Based on Lamb, 2017).***

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[5]. 4G devices must be capable of supporting at least 100 Mbps download speeds (50 Mbps upload) (Table 3-1). 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 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 3-2, 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 in 2017 (ACMA, 2017), and ostensibly under similar rules as the earlier 2013 auction. TPG Internet Pty Ltd secured 2 x 10 MHz (TPG Internet, 2017) 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 3-2). 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 employs the 850 M MHz band in their 4G+.

3.3.2 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

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

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.

The issue of fluctuating data speeds on mobile networks is a major concern for feedlot operators. In the language of telecommunications, 'contention' refers to the relationship between the actual user demand for bandwidth compared to the available bandwidth (Lamb, 2018). The lower the contention ratio, the higher the quality of service. For example, a 50:1 contention ratio effectively means 50 users could be sharing the same bandwidth to the local exchange at any one time. An uncontended network connection with a 1:1 ratio is essentially a service where the provider can guarantee a fixed connection speed to a user regardless of the time of day that it's being used, or regardless of how many people share the connection to the local exchange. On a single owner-single user connection, the contention ratio is of course 1:1.

Operators who experience diminishing speeds are experiencing the realities of dynamic contention ratios on their local network as more users are accessing it. This is particularly felt on mobile broadband networks as multiple mobile users (i.e. travelling public) move into and out of cells. On their own, contention ratios don't tell the full story as the carrying capacity of the local network is also important. For example, take a situation where a user is provided with a 2 Mb/s connection but where there are another 49 users given the same capacity connection. All of these connections are working through a single 2 Mb/s link. Here we have a 50:1 contention ratio (i.e. a total of 50 users attempting to exploit their 2Mb/s capacity connection = 100 Mbps in total) but on a single 2Mbps link (i.e. 100:2 = 50:1). During peak periods, that is where all users are trying to utilise their connection, those users could conceivably experience as low as 40 kbps. During quiet times with only, say, two active users, each would then share the link and experience 1 Mbps. Here the net capacity plays a major role in the fluctuation. The only solution is to reduce the contention ratio.

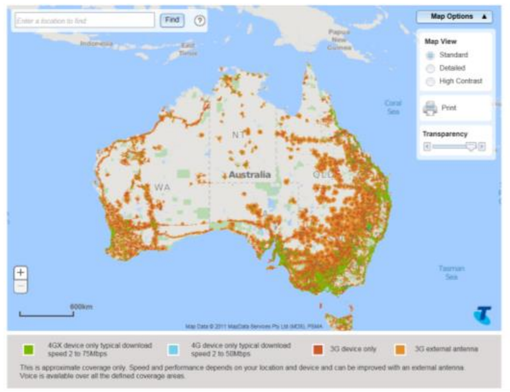
Now, in a larger capacity 40 Mbps network segment, catering for as many as 1,000 users each promised 2 Mbps (a total of 2000 Mbps) also equates to 50:1 (i.e. 2000:40) contention ratio. The worst-case scenario is again 40 kbps. However, this assumes absolutely 100% peak demand from every user and, with a larger pool of users, there is an increasing likelihood that not EVERY user will be active at the same time. Therefore, the peaks and troughs are smoother. Certainly, during quieter times (say when 990 users aren't using it), 10 users could enjoy up to 4 Mbps, and if only 2 users are active then they experience 20 Mbps.

The highest maximum speed is obviously only achieved at low usage times, for example during the night. The bandwidth capacities of the supporting network in a producer's area may have a greater impact on internet speed. This is what really frustrates feedlot operators reliant upon the mobile network for their primary internet access (e.g. from the Office); contended services are quite often sold 'quoting' the highest maximum speed but usually only 'guarantee' a minimum data throughput speed. They want the gap between quoted and guaranteed speed closed.

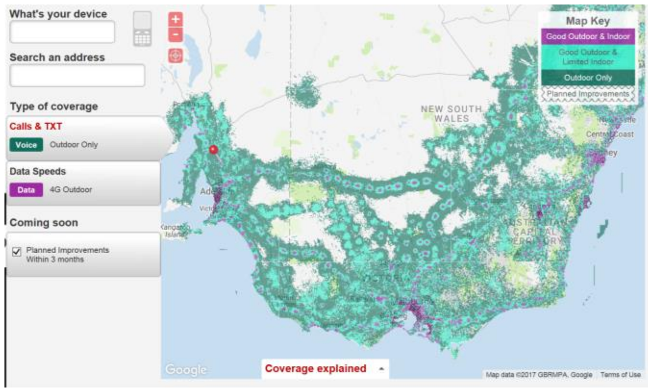
3.3.3 Mobile phone coverage for Australian producers

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. 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 (MNOs) may apply different assumptions. For example, one MNO may base 'coverage' on 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.

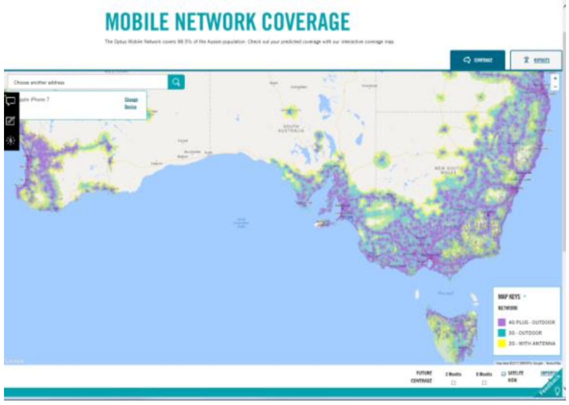
Mobile coverage maps refer to the probability of a certain percentage of devices working- that is, experiencing sufficient signal strength to 'work'. The major mobile network operators publish coverage maps in one form or another (Figure 3-6). This is not to be confused with any form of speed or carrying 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 play 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 apply quite sophisticated models. 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.



(a)



(b)



(c)

*Figure 3-6. **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 (Extracted from Lamb, 2017).***

Mobile networks in Australia, like anywhere else in the world, concentrate coverage around the consumers. This means that, while mobile network operators purport to reach in excess of 95% of the population, considerable swathes of the landmass are left devoid of any coverage (Figure 3-7). 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 3-7). Geographical coverage is therefore only effectively that provided by the largest MNO; namely ~30%.

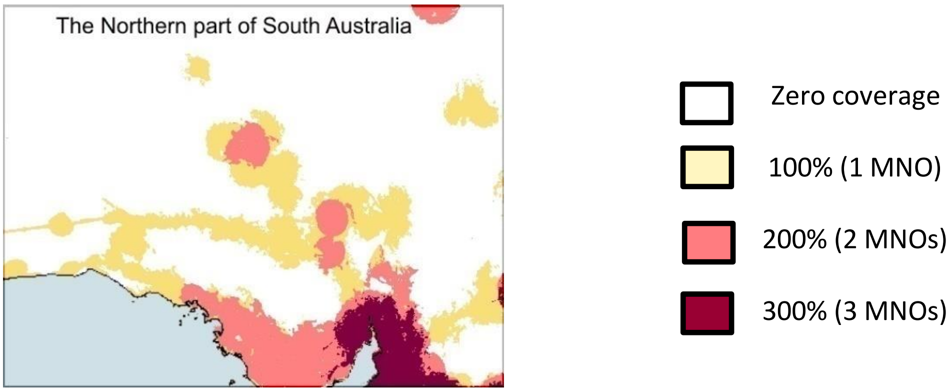


*Figure 3-7. **Map of coverage overlap in a segment of South Australia (Source: Lamb, 2015).***

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 3-8) 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 in the vicinity of feedlots. 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	LICENSINC	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 3-8. **(a) Example of ACMA database output ('site') and (b) output of tower location search via OzTowers in map form (Source: https://oztowers.com.au) (Extracted from Lamb, 2017).***

3.3.4 The use of cell boosters

A cell phone signal booster ('Cell booster') is a system that receives the cell signal via an external antenna and amplifies the signal to create a zone of amplified signal in the vicinity of, for example a key operational location such as a shed or in the yards. Such a system usually comprises of an outside antenna (called a 'donor' antenna), the signal amplifier and then one or more inside antennas, and associated cabling (Figure 3-9). The signal booster also works in reverse in that when a phone call is made, or data is used by a mobile device, it passes through the system, is amplified, and then broadcast to the nearby cell tower.

Ultimately, a cell phone signal booster is designed to assist in situations where

(a) The user is located a long way from the nearest cell tower and, hence, has a weak signal. The signal booster simply amplifies the weak outside cell signal, both to and from the nearby cell tower, to compensate for the distance; and

(b) Where there are obstacles such as sheds, elevators, hills etc in the way. When using, say, an omnidirectional external (top of shed) antenna, the user can receive and broadcast a strong cell signal in all directions to maximize the chance that the signal will make it around those obstacles. Alternatively locating the 'donor' antenna may provide a line of sight around the obstacles in question.

As long as there is some 'usable' cell signal in the feedlot precinct, a cell phone signal booster will likely provide the user with an improved service in their precinct. It is important to note that cell boosters will amplify a weak signal, and usually result in an improved voice call, but not all will necessarily increase data speeds for a given connection. Users need to ensure that they select boosters specifically compatible with data-rich networks such as 4G (LTE/5G)

(a) (b)

Figure 3-9. ***(a) Example of a small (shoe-box) sized cell booster used to create a zone of amplified signal strength in an around a building, in this case around a mill shed. The 'donor' antenna is located on the shed roof. (b) An example of a vehicle cell booster (www.ubersignal.com). Whilst cell boosters can increase the signal strength and hence provide improved call quality, they do not necessarily increase data speeds.***

3.3.5 Mobile Roaming

From an operational and business perspective, each of the mobile network operators 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. 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 mobile network operators in areas in Australia where the user's network operator does not offer coverage, but where it is available through another operator, in effect extending coverage available to the user. Domestic roaming is available in 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 real value of roaming is derived where different mobile network operators have coverage in different geographical regions.

A recent investigation by the Australian Competition and Consumer Commission (ACCC) into whether domestic roaming would make a difference in terms of improving coverage in rural/regional Australia (ACCC, 2017) concluded that mandating mobile domestic roaming "…would not promote the long-term interests of end-users to an extent that would justify a declaration".

3.3.6 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 3-3. 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),
- 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 3-3. **Indicative signal strengths for mobile phones (based on Lamb, 2017).***

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 3-4). 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 3-4. **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 pen or in the feedlot office, the data speed experienced by producers utilising the mobile network is governed by a number of factors:

- The mobile network itself and whether the base station (tower) is capable of handling 3G (various sub-classes) and 4G;

- 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 (this impacts the contention ratio as discussed earlier);
- The wider the frequency channel bandwidth the carrier is using the greater the capacity for transmission; and
- If using 4G (LTE Advanced), there is also the number of bands the carrier is utilising for carrier aggregation (Table 3-2).

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 for an uninterrupted signal (Figure 3-10). 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) and 'Cat number' are important.

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.

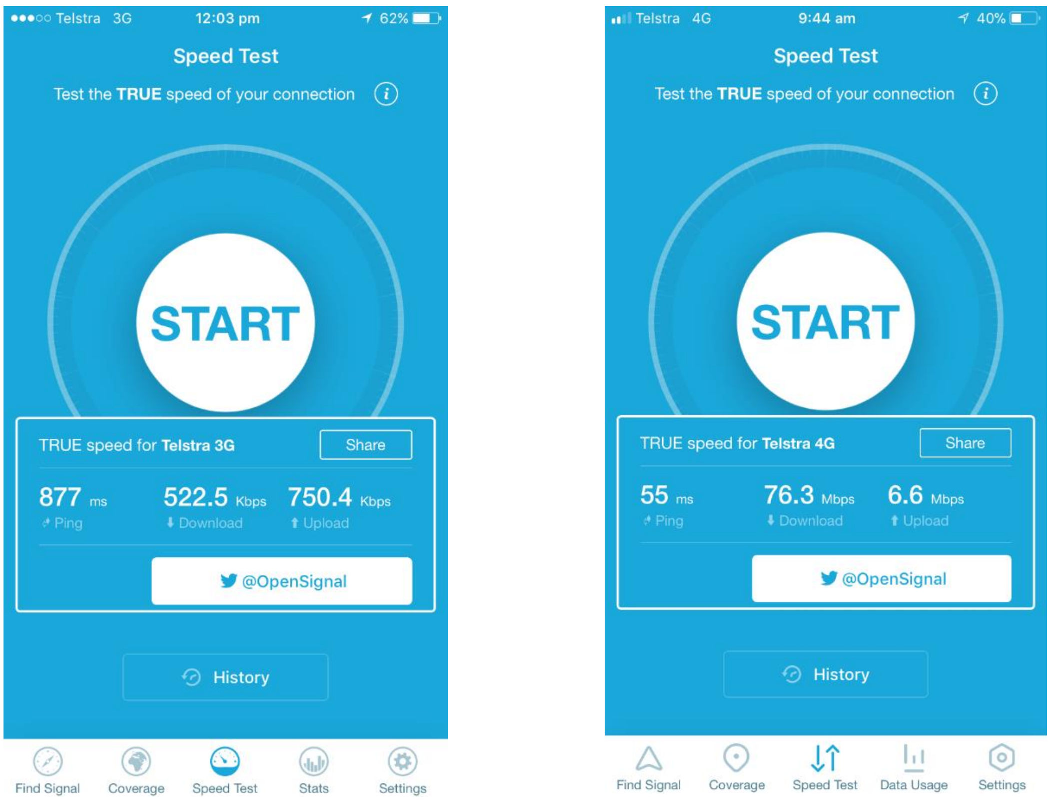


*Figure 3-10. **In the vicinity of two different feedlots, both within 15 km of nearby mobile network towers. Same handset, two different towers (including 3G and 4G), two different times, two different signal strengths and two entirely different outcomes in terms of speed. There are a multitude of factors that influence the relationship between signal strength and resulting (data) speeds.***

3.4 Cellular devices in feedlots

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 environmental parameters used to model (and predict) heat load), primarily because of the costs of data on the mobile network. Weather has always been a principle decision point in feedlot management.

3.4.1 Automatic weather stations

Capable of recording and transmitting at regular intervals, at the very least, rainfall, temperature, humidity, wind speed and direction, an automatic weather station (AWS) requires only modest data transfer rates and AWSs incorporating mobile network links are a popular sensor available on the market to producers (Figure 3-11a). For example, the device depicted in Figure 3-12b, which transmits data every ~15 minutes, consumes only 5 Mbytes data per month.

(a) (b)

*Figure 3-11**. Two examples of automatic weather stations (AWS) located in feedlots incorporating mobile phone network links.***

3.4.2 Safety and performance monitoring systems – telematics

The use of the mobile network to link moving objects is more challenging as mobile devices may experience varying levels of connectivity due to terrain and other obstructions (e.g. when inside mill sheds and nearby elevators). An example of a moving sensor 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 3-12) (www.usee.com.au) and Austracker (www.austracker.com).

(b)

(a) (c)

Figure 3-12. ***(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; extracted from Lamb, 2017).***

Many of the larger farm and construction machinery manufacturers, for example John Deere, Case IH and New Holland, offer mobile network-enabled, 2-way data transfer capability between machines (Figure 3-13) 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 Table 3-5.

There are also numerous telematics service providers in agriculture that are not brand specific, and that offer both hardware and 'air time'[6] 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.

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

Table 3-5. ***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 3-13. ***Examples of telematics systems (a) tractor and spreader (Source: Andy Duncan, 'Urara' WA; reproduced from Lamb, 2017), and (b) front end loader operating in the mill shed. Feedlot operators report the latter application as challenging given the often cluttered operational environment.***

3.4.3 Positioning and guidance

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)[7]. Data consumption rates can be typically 1-2 Gbytes data per month for farm machine guidance use.

An alternative and more widely used method in feedlots is to establish a receiver base station on a prominent (preferably central) location such as an elevator tower and transmit the correction signal to the rover (on the machine) via UHF radio link. This does not require external connectivity and so does not incur data usage. However, in some cases, feedlot operators may wish to utilise an existing mobile network coverage to facilitate transmission of the correction signal from the base station to the rover. This setup would then require a mobile sim card on the base station (to transmit the signal onto the mobile network) and a mobile sim card in the rover to receive the correction signal via the mobile network. When operated this way, a system can consume ~ 1 kbps per deployment.

3.4.4 Remote vision system utilising the mobile network

Images are larger data files and their 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 3-14). Single image frames of 200 x 300 pixels (15 kbytes) can be transmitted every 2-3 seconds for live viewing[8] 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[9] and delays (latency). This is further 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’[10]). 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). While no systems are currently known to be

[7] GPRS is a mobile data service on the various 2G and 3G cellular communications networks) to users via a wireless internet connection, ultimately relying upon 3G cellular network access at the user device end.
[8] 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.
[9] 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.
[10] Edge of cloud storage refers to the use of local storage (e.g. 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.

operating in Australian feedlots, the RMCam system, for example, is known to be deployed in poultry sheds and for monitoring other on-farm environments (Figure 3-14) so it is expected that the system is equally amenable to feedlot environments

(a)

(b)

*Figure 3-14****. 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).***

3.4.5 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 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. This number is likely to have increased significantly in the three years since the release of this second edition.

Some examples (amongst many) of apps identified as of potential (or existing) relevance to feedlot operators are depicted in Figure 3-15. These examples were indicated for their value in using them on site (e.g. in the paddock or shed, assuming mobile network access) rather than in the farm office, and are indicative of the value that can be derived from smart phone/tablet data connectivity everywhere in the feedlot.

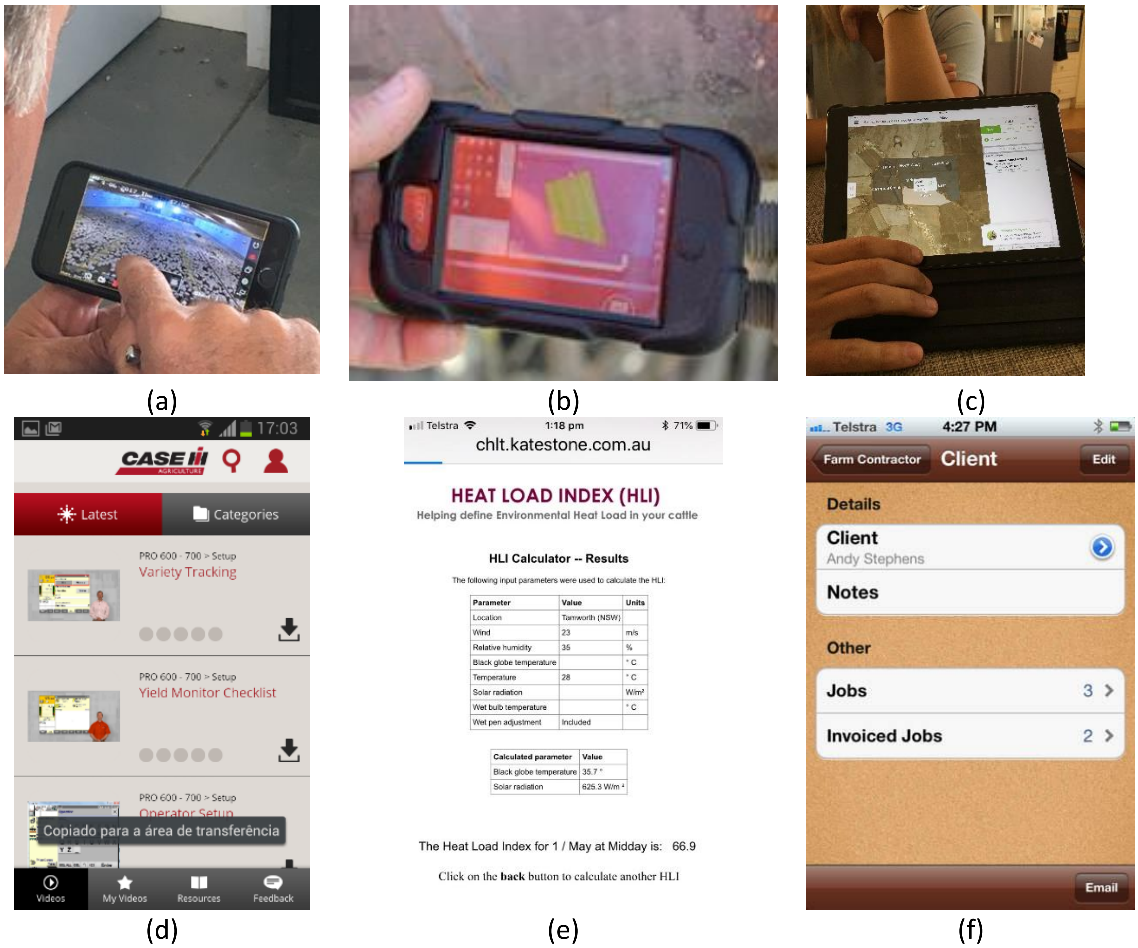


*Figure 3-15. **Some examples of smart phone tools that are of potential (or existing) use to Australian feedlot operators to access device/animal status, visually monitor or record aspects of their operation (including weather) or enable data sharing. These have been selected based on potential (or existing) relevance to feedlot operators and the value from accessing them on site; (a) remote vision (e.g. poultry but applicable to feedlots), (b) pump control (Source: www.canegrowers.com), (c) paddock data sharing and zoning for management (d) onsite learning and tutorial tools for feedlot machinery (Source: www.caseih.com), (e) animal stress monitoring/forecasting (Source: www.KateStone.com.au), and (f) feedlot contactor management.***

3.5 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 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 3-16a).

Globalstar is another LEO satellite communications system that 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 that offers low powered micro-transmitters that presently access one of the Canadian ExactEarth LEO satellites Figure 3-16b). This system is appropriate for devices that only require periodic monitoring, for example a 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. While not presently available to feedlot operators, Boeing recently announced ~$19.4 M of venture capital investment for Myriota to bring the communications platform into the market place (Boeing 2018).

(a) (b)

*Figure 3-16. **(a) An example of an Iridium IoT hub and (b) a Myriota-developed LEO satellite transmitter connected to a tank water level sensor. (Source: Ric Otton, Dosec Design and Tom Rayner, Myriota; extracted from Lamb, 2017).***

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. There are several of telecommunications companies and networks that use geostationary satellites. For example:

- 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 3-17.

(a) (b) (c)

*Figure 3-17. **(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). (Figure extracted from Lamb, 2017).***

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.

3.6 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:

1. Wired,
2. Fixed wireless, and
3. Satellite wireless.

The 'wired communications' platform comprises four subsets, namely fibre to the premises (FTTP), fibre to the node (FTTN), fibre to the building/basement (FTTB) and hybrid fibre coaxial (HFC). Recently, NBN announced a fifth option; Fibre to the curb (FTTC). FTTP connection is used in circumstances where an optical fibre is connected from the nearest available fibre node, 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 where 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. FTTC utilises a fibre link to the nearest service pit (usually located in the vicinity of a household) and the domestic twisted pair cable running from the pit into the home. 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 the key platforms available to feedlot operators. These are designed for wide space applications such as rural and regional areas.

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 (ISPs) 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 3-6. **Number of premises activated for NBN satellite and fixed wireless service. Date with effect of 31 December 2017 (Source: NBNCo 2018).***

Ready for Fixed wireless	Activated coverage	% of ready premises	Ready for Satellite	Activated coverage	% of ready premises
565,557	212,917	37.6%	424,184	83,400	19.7%

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 FTTN and FTTP is given by Tucker (2017). Fixed wireless and satellite NBN access is effectively the only platforms available to feedlot operators. With effect of 31 December 2017, 3.4 million premises were actively serviced by NBN across Australia (NBNCo 2018), with approximately 37% of premises covered by fixed wireless activated and almost 20% of those covered by Sky Muster activated (Table 3-6). It is noteworthy from the context of feedlots that fixed wireless and satellite (Sky Muster) NBN activations across rural and regional Australia amount for one third and one fifth of the available premises respectively. For the purpose of this review, a brief introduction to both fixed wireless and satellite NBN follows.

3.6.1 Fixed wireless

Fixed wireless NBN is a wireless solution with transmit/receive ranges up to ~14 km between towers and receivers (Figure 3-18). 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 3-18. ***(a) NBN fixed wireless tower in a rural town and (b) fixed wireless antenna (diamond shaped) on a nearby feedlot office (4 km away).***

3.6.2 Satellite NBN - Sky Muster

Satellite NBN was initially available through an interim satellite service (ISS) which was shut down in February 2018 and is now facilitated through the Sky Muster satellites.

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. 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 (discussed earlier).

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 when all subscribers migrated over to the new Sky Muster service.

3.6.3 Broadband data plans - Speed, capacity and ‘shaping’

Access to high internet speeds can cause problems for feedlot users if they haven’t got an adequate data plan. One consequence of exceeding data allocations is ‘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, if a subscriber exceeds a monthly limit, financial (sometimes significant) penalties may be incurred. This often triggers adverse (media reactions). From an Internet Service Provider (ISP) perspective, the alternative approach (which is favoured 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, broadband users either under-estimate their feedlot management data use (and hence do not select an appropriate data plan), or simply selected a plan on the basis of what they feel 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 operators feel the cost of data access is expensive, and sometimes 'too expensive'. An indicative summary of data costs (per Gbyte) is given in Table 3-7 (Graham, 2016):

*Table 3-7. **Data costs based on a survey of 199 rural broadband users in 2015 (reproduced from Lamb, 2017, with original data extracted from Graham, 2016 and 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[11]
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**

The Sky Muster satellite has a Fair Use Policy (NBN, 2016) in place 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 3-8).

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

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

Table 3-8. ***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**

3.7 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 ‘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).

More recently, companies such as Pivotel (www.pivotel.com.au) are offering custom-designed cell networks for voice, data and Iot connections. The Pivotel ecoSphere® includes a mix of LTE (4G) and satellite connectivity, or terrestrial connectivity where a 4G network exists. By creating what is effectively a private cellular network with a network server located onsite, encapsulating the extent of a feedlot, the connectivity 'bubble' offers secure voice, data, video, tracking and monitoring connections for on-site and remote assets. Typically, Pivotel builds the onsite infrastructure (cell tower(s)) and then charges a monthly access fee (~$2,000 per month) plus data. The company typically assumes responsibility for maintaining the infrastructure.

3.8 Optical fibre to feedlots

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 farm/feedlot locations. 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 3-19). The remaining 7% included, of course, the bulk of Australian rural properties.

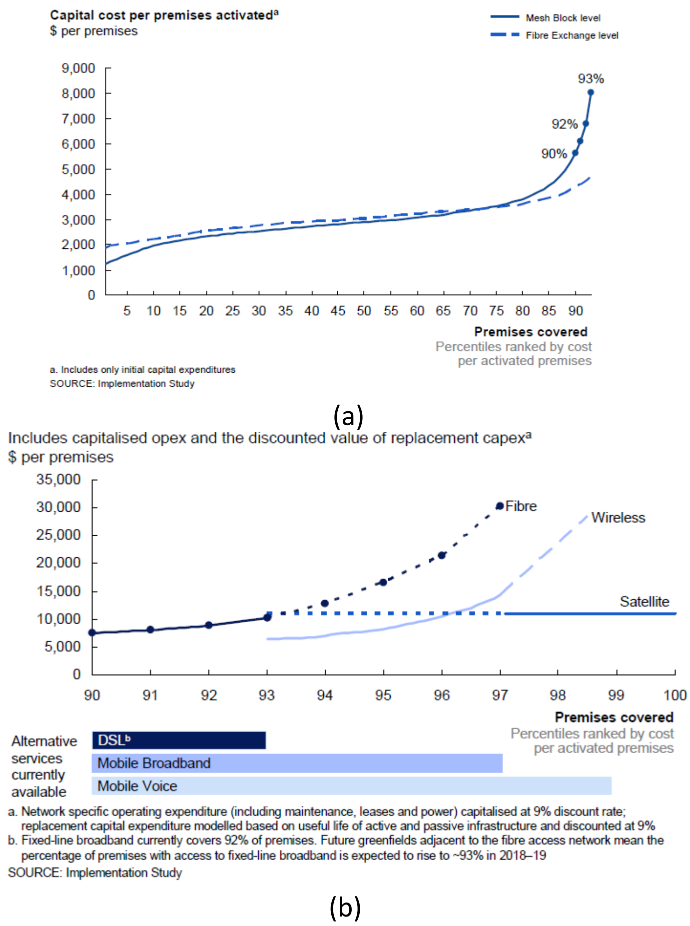


*Figure 3-19. **Rapidly escalating costs of FTTP (a) up to and (b) beyond the 93% threshold. (Source: NBN, 2010).***

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 150 km from Yass to Rye Park to Boorowa (NSW).

3.9 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 option 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 3-20.

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).

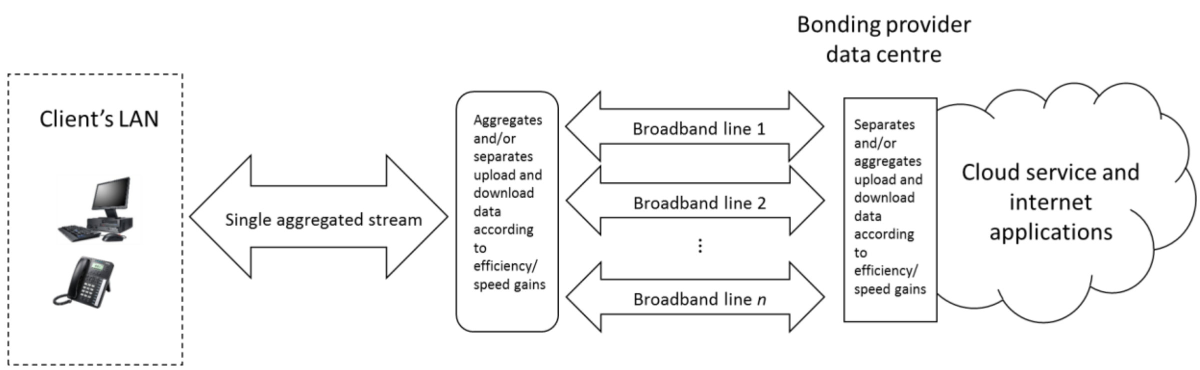


*Figure 3-20. **Schematic of broadband bonding (Extracted from Lamb, 2017).***

4 Second tier telecommunications providers

The last 2-3 years has seen the emergence of 'second tier' telecommunications service providers (introduced earlier) seeking to deliver end-to-end services onto feedlots. While offering a 'fresh' alternative to existing network operators (tapping into frustrations around perceived accessibility to service and support), what they are really selling is 'guaranteed performance/speed' on what is, in many cases, a taylor-made uncontended (1:1) network.

These providers, typically certified carriers in their own right, have access to large capacity transmission infrastructure such as dark fibre and regional POP from which to launch wireless connectivity. They are often offering managed fibre services, purchasing portions of spectrum for necessary point-to-point links and are seeking physical space on existing point-to-point transmission infrastructure or negotiating access to high points such as local SES towers and grain elevators (refer to schematic in Figure 3-2). At the feedlot 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 LWAN providers, and even with IoT providers to run connectivity literally into the sheds, troughs, tanks and machines (the types of connected devices/entities in feedlots were summarised earlier in Figure 1-1).

In addition to offering the networking capability, many of these second tier providers act ISPs and offer 'defining' data packages that include immunity from 'shaping', such as occurs under the NBN Fair Use Policy and competing carriage service provider (CSP)/ISP data agreements. The defining point is that they seek to guarantee speeds of 10 MBps up to 100 MBps up AND down. For many clients (and especially the first ones connected) in a sequence, contention ratios are 1:1 and, invariably, the gap between quoted and guaranteed speeds is small. This is what feedlot operators want: Speeds in the morning (and at night) that are almost equal to speeds during the afternoon.

For the purposes of this review, a number of examples will be discussed below. These have been selected purely on the basis of illustrating the breadth and depth of services on offer in this rapidly emerging marketplace[12].

Wi-Sky (www.wi-sky-com.au) is an example which focusses on shared infrastructure. In early rollouts in central NSW, they focussed on a limited number of 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 (NSW) 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 trialled 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 80 Mbps download and 4 Mbps upload speed (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 restrictions of ADSL aggregation.

Another example is Field Solutions Group (FSG; http://www.fieldsolutions-group.com/). As a licensed Australian communications carrier, FSG partners with other Telcommunications Carriers to

[12] No endorsement of a particular product or service is intended, offered, nor should be implied by the reader

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 connectivity options including lit and dark fibre, microwave (through lease or purchase of bandwidth at nearby telco POP sites), establishing ethernet links and Wi-Fi cells, or via NBN (fibre and wireless) and satellite.

Many of these second tier providers have staff with experience covering WANs, backhaul telecommunications (including fibre rollout) and core infrastructure development and management, These emerging businesses are capable of offering full end-to-end solutions for producers (for example as depicted in Figure 3-2). All aspects of the connectivity are included, such as:

- Reserving a portion of the 11 GHz beam (POP – local 3G/4G tower, fibre access etc),
- Installing the antenna on the tower,
- Establishing the point-to-point (e.g. 5 or 11 GHz) link to the client cell, and
- Establishing the point-to-multipoint connections to outlying buildings and regions within the feedlot.

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 360^{o} 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). These networks are built for low latency, hence supporting voice (e.g. VOIP) and video as well.

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 the base of the HSE business.

Facing limited and unreliable connectivity, HSE established a 46 km-long wireless link (Figure 4-1) 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 4-1) will be set to connect a group of other cattle stations in the Richmond area.

A sample list of second tier providers currently in the marketplace (in Australia) is given in Table 4-1. This is not an exhaustive list and is merely a representation of the breadth of providers in the marketplace.

Figure 4-1. ***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).***

Table 4-1. ***A sample[13] of some of the second tier providers currently active in the Australian marketplace. (Source: MLA, 2018).***

Supplier	**Website (where idenfiable)**							**Connectivity Type**								**Service**				
		Phone (Mobile)	Satellite (excl Skymuster)	Dark Fibre	Microwave	Other Wifi	NBN (Fibre/Wirelsss)	LoraWAN	Skymuster	Radio	Digital Radio (UHF)	Push to Talk Cellular	Cable (copper or fibre)	Transportable Solns.		**Voice (phone)**	**Data**	**Voice (emergnecy)**	**Homestead**	**Paddock**
Community Telecommunications Group	http://www.ctg.org.au/				●		●							●		●	●	●	●	●
Harrington Systems / Wi-Sky	http://www.harringtonsystems.com.au/				●											●	●	●	●	●
Radlink	www.radlink.com.au										●									
ToooAir	www.toooair.com.au											●				●		●		●
Southern West Wireless	http://southwesternwireless.com/																			
Origo.farm	http://www.origo.farm/					●											●			
Belay Consulting	http://www.belayconsulting.com.au/																			
March IT	www.marchit.com.au					●											●		●	●
Optus	www.optus.com		●														●			
Hitachi	www.hitachi.com		●														●		●	●
NNNCo	www.nnco.com.au							●									●			
Connected Country (NNCo & Discovery Ag)								●									●			
Field Solutions	http://www.fieldsolutions-group.com/	●		●	●	●	●	●	●											
World Telecom Labs	www.wtl.be																			
Myriota	http://myriota.com/		●														●		●	●
Fleet Space Technologies	www.fleet.space		●														●		●	●
Pivotel	www.pivotel.com.au		●													●	●	●	●	●
Digital Drift	www.digitaldrift.com.au												●				●			●
Pacific Data Systems	www.pacdatasys.com.au	●							●	●										
Activ8me							●		●											
AusLogic		●		●	●	●	●	●	●	●			●							
March IT	https://marchit.com.au	●		●	●	●	●	●	●	●			●							
Cirrus Communications	www.cirruscomms.com.au	●		●	●	●	●	●	●	●			●							

[13] No endorsement of a particular product or service is intended, offered, nor should be implied by the reader

5 A selection of other emerging communications technologies that may make a difference to feedlot telecommunications

5.1 Deployable networks for transient or moving targets

A number of feedlot operators identified the desirability of high capacity internet access while moving around their feedlots or to meet peak demands at fixed (although temporary) locations during certain operations. This could include cattle yard operations (for example induction), out in the field harvesting or similar intensive field machinery operations, or local field days and on-site auctions. 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 5-1).

*Figure 5-1. **An example 'auto-align' MIMO terminal providing high-capacity links to a central (line of sight) base station (Photo http://rdlcom.com/products/view/ras-elite) (Extracted from Lamb, 2017).***

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.

5.2 Voice communications over Internet and Wi-Fi (VoWIFI)

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 reduce 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 trialling 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)

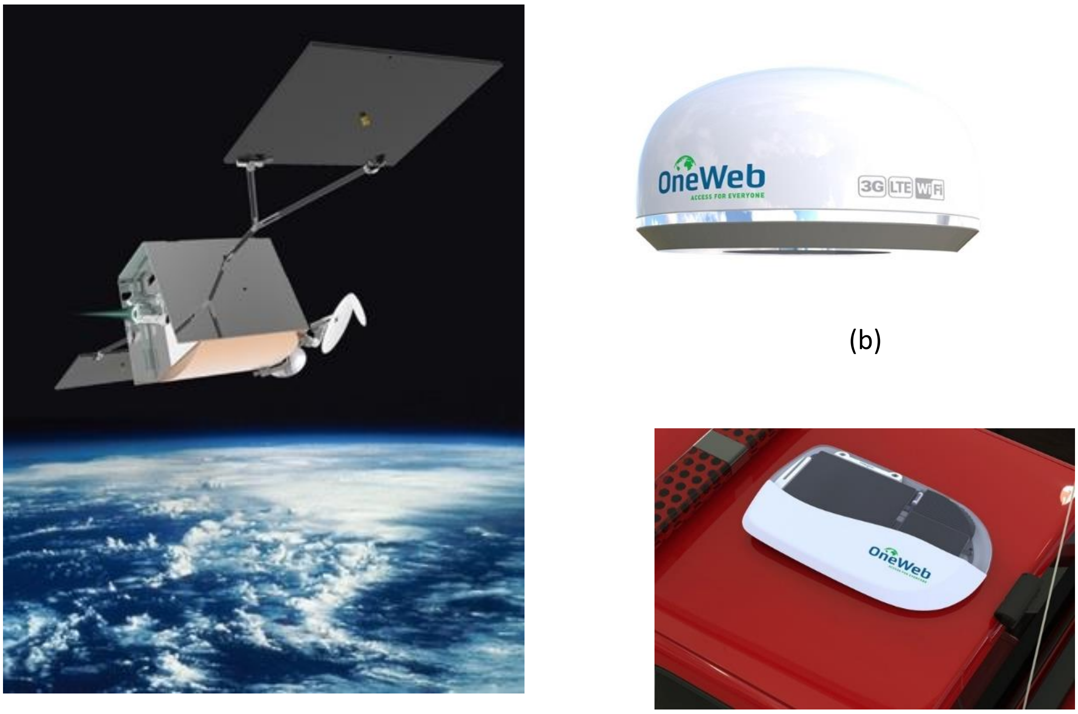
Radio over internet (RoIP) is similar to VoIP but it augments radio communications rather than telephone calls. Ultimately RoIP is VoIP with 'push to talk' functionality afforded by radios, allowing 2-way radio communications over vast geographic areas or for linking disparate regions (for example providing 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.

5.3 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. 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.

5.4 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 5-2). 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, which are effectively supplementary network services that can be used by any ISP or telecommunication provider to extend any network, partners use the infrastructure with their current clients, devices and billing systems.



(a) (c)

Figure 5-2. ***(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) (Extracted from Lamb, 2017).***

5.5 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 FDD. 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.

6 Emerging technologies for the feedlot industry and implications for connectivity

The following section provides descriptions of emerging technologies that are being used, or are soon to be commercialised for use, in the feedlot industry. Each product example includes a description of the current status of the product and how it works, as well as tabulated conversation from interviews conducted with developers and distributers.

6.1 Smart tags

6.1.1 Example - Provenance4

Provenance4

Provenance4 - Australian, New Zealand & Asia–Pacific distributors of: QUANTIFIEDAG

Key product on offer/in development

Figure 6-1. ***An example of a self-illuminating smart tag designed to provide pen riders a visual indicator of animal health (Source: Stewart McConarchy).***

Provenance4 is the Australia-NZ distributor of Quantified Ag Biometric Sense Tag® such as the one depicted in Figure 6-1. This tag offers the capability to monitor motion (accelerometer) and temperature on individual animals and transmit it every 1 hour at 918- 956 MHz spectrum (Section 2.3). A new tag is to be launched later this year.

Provenance4 is currently undertaking trials at a number of Australian feedlots in South Australia, Victoria, New South Wales and Queensland. Once tags are deployed in the pens, the cloud-based system monitors temperature and movement data to identify outliers that help improve overall animal health.

Provenance4 has a global contract with satellite telecommunications provider InmarSat, so is potentially capable of supporting connectivity-enabled technologies anywhere in Australia, if required. From October 2017 Inmarsat released their IoT platform for Agriculture and Provenance4, as a partner, has access to the IoT platform. Provenance4 also has supply of communication solutions from M2M One (Telstra Jasper Platform provider) plus has access to the SIGFOX network.

The system involves an onsite base station/hub aerial (omni-directional) positioned on top of a silo/elevator. It is capable of reading tag transmissions up to 3 km away. It collects tag readings every ~ 10 minutes. Interview question and answers are recorded in Table 6-1.

Basic Connectivity Schematic

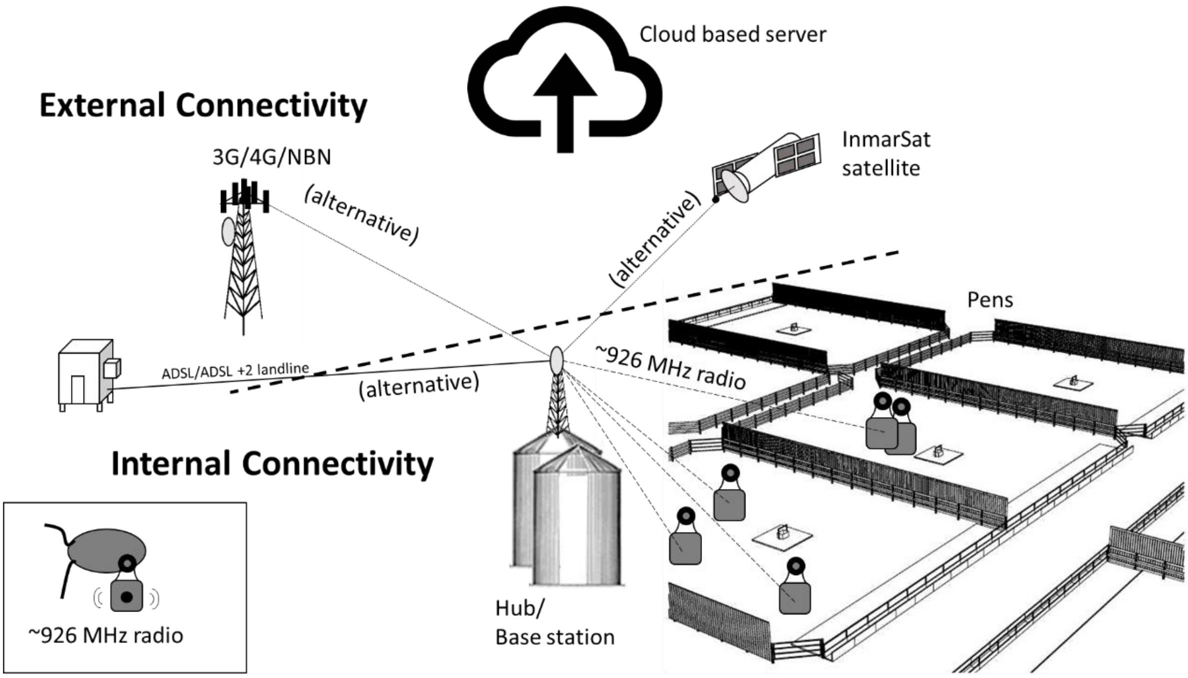


Figure 6-2. ***A schematic showing connectivity between smart tags and internal and external systems (Source: Stewart McConarchy).***

6.1.2 Example - REDI tag

Key product on offer/in development

*Figure 6-3. **Feedlot cattle with REDI tags (ear tag in animals left ear) and behind them is a pole-mounted receiver (linked via ethernet cable). In the Australian trials the system is entirely wireless (Wi-Fi 2.4 GHz). (Source: Precision Animal Solutions).***

Precision Animal Solutions is developing and trialling (in Australia) an automatic disease detection and animal identification system 'REDI'. The system utilises ear tags with a Wi-Fi (2.4 GHz) transmitter. An array of receivers ('readers') located around the pen precinct enables the individual animal locations to be determined via a process known as trilateration. The Wi-Fi trilateration is capable of achieving 0.5 m location accuracy, necessary for health status algorithms to work. In practice, stationary tag testing over 24 hours, indicates 95-98% of position records to be within this threshold. Readers are placed approximately 80 m from each other around the pens and a minimum of 4 readers are required for trilateration.

The readers are linked via wireless to the onsite server. The readers and access point may be inter-linked and subsequently on to the onsite server via entirely wireless (2.4 GHz) means or Cat 5 ethernet cable (e.g. Figure 6-3). The onsite server is connected to the cloud-based server via external connectivity- e.g. mobile network, NBN, landline) where the algorithms are operated.

The detection and identification algorithm trains on 3 days of accumulated baseline data, and from then on, the algorithms are put to work.

A 2-way transmit/receive capability on board the tags allows the system to activate coloured indicator lights on those tags where the location/movement metrics indicate the animal to be unwell. This makes it easier for pen rider to identify and pull the suspect animal.

Whilst the livestock tags transmit at ~ 1 s intervals, the location sampling frequency to the server is often limited by the reader- server distance. For the health algorithm to work, the frequency of location readings is just as important as the (individual) positional accuracy readings. Reading are usually received every 4-15 seconds, typically every 15 seconds. Interview question and answers are recorded in Table 6-2.

Basic Connectivity Schematic

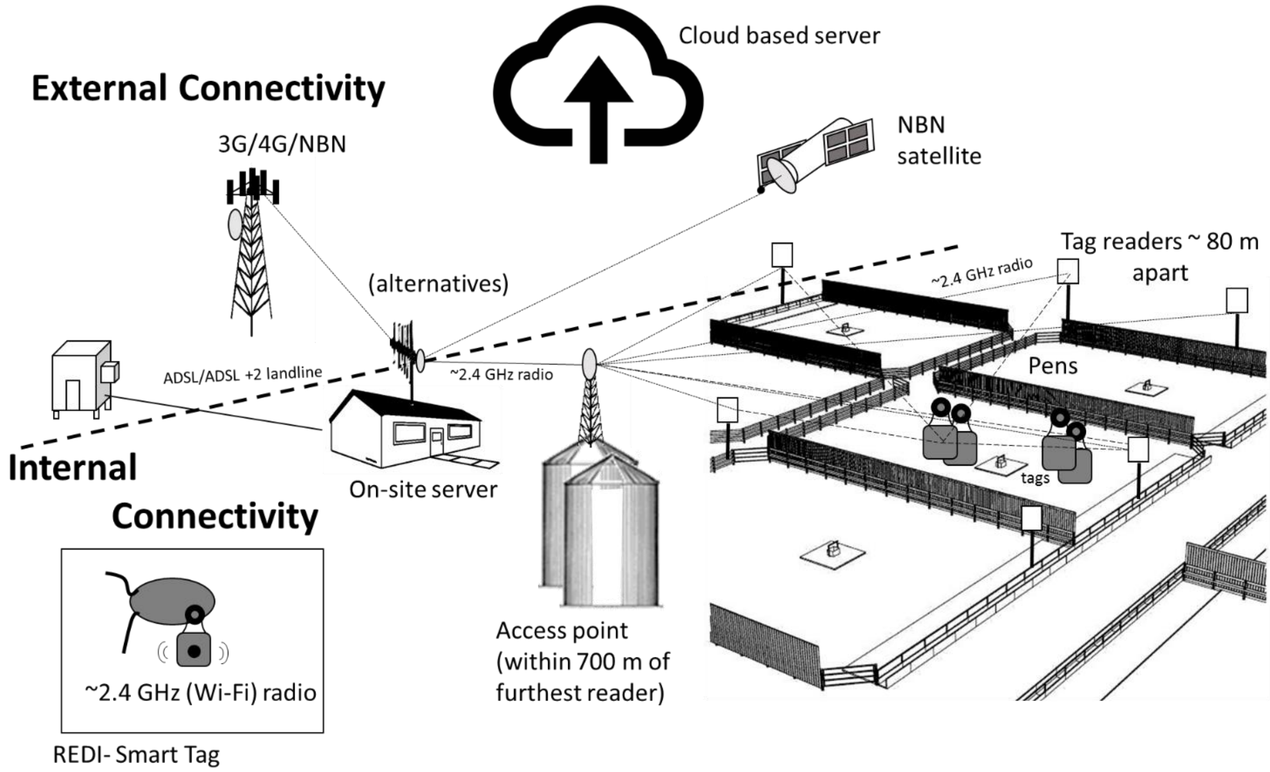


Figure 6-4. ***A schematic showing connectivity between REDI smart tags and internal and external system***

6.2 Bunk scanners (e.g. Manabotix)

MANABOTIX

Key product on offer/in development

(a)

(b)

*Figure 6-5. **(a) A LiDAR bunk scanner that measures feed volume in the bunk and calculates amount of feed and (b) view of feed presentation to the scanner. (Source: MLA, 2018b).***

Manabotix have developed a prototype bunk scanning system which allows the user to estimate the amount of feed remaining in bunks. Current trials involve assessing the accuracy and precision of the estimation algorithms for a range of diets, as well as to quantify the accuracy and precision of visual estimations. The only external connectivity required is to support the RTK GNSS receiver which is required periodically to provide 6 mm horizontal accuracy during the estimations. In the current arrangement this is facilitated by a RTK base station installed on the feedlot office that transmits the correction signal on the 4GX mobile network band (Table 3-1). The GNSS ‘rover’ receiver installed on the vehicle is also connected via the 4GX mobile network to receive the correction signal. If mobile network (3G/4G/4GX) is not available for extended durations then a radio link could be used between the base station and receiver, similar to that used in broad-acre farming RTK systems.

The system works entirely inside 'the box' which is installed on the vehicle. Interview question and answers are recorded in Table 6-3.

Basic Connectivity Schematic

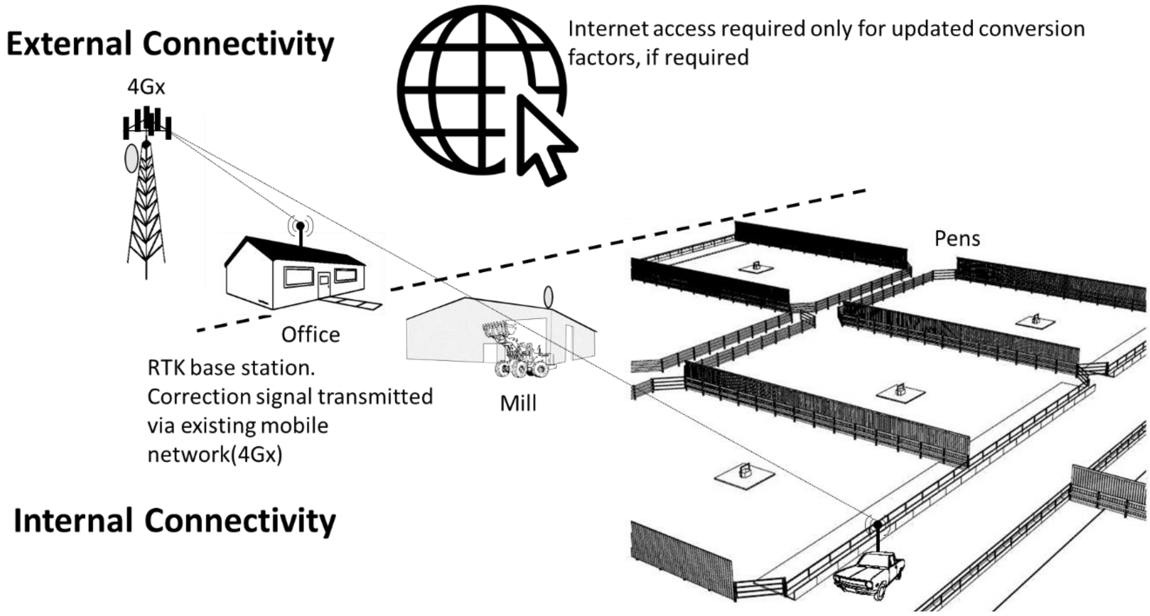


Table 6-1. Interview conducted with distributors of Quantified Ag Biometric Sense Tag® - Provenance4

<table>
<tr><th>Question</th><th>Response</th></tr>
<tr><td>How much data does the system generate – e.g. when/if scaled to 1,000 head, 2,500 head, 5,000 head, 12,500 head, 25,000 head monitored (I gather this will be an estimate)? How scalable is it and are there extenuating requirements that need to be factored in when/if contemplating scaling upwards.</td><td>Individual ear tags continually transmit data and stores it in the base station.
Hub/base station collects 34 bits to 1kb per hour (per animal).

Data transmitted from Hub to cloud every 1 hour (Can program hub to send data anytime to avoid network congestion periods).

<table>
<tr><td>Number of head</td><td>Accumulate data to hub (per hour)</td><td>Frequency of transmission</td><td>Data per month</td></tr>
<tr><td>1,000</td><td>34 bits PLUS</td><td>Every 1 hour</td><td>24.4 Mb</td></tr>
<tr><td>5,000</td><td></td><td></td><td>122.4 Mb</td></tr>
<tr><td>20,000</td><td></td><td></td><td>489.6 Mb</td></tr>
<tr><td>100,000</td><td></td><td></td><td>2.4 Gb</td></tr>
<tr><td>100,000</td><td>Assuming 100 bits (16.7 bits/10 mins)</td><td></td><td>7.2 Gb</td></tr>
</table></td></tr>
<tr><td>How important is internet access (or cloud) to the system. How would it operate in situations where connectivity is unreliable (i.e. may exist but speeds vary during day/night).</td><td>If the feedlot does not have access to 3G/NBN/ADSL, then the system can be connected via the InmarSat IoT platform.</td></tr>
<tr><td>Is the system wholly reliant upon cloud-based platforms? Is there an edge of cloud option (existing or in planning)?</td><td>This is a cloud-based system.</td></tr>
<tr><td>What on-farm (internal) connectivity would be required if the data gathering system (e.g. in pens) were distant from the external connectivity point (e.g. farm office)- e.g. would it require a certain Wi-Fi-type spec system or LPWAN or for P-P transmission?</td><td>The tags offer capability to monitor motion (accelerometer) and temperature and transmit it every 10 minutes on the 918 – 956 MHz spectrum. If there is power/internet outage, the hub/base station has a 32GB drive onsite storage capability to hold on to the data.</td></tr>
</table>

Are there any other specific wireless requirements for your system to work. For example ultrawide bandwidth TxRx in the pen environment may require access to spectrum that is presently outside of the ISM bands and hence would require licensing/approvals etc.	None- the system work on the LIPD 918 - 956 MHz spectrum.
What is the level of complexity of the system? Here I'm after an indication of whether it is a system that requires professional support all of the time, part of the time, none of the time (unless 'emergency' e.g. storm damage)	The physical infrastructure is a single hub/base station. Online support will be available.
(If not discussed in above) Are there any important aspects you see that is necessary for your system to succeed under Australian conditions (e.g. digital literacy of users, connectivity/remoteness etc etc.).	None foreseen
How close do you think you are to an operational rollout status of your product in Australia (bearing in mind the points discussed above) (i.e. not constrained by your service model or resourcing). Or do you think your product is likely to be constrained.	We expect new tags to be available on the Australian market by the end 2018.

Table 6-2. Interview conducted with developers of the Remote Early Disease Identification (REDI) System – Precision Animal Solutions

<table>
<tr><td>Question</td><td>Response</td></tr>
<tr><td>How much data does the system generate – e.g. when/if scaled to 1,000 head, 2,500 head, 5,000 head, 12,500 head, 25,000 head monitored (I gather this will be an estimate)? How scalable is it and are there extenuating requirements that need to be factored in when/if contemplating scaling upwards.</td><td>
<table>
<tr><td>Number of head</td><td>Accumulated data to cloud for each location fixes (approx..)</td><td>Frequency of transmission</td><td>Data per month</td></tr>
<tr><td>1,000</td><td>1.2 Mb</td><td>Every 15 seconds</td><td>207 Gb</td></tr>
<tr><td>5,000</td><td></td><td></td><td>1,037 Gb</td></tr>
<tr><td>20,000</td><td></td><td></td><td>4,147 Gb</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td>
<table><tr><td>100,000</td><td></td><td></td><td>20.7 Tb</td></tr></table>

Note that as this system is running live from the on-site server to the cloud, in order to achieve this data throughput, a feedlot may require minimum access speeds of 80 kbps (1000 head) to 1.6 Mbps for 10,000 head to send this data across to the U.S. This is entirely achievable with mobile broadband and NBN connectivity to a feedlot.
</td></tr>
<tr><td>How important is internet access (or cloud) to the system. How would it operate in situations where connectivity is unreliable (i.e. may exist but speeds vary during day/night).</td><td>The system is currently fully dependent of continuous access to the cloud as the on-site server does not currently possess a store-on-board capability.</td></tr>
<tr><td>Is the system wholly reliant upon cloud-based platforms? Is there an edge of cloud option (existing or in planning)?</td><td>Currently there is no edge of cloud option however Precision Animal Solutions are considering this. Such as strategies to process data on the onsite server with packages of pre-processed data sent into the cloud for centralised checking. Such a system could also support remote system performance checking and software/firmware upgrades.</td></tr>
<tr><td>What on-farm (internal) connectivity would be required if the data gathering system (e.g. in pens) were distant from the external connectivity point (e.g. farm office)- e.g. would it require a certain Wi-Fi-type spec system or LPWAN or for P-P transmission?</td><td>The system works entirely on 2.4 GHz (Wi-Fi) band and all 16 available channels within this band. It is preferable that the server is located as close to the readers as practicable. Wi-Fi (2.4 GHz) interference is a critical challenge for this system in its current format. All available Wi-Fi channels are utilised and the system ‘channel hops’ to utilise available channels. With increasing usage of 2.4 GHz Wi-Fi links (for example trucks-mills-office and other point-to-point links this challenge will increase). One solution is for users of this system to replace other point-to-point links with Wi-Fi-n (5 GHz). Moreover, as increasing numbers of Australian feedlots are installing internal fibre loops, this may alleviate the issue. Currently the onsite server doesn’t store data, hence continuous (and reliable) internet connectivity is required. Precision Animal Solutions are working towards a store-on-site capability for the servers.</td></tr>
<tr><td>Are there any other specific wireless requirements for your system to work. For example ultrawide bandwidth TxRx in the pen environment may require access to spectrum that is presently outside</td><td>Precision Animal Solutions are considering ultra-wide bandwidth (UWB) options although this band is not presently recognised as part of the ISM spectrum available for use. Use would therefore likely require ACMA approvals.</td></tr>
</table>

of the ISM bands and hence would require licensing/approvals etc.	
What is the level of complexity of the system? Here I'm after an indication of whether it is a system that requires professional support all of the time, part of the time, none of the time (unless 'emergency' e.g. storm damage)	Ultimately this system is designed to be a simple plug and play, requiring only hardware mounts (for Wi-Fi transceivers). The system will likely need establishment and ongoing running support.
(If not discussed in above) Are there any important aspects you see that is necessary for your system to succeed under Australian conditions (e.g. digital literacy of users, connectivity/remoteness etc etc.).	Precision Animal Solutions recognise the need for onsite support during initial deployment phases on each feedlot.
How close do you think you are to an operational rollout status of your product in Australia (bearing in mind the points discussed above) (i.e. not constrained by your service model or resourcing). Or do you think your product is likely to be constrained.	The REDI system is currently undergoing operational trials in Australia. Currently there is an expectation of operational deployment within 6 months to 1 year.

Table 6-3. Interview conducted with developers of the Bunk Scanner – Manabotix

<table>
<tr><th>Question</th><th>Response</th></tr>
<tr><td>How much data does the system generate – e.g. when/if scaled to 1,000 head, 2,500 head, 5,000 head, 12,500 head, 25,000 head monitored (I gather this will be an estimate)? How scalable is it and are there extenuating requirements that need to be factored in when/if contemplating scaling upwards.</td><td>N/A - the system calculates feed volume in the bunks from the LiDAR data and, via a conversion factor (depending on feed type) converts this to a feed mass. All data processing is completed by an on-board mobile system. Ultimately the feed calculation generates a single number per feed management unit, namely the individual bunks/pens depending on the feedlot management configuration. This can be communicated by paper, voice (UHF), mobile network, or ultimately via a radio link (requiring ~ 64 kb per bunk call).
<table>
<tr><td>Data per bunk call</td><td>Frequency of transmission (per bunk)</td><td>Data per month (per bunk)</td></tr>
<tr><td>Assuming 9.6 kb</td><td>1 bunk call per day</td><td>288 kb</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>(8 kb for header and 1.6 kb for message)</td><td>2 per day</td><td>576 kb</td></tr>
</table>
<table>
<tr><td>Data for RTK</td><td>Frequency of transmission (per bunk)</td><td>Data per month (per bunk)</td></tr>
<tr><td rowspan="2">Assuming 800 bps and 2 mins per bunk = 96 kb per bunk</td><td>1 bunk call per day</td><td>2.88 Mb</td></tr>
<tr><td>2 per day</td><td>5.76 Mb</td></tr>
</table>
</td></tr>
<tr><td>How important is internet access (or cloud) to the system. How would it operate in situations where connectivity is unreliable (i.e. may exist but speeds vary during day/night).</td><td>There is no requirement to be connected to the internet. The measurement of feed volume is completed on-board the vehicle. The only external connectivity is that used for the RTK GNSS positioning that is necessary to provide an accurate volume estimates. The trials completed to date have made use of the external 4GX mobile network to link the RTK base station to the rover. If unavailable, then alternate UHF/radio links could be used.</td></tr>
<tr><td>Is the system wholly reliant upon cloud-based platforms? Is there an edge of cloud option (existing or in planning)?</td><td>Cloud-based platforms are not a necessary platform. At a later stage, and based on availability, system upgrades or user inputs for the latest in volumetric/mass conversion factors (literally a single number) may be made available via internet connection.</td></tr>
<tr><td>What on-farm (internal) connectivity would be required if the data gathering system (e.g. in pens) were distant from the external connectivity point (e.g. farm office)- e.g. would it require a certain Wi-Fi-type spec system or LPWAN or for P-P transmission?</td><td>This is dependent on the most appropriate localisation technology for the producer’s operation. Manabotix may consider alternative deployment methods to mitigate the reliance upon external connectivity for positioning- i.e. RTK GNSS, though their feasibilities will be front-of-mind, especially regarding performance requirements versus cost and installation implications.</td></tr>
<tr><td>Are there any other specific wireless requirements for your system to work. For example ultrawide bandwidth TxRx in the pen environment may require access to spectrum that is presently outside</td><td>None - the only connectivity requirements is associated with currently available (and approved) RTK GNSS units.</td></tr>
</table>

of the ISM bands and hence would require licensing/approvals etc.	
What is the level of complexity of the system? Here I'm after an indication of whether it is a system that requires professional support all of the time, part of the time, none of the time (unless 'emergency' e.g. storm damage)	It is provided as a simple plug and play system requiring only hardware mounts on the vehicle chassis.
(If not discussed in above) Are there any important aspects you see that is necessary for your system to succeed under Australian conditions (e.g. digital literacy of users, connectivity/remoteness etc etc.).	None foreseen
How close do you think you are to an operational rollout status of your product in Australia (bearing in mind the points discussed above) (i.e. not constrained by your service model or resourcing). Or do you think your product is likely to be constrained.	Evaluation trials of this system have already been completed (funded by MLA). So far, accuracy in feed estimates has returned a mean absolute error of 12 kg, from slick bunks up to 330kg feed remaining, under normal operating conditions; equivalent results were returned in a non-operational test bunk, from slick up to 1.5t feed remaining masses.

7 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.

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 (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.

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

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.

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

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.

Boeing (2018). http://www.afr.com/technology/boeing-backs-myriota-an-aussie-satellite-startup-thats-raised-194m-20180325-h0xy2u). Accessed May 2018.

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

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.

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

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.

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.

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), September 2017, 128 pages. ISBN 978-1-921597-74-9 (Hard copy), ISBN 978-1-921597-75-6 (Digital).

Lamb, D.W. (2017b) "Telecommunications and Australian agriculture: Will top down meet bottom up?" Australian Farm Policy Journal. FPJ1403E 14 (3): 31-47.

Lamb, D.W. (2018) "Connecting Australian farmers: Gateways, gatekeepers and a forgotten solution" Australian Farm Policy Journal. 15 (1): 51-59.

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

MLA (2018) Data provided by Sean Starling, Meat Livestock Australia (personal communication).

MLA (2018b) https://www.mla.com.au/news-and-events/industry-news/automated-bunk-scanner-a-reality/. Accessed April 2018.

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.

NBNCo (2018) “Half yearly report (for the 6 months ended 31st December 2017). https://www.nbnco.com.au/content/dam/nbnco2/images/Half-hear-results-2018/nbn%20Half%20Year%20Report%202018.pdf. Accessed May 2018.

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.

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.

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.

Telstra Media (2016) 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.

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.

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.

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

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.