# Fifth Generation Cellular Networks

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## Abstract:

In this article the emerging requirements that are driving the fifth generation of mobile cellular networks are discussed and the technologies that will most likely be used to satisfy those requirements are identified. Proposals for 5G are at an early stage, but there is an expectation that the early 2020s will see the first deployments.

The requirements for 5G are increased download speeds, the need to deal with increased cell density, increased bandwidth efficiency and availability of new bandwidth. It is likely that 5G will play a role in the emerging Internet of Things, potentially resulting in enormous increase in the number of attached devices.

To meet the expected requirements 5G is likely to make use of spectrum in the millimetre range, beam-forming antenna arrays, massive Multi-Input Multi-Output, and fundamental changes to base station design. In this paper the key drivers for 5G are discussed including the very large numbers of devices in cells, the need to make available new spectrum, energy efficient ways of implementing base station capabilities, standards developments so far and 5G related issues for Australia.

**Keywords**: Fifth generation Cellular networks, 5G

## Introduction

The fifth generation cellular network (5G) is starting to gain attention from standards bodies, carriers, manufacturers and researchers. There is an increasing need on the part of carriers to support much larger numbers of end devices than in the past and at much greater bit rates. Within less than a decade the Internet of Things is expected to more than double the number of devices attached to the Internet, a substantial number of which will likely be attached via cellular networks. At the same time there is a need to make more efficient use of existing spectrum allocated to cellular systems and if possible open up new spectrum. Fortunately, there have been developments in wireless communications technologies that



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should be able to meet these challenges, but the changes are sufficiently substantial as to constitute a new generation of cellular systems; a fifth generation or 5G.

In this paper we look at the factors leading to these increased demands and the technologies of 5G that are likely to be used to meet them. We also consider the impact 5G might have on the Australian communications environment.

Developments in cellular systems have been classified as generational when there has been a dramatic change in what the system can do and in how it does it. Although generational change typically results in higher data rates for customers and improved bandwidth efficiency for carriers, it has also usually meant a substantial change in the way the technology works, in what the technology can do for consumers, and how it is implemented and managed by operators. Each generation has delivered significant changes to the cellular environment compared with its predecessor, benefiting both customers and operators. Looking at the key changes each generation brought, 1G introduced mobile telephony. 2G introduced digital voice communication, some data services, improved security and SMS messaging. 3G introduced multimedia communications and native Internet access. 4G enabled seamless handover between different access networks and allowed carriers to rationalise their networks to all use a common Internet Protocol (IP) based core (Pereira & Sousa 2004).

Each new generation has seen new spectrum become available, improvements in the efficiency with which spectrum is used and hence the ability to support more customers, as well as efficiencies in how the network is constructed and managed enabling reductions in operational expenditure (ACMA 2016b).

The most successful first generation cellular technology in Australia was the AMPS system. AMPS was introduced into Australia in 1987. It was an analogue system making use of frequency division modulation (FDM). Handsets were bulky and heavy, communications were insecure and the cost of subscribing to a service was high. Nevertheless, the demand for the mobile voice service it provided made it a success (The Economist 2016).

A number of 2G technologies were introduced into Australia including CDMA and GSM, the most successful of which was GSM. GSM was introduced to Australia in 1993. It is still very widely used throughout the world and is only now (1st December 2016) being shut down in Australia by Telstra. GSM is a digital system, provides very good security but the main service it provides is still voice. It does offer some limited data capabilities but at quite low bit rates (Pereira & Sousa 2004).

The most widely used third generation cellular technology currently available within Australia is the Universal Mobile Terrestrial System (UMTS). UMTS was developed to



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support Internet services as well as voice. It incorporated capabilities and technologies from intermediate generations, notably the General Packet Radio Service (GPRS) which is sometimes referred to as 2.5 G.

In 2015 the Long Term Evolution (LTE) system was released in Australia. Telstra, Optus and Vodafone all run LTE in Australia. A 4G technology should be able to achieve download speeds of up to 1 Gbps. Early releases of LTE increased the speed possible for cellular users, but rarely achieved that rate. However, LTE has evolved and releases since are able to achieve that rat (Rost et al 2016). Although the download speed requirement of 4G took some time to be met by LTE it was nevertheless regarded as 4G because it achieves the other goals that define a 4G network: namely wider spectrum and an IP based core network, making possible rationalisation of networks supported by a carrier and seamless handover between radio access networks (Pereira & Sousa 2004).

So what might we expect of 5G? The GSM Association (GSMA Intelligence 2014) have identified seven characteristics that they believe are needed for the next generation of cellular systems. These are

- data rates of between 1 to 10 Gbps,
- extremely low latency,
- 1000 times more bandwidth per unit area than is currently available with 4G,
- 10 to 100 times as many connected devices,
- very high levels of availability and coverage,
- 90% reduction in network energy usage, and
- for low power devices, up to 10 year battery life.

5G is likely to meet these requirements by making use of previously lightly-used spectrum, increasing the efficiency in the way spectrum is used and by providing more flexible infrastructure for the development of new services (Agiwan et al *in press*). It is likely to have download speeds of up to several Gbps. Most operators believe 5G will play a significant role in the Internet of Things (Ericsson 2016). Depending on the extent to which IoT relies on cellular networks it may well result in an enormous increase in the number of new devices attached to cellular networks, with quite different requirements from those of the current user population.

In the next section we consider how these factors may combine to create the next generation of cellular networks.

## The need for a new Cellular Generation

The need for cellular systems to support an increased number of attached devices and increased speeds for those devices continues its seemingly inexorable progress (The Economist 2016). The ubiquity of the smart-phone has increased the number of end users, the amount of data they consume and the rate at which they consume data.

This trend is unlikely to change. However, it is the arrival of the Internet of Things (IoT) that may well contribute to a dramatic increase in the number of attached devices (Press 2014). The IoT is the bringing together of sensor and actuator networks that are monitored and controlled by cloud based processes. The IoT encompasses many applications: from stationary sensor networks, smart cities where sensor and actuator networks are used to monitor and control the flow of people, traffic and utilities, smart buildings where networks are used to minimise energy consumption, through to vehicle-to-vehicle communications, and ad hoc emergency management.

The speed with which the Internet of Things is expected to be deployed and the sheer scale of it is extraordinary. There are currently approximately 14 billion devices connected to the Internet, most of which are used for conventional communication such as telephony, messaging, social media, email or web browsing. However, according to IDC (Kennellos 2016) by 2025 there will be approximately 80 billion devices connected to the Internet, most of which will be communicating with other devices or cloud-based services.

Although IoT home based services have attracted most attention, it is industrial and infrastructure services such as transport, agriculture and 'smart city' applications that are likely to account for most of the growth in the number of devices (Condon 2016).

There is an expectation that 5G will be the main communications technology supporting the IoT. If true, then the increase in the number of devices within urban areas is likely to be dramatic.

However, it is worth noting that this belief is not shared by everyone (ACMA 2016a). There are other competitor technologies to 5G as an IoT communications technology, such as LoraWan (Lora Alliance 2016), Weightless (Webb 2012) and WLAN (Aust et al 2012). Nevertheless, cellular has advantages over potential competitors in that it is well understood, geographically widely deployed and is the dominant communications technology in the Machine-to-Machine space which is one of the forerunners of the IoT.

Regardless of the future impact of IoT on 5G we will still see a great increase in the number of attached devices per cell, usually referred to as "densification". Densification is managed within a cellular network by making cells smaller. In densely populated urban areas such as



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central Tokyo and New York cell sizes are already frequently measured in 100s of metres rather than the tens of kilometres of earlier cellular generations. This densification is likely to continue.

Managing networks consisting of very large numbers of densely packed small cells creates many management challenges, but it also creates opportunities. In particular, small cells make possible the use of previously unused spectrum (Rappaport et al 2014). Other technological developments that might be included in 5G include advances in massive-input, massive-output (MIMO) antenna systems, beam forming antenna arrays and changes to technologies for provisioning services (Andrews et al. 2014).

The purpose of this paper is to provide readers with a wide overview of the requirements leading to the need for 5G and the technologies being developed and incorporated in standards that will comprise it. In the next section we look at each of the technology areas in more detail. We then discuss the state of standards development and conclude with some comments on the Australian perspective of 5G.

# Enabling Technologies for 5G

## Requirements of 5G

As noted, the GSM Association have identified the following characteristics that they believe are needed for the next generation of cellular systems. These are: data rates of between 1 to 10 Gbps; extremely low latency; 1000 times more bandwidth per unit area than is currently available with 4G; 10 to 100 times as many connected devices; very high levels of availability and coverage; 90% reduction in network energy usage; and for low power devices, up to 10 year battery life.

Some of these requirements are a result of 5G's expected role in IoT and related areas such a public safety, smart cities and smart buildings. Other requirements, such as very low latency, are needed for online games, but also to enable quick reaction times for emerging applications such as haptic feedback where a sense of touch is included in the user interface. Such capabilities make possible applications such as remote surgery and other forms of remote robotics where a rapid response is needed.

As well as new applications 5G will need to support familiar applications such as media streaming. Media companies are likely to want high bandwidth so that they can stream video at high resolutions. Consequently, mobile broadband is expected to be an important user of 5G (Wang et al 2014).

There is an expectation that 5G will contribute to infrastructure sharing, where the owners of the infrastructure and its operators are not necessarily the same. There are a number of scenarios possible: from passive sharing where the physical sites are shared, through active sharing where antennae, Base Stations, Radio Access Networks and possibly even Core networks are shared, through to the Mobile Virtual Network Operator where operators do not own any infrastructure of their own but enter into agreements with carriers to support their clients. In particular there has been standards development for a 5G network slice broker defining signalling protocols necessary to enable dynamic leasing of resources (Samdanis et al. 2016).

There is some discussion as to whether 5G is likely to be driven primarily by consumer or business needs (ACMA 2016a). Certainly media content delivery is more likely to be consumer oriented but some of the novel applications proposed for 5G such as smart cities and smart buildings are more likely to be business rather than consumer oriented.

In the next section we discuss the technologies that are expected to be used to meet the requirements of 5G.

## Millimetre Spectrum Technologies

Previous generations of cellular networks have usually enabled additional spectrum to be used. Mostly this has been in a limited range of frequencies around 1 GHz which has been regarded as the ideal frequency for cellular communications. Communications at this frequency has good coverage characteristics and handsets require only a small antenna. Unfortunately, frequencies in this range are mostly occupied, so options for 5G to make use of additional frequency might seem limited. However, the increased density of cells, and developments in wireless communications technology mean that frequencies that were once regarded as unsuitable now appear to hold quite a lot of promise. In particular the millimetre band with frequencies in the 10 to 60 GHz range are likely to be used in 5G (Rappaport et al. 2014).

Propagation of a wireless signal can be through direct line of sight, diffraction, reflection or scattering. Diffraction is where a wavefront bends around an obstacle, reflection is where it bounces off smooth surfaces, and scattering is where it bounces off rough surfaces. As frequency increases diffraction becomes a much less suitable mechanism for propagation of the signal. Also, as frequencies become higher, the ability of the signal to penetrate materials such as concrete decreases. Consequently, frequencies much more than two or three GHz have long been regarded as unsuitable for cellular networks.

However, the process of cell densification, where cell size decreases in urban areas as the number of devices increase, while causing problems in other ways, that will be discussed later, also opens up the possibility of using higher frequency spectrum in the millimetre range.

The potential range of millimetre spectrum is much less than that of lower frequency spectrum. In earlier generations cell sizes were originally up to about thirty kilometres whereas millimetre spectrum has a typical range of less than a kilometre. Also, diffraction is a much less effective propagation mechanism at this frequency. However, where cell densification has emerged as an issue, diffraction and range are much less important. In a densely populated urban environment cell sizes can be as small as a few hundred metres. Also, reflection off buildings is a more significant propagation mechanism than diffraction. With small urban cells the possibility of line of sight as the main propagation mechanism also becomes feasible. For all these reasons, attention has turned to the feasibility of using short wavelength spectrum in the millimetre range.

This spectrum has been largely unused for the reasons noted above. There are also physical factors that can affect the strength of signals at this frequency, notably absorption by water vapour and oxygen. However, these are only significant for distances of a kilometre or more in only a few frequency ranges. Oxygen absorption occurs at 57 to 64 GHz and water vapour at greater than 164 GHz. There is a great deal of unused or lightly used spectrum in the millimetre range.

Millimetre waves also have advantages in that the optimal antenna size is approximately half the wavelength. For millimetre length waves, this means it is possible for a handset to have a large number of antennas and still remain a reasonable size. Another advantage is in the area of space division multiplexing where most signal strength is directed in a tight beam to an individual user. It is possible to direct a small wavelength signal far more accurately than signals with longer wavelengths (Rappaport et al. 2014).

Using millimetre waves might be suitable for devices that are fixed within a densely packed cell, such as might occur in the IoT or when the handset owner is outdoors in an urban area, but when the device moves inside or to a less densely packed area the problems of millimetre waves become apparent. Either additional infrastructure will need to be deployed in remotely populated areas, lower frequencies used or a different radio access network will be needed. The issue of seamless handover from one radio access network to another was dealt within LTE but may be of greater significance within 5G.

## Beam Forming Antennae

One of the key challenges of cellular networks is extracting the most use from the available spectrum. Spectrum is a scarce, expensive resource. It needs to be used in such a way as to maximise the number of users that can be supported or provide very high data rates to individual users who need them. The key way in which efficient use of spectrum is achieved is through reuse. The same spectrum is used in multiple cells across the network. Reusing spectrum introduces "co-channel interference" where two or more users, using the same spectrum, interfere with each other. In the past this has been dealt with by allocating spectrum across cells in such a way as to maximise the distance between co-channels, and through sectoring, where transmission and reception of a signal is towards only a particular sector of the cell.

One technology likely to be implemented within 5G that dramatically reduces co-channel interference is space division multiplexing (SDM). This approach makes use of highly-directional antennae where the main beam of the transmission signal is directed at the intended device or where interfering devices are placed within a null of the reception pattern (Agiwan et al. *in press*).

Early experiments with SDM involved electro-mechanical devices where horn-antenna were physically directed towards the mobile device. However, the approach now is to make use of an array of antennae and adjust the amplitude and the frequency of individual antennae in order to create a highly directional beam towards the attached device.

Small wavelengths lend themselves well to this approach. First the antennae can be small, since optimal antenna size is approximately half the wave-length, meaning that arrays with large numbers of antennae can be constructed relatively easily. Second, the size of the beam depends on the wavelength, with small wavelengths able to create more focussed beams than larger wavelengths.

To this end it is likely that 5G will include ways of making use of beam-forming antennae.

Base station antennae are likely to be quite different from what we have seen in the past. Because frequencies will be higher and cells will be smaller, antennae can be smaller. Also, antennae are likely to be less conspicuous and distributed, again a consequence of cell densification and smaller distances involved. Distributed antennae have been a feature of cellular since 2G but 5G is likely to take it to an extreme. A cell may have a number of transmit and receive antennae within it at different locations.

Arrays of antennae can also be used in other, related ways, which we discuss in the next section.



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## Multi-Input Multi-Output (MIMO)

In the previous section we discussed how antenna arrays can be used to construct tightly focussed beams in order to reduce co-channel interference. Antenna arrays can also be used to increase the amount of information transmitted using the same frequency band through a technology known as Multi-Input Multi-Output (MIMO).

With MIMO both the transmitter and receiver have an array of antennae. In MIMO antennae are separated by a distance comparable to the wavelength of the signal. Depending on implementation, each antenna transmits a different data stream. The aggregate signal is received by each receive antenna. However, because there is a separation between each of the transmit antennae and between each of the receive antennae, the receiver can determine the original signal on each transmit antenna. Essentially, MIMO takes advantage of the different path lengths between the multiple transmit and receive antennae and carries out computation to determine what was originally transmitted on each antenna.

MIMO has been used successfully in the WLAN technology IEEE 802.11n to obtain much higher bit rates using the same spectrum as 802.11a and 802.11g. Typically, two or three antennae are used since the size of the array is constrained to be comparable to the wavelength of the transmitted signal.

However, once again, the small wavelengths proposed for 5G become an advantage, since the small antenna size and separation needed for millimetre waves makes it feasible to include multiple antennae not just in the base station but also in the mobile device. Samsung have experimented with attached devices with 32 antennae (Rappaport et al. 2014).

Given its ability to increase the bit rates achievable it is likely that 5G will include "massive MIMO" where there are a large number of transmit and receive antennae.

## Network Management

The use of millimetre waves has great advantages for beam-forming, MIMO and cell densification but the factors that prevented its use in the past will need to be addressed in any 5G network. In particular, communications indoors and in more sparsely populated areas where larger cells are desirable are challenges. There is quite a lot of discussion as to how this is likely to be done. One suggestion is that antenna would be placed indoors and become as ubiquitous as WLAN access is. However, given that most smartphones support WLAN it may be that it becomes the standardised mode of access in those situations. For wider areas there is the choice of deploying many more antenna to cope with the much smaller cell size, using lower frequencies than is currently proposed, or having handover to another network (most likely LTE) for use in more conventional spectra. LTE addressed the



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issue of seamless handover between Radio Access Networks and it is expected that 5G will continue with developing this approach further.

Achieving all the goals of 5G will require complex coordinated management of resources. To this end another approach to network design denoted as "Cloud Radio Access Network" (C-RAN) is likely to be included within 5G (Checko et al. 2015). C-RAN involves the centralisation of much of the functionality previously allocated to individual base stations. MIMO and SDM require huge amounts of processing power to convert the baseband signal from the backhaul network into an RF signal. Usually this processing has been co-located within individual base stations. With C-RAN this computational power is shared among many base stations with savings in terms of equipment deployment and in obtaining greater utilisation of the equipment responsible for the computation. Base stations of necessity are usually designed for the busiest time of the day. Unfortunately, a consequence is that much of the installed capacity lies idle outside those busy times. C-RAN enables multiple cells to share the same infrastructure with consequent increased utilisation.

## Other Potential Technologies for 5G

The consensus seems to be that 5G will adopt millimetre wave spectrum, massive MIMO, space division multiplexing and cloud based RAN. However, a number of other technologies have been identified that may have an impact.

Cognitive Radio (CR) involves the constant monitoring by receivers and transmitters for free bands within licensed spectrum, which can be used on a temporary basis while the licensee is not using it. It has been proposed as a way of improving the utilisation of congested RF spectrum. Visible Light Communication (VLC) has also been proposed as another way of dealing with congested RF spectrum.

Given the relative abundance of spectrum in the millimetre range it may be unnecessary to make use of these technologies. However, if 5G does include use of spectrum in the congested RF bands they may well play a useful role.

## Standards Development

Standards development for 5G is still in the early stages. However, a recent notable development is that the FCC have designated blocks of spectrum for 5G. These are 28 GHz (27.5–28.35 GHz), 37 GHz (37–38.6 GHz) and 39 GHz (38.6–40 GHz) bands, and a new unlicensed band at 64-71 GHz. The hope is that this will encourage research and development along with technology trials (FCC 2015).

The ITU have also established a number of working groups to investigate options for 5G under IMT2000. These are groups for determining the requirements of 5G, the wireless technology to be used, the network technology, spectrum considerations and issues related to Intellectual Property Rights (Agiwan et al. *in press*).

Most commentary seems to agree that the technological changes planned for 5G will result in a new generational change in a similar manner to past generational changes, but there has been some discussion as to whether the use of the technologies proposed for 5G might be more evolutionary than revolutionary. In particular, the changes might be implemented as a development of LTE. The problem of dealing with sparsely populated cells or communications within buildings is likely to guarantee that LTE remains a widely used technology even after 5G is deployed in more densely populated areas. An alternative scenario is that 5G functionality might evolve as a development of IEEE 802.11 WLAN technology. In many ways the proposals for 5G, particularly small cells and MIMO, have more in common with WLAN than with traditional cellular technology. Most likely though is that there will be a cellular network generational change. It is worth noting that a summit sponsored by the European Telecommunications Standards Institute (ETSI) concluded that to make use of the emerging wireless technologies and to meet the requirements envisaged for cellular, evolution through LTE is unlikely to be effective and a new generation will be necessary.

Within Australia, the major carriers have all made commitments to providing 5G services when the technology becomes available. Most expect this to be around 2020.

The Australian Communications Media Authority (ACMA) have sponsored a consultation process on emerging issues for 5G which attracted considerable attention from carriers, manufacturers and other interested parties. The consultation process was based on the GSMA's characteristics of 5G (ACMA 2016b).

Telstra, in their submission noted that the emphasis on using high frequency bands meant that the issue of providing a service to regional and rural communities had been inadvertently overlooked. This is a significant issue for Australia with its very large but sparsely populated geographical area. Telstra would like to see lower frequencies included in any 5G standards. Lower frequencies are needed in order to provide coverage in a cost effective manner to larger, more sparsely populated areas.

Perhaps the key message is that there is still much to be resolved regarding 5G standards.



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## Conclusion

In this paper we have discussed the requirements driving the development of 5G and the technologies that will most likely be used to meet those requirements.

The fifth generation of cellular networks is being driven by increasingly dense populations of attached devices, demand for increased bandwidth, and an expected rapid increase in the number of devices attached to the Internet. The key developments that will enable this are the use of higher frequencies, beam forming antennae, massive MIMO and new radio access network approaches.

Most likely this will be achieved through a new cellular generation, but there are still many technical and standards related issues to be resolved.

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