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Technical advice by Plum Consulting concerning potential rights of use in the 3.6 GHz band

Updated Report 3: Analysis of the potential spectrum requirements for NGA services.

A report for ComReg

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Technical advice concerning potential rights of use in the 3.6 GHz band

Report 3: Analysis of the potential spectrum requirements for NGA services

A Report for ComReg

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Executive Summary

This report provides an assessment of potential spectrum requirements per operator to provide fixed broadband connectivity at a minimum headline speed of 30 Mbps using a typical state of the art wireless technology such as LTE-Advanced. Broadband connection speeds have been steadily increasing in recent years, largely driven by applications such as streaming video. For example, Cisco's Visual Networking Index (VNI) projects average broadband speeds in Western Europe to rise 150% between 2013 and 2018, to 49 Mbps. The 30 Mbps requirement is based on the target set in the European Union (EU) Digital Agenda for Europe (DAE), which seeks to ensure that every household in the EU has access to at least 30 Mbps by 2020. The figure is also consistent with the objectives set out in Ireland's National Broadband Plan.

In estimating the spectrum requirement, we have assumed that wireless broadband access would offer contended (shared) access to network capacity, in a similar way to existing cable broadband networks. The latter typically have contention ratios of the order of 8:1, which means that the available network bit rate may be shared between up to eight users. In practice, users will still be able to obtain close to the maximum available speed for most of the time, since the average bit rate per user across a network is typically at least an order of magnitude lower than the peak available bit rate, even during the busiest periods. For example, Cisco's estimate of total busy hour IP traffic across Western Europe in 2018 equates to approximately 1 Mbps per household, compared to the 49 Mbps average headline bit rate projected for that year.

There is a growing international consensus that the preferred technology for wireless broadband services in the future is LTE – Advanced (LTE-A), the long term evolution of the IMT-2000 family of wireless standards. We have therefore assumed deployment of LTE-A in our analysis, although this does not preclude the deployment of alternative technologies so long as these comply with the co-existence criteria for adjacent frequency bands and geographic areas described in ComReg document 15/73. Achieving such high speeds on a consistent basis requires the use of outdoor, rooftop mounted directional antennas at the customer premises. We have factored this assumption into our analysis and further assumed that in typical deployments 80% of subscriber antennas will have a line of sight path to at least one wireless base station. Assuming deployment of state of the art LTE-A technology with fixed directional antennas, up to 256QAM modulation and use of capacity enhancement techniques such as orthogonal polarisation to minimise co-channel inter-sector interference or deployment of dual polarisation MIMO, we estimate that over the medium to long term this should result in an overall spectrum efficiency of approximately 4 bps per Hz across a fixed wireless network.

To estimate the required radio spectrum, we have analysed population data for three representative areas in Ireland, representing typical urban, suburban and rural environments. Estimates have been made for three potential market scenarios, namely (i) the market share of wireless broadband remaining at its current level (4%), (ii) all broadband subscribers being served by a wireless network and (iii) a more realistic "best case" growth scenario where FWA market share grows considerably but is constrained by the presence of other competing broadband offerings. Finally, a worst case scenario was also considered based on uncontended wireless broadband provision to all households (in all the other cases a contention ratio of 8:1, in line with existing cable networks, was assumed).

The results for each location and scenario are presented below, in terms of the number of base stations required by a single wireless network having access to various amounts of radio spectrum.

For comparison, the current approximate number of fixed wireless (FWALA) base stations (where known) and mobile stations per operator (based on ComReg Siteviewer data) are also shown.

Figure 1-1: Estimated number of Base Stations per Operator in typical urban, suburban and rural locations

The provision of uncontended high speed wireless access to all households would require over 2,000 base stations for the Dublin area alone, even if all 400 MHz of the 3.6 GHz frequency band were to be made available.

Our analysis suggests that a total of up to 80 MHz would be required by a single network to cater for a future high speed wireless broadband service compatible with the DAE 30 Mbps target, based on current FWALA infrastructure density and market share (4% of the total broadband market). This estimate is also based on the assumption that there would be a single wireless operator in each area. In a multi-operator environment and with the same overall wireless market share, 40 – 60 MHz per operator is likely to be sufficient. If advanced wireless services attain a higher share of the overall broadband market (reflecting the improved performance using LTE-Advanced or a similar state of the art wireless technology), we estimate that with 100 MHz in total and an infrastructure density comparable to one of today's mobile cellular networks, LTE-A could serve up to 30% of all broadband subscribers in a typical suburban area and up to 50% of all subscribers in more rural areas.

On this basis we would recommend that in the order of 100 MHz in a given area would be sufficient to provide a high speed (30 Mbps or more) broadband service with a similar infrastructure density to existing wireless services, with any additional spectrum dependent on local demand. This amount of spectrum is also sufficient to support more than one operator where demand exists, or to allow a single operator the scope to offer the highest available headline speeds by taking full advantage of the carrier aggregation capabilities of LTE-Advanced technology. The 20 MHz[1] minimum block size is recommended to maximise spectrum efficiency (since signal processing overheads are proportionately higher for narrower channels) and to ensure that there is sufficient capacity at each base station to support multiple simultaneous high speed connections.

Continued deployment of existing fixed wireless technologies such as WiMAX or wireless DOCSIS would likely result in a higher spectrum demand to provide a similar service offering, reflecting the lower spectrum efficiency of these technologies in their current form.

[1] Where this is not practical, e.g. due to adjacency to the State Services allocation, where an operator wishes to deploy an unsynchronised network requiring the internalising of guard bands or where an operator wishes to deploy a technology requiring a bandwidth that is not a multiple of 20 MHz, block sizes should be multiples of 5 MHz

1 Introduction

This report provides an assessment of potential spectrum requirements per operator for fixed broadband connectivity using a typical state of the art wireless technology such as LTE-Advanced (LTE-A). We have assumed that a headline download speed of at least 30 Mbps would be required, to be compliant with the objectives of the European Union (EU) Digital Agenda for Europe (DAE) target for next generation broadband access (NGA)[2] and to meet the growing demand for bandwidth-intensive content such as high definition video streaming. Although no minimum uplink speed is specified in the DAE, we assume this will be of the order of 10 Mbps, in line with existing typical downlink / uplink ratios of 3:1.

In order to meet this demanding target, we have assumed that a dedicated, fixed wireless access network would be deployed and configured in such a way as to optimise the network spectrum efficiency (i.e. the data throughput in Mbps that can be carried per MHz of available radio spectrum). In practice, this requires the use of outdoor, rooftop mounted directional antennas at the customer premises. Whilst broadband connectivity can be provided to indoor modems or handheld devices (as is sometimes currently the case), this leads to much greater variability in the quality of the radio link, resulting in much smaller transmission ranges and lower average bit rates that would be inconsistent with the DAE target.

It is worth noting that the speeds available from the latest broadband wireless technologies such as LTE-A are substantially higher than those generally available from existing FWALA systems. Innovations such as multiple input multiple output antennas (MIMO), carrier aggregation and improved modulation and coding schemes enable peak bit rates of potentially hundreds of Mbps and could provide an order of magnitude improvement in end user speed compared to legacy systems. Nevertheless, guaranteeing bit rates of 30 Mbps or more consistently and economically remains challenging in a real world environment, where there may be many simultaneous users sharing the available capacity and radio signals may sometimes be obstructed by terrain, buildings or other obstacles.

The intention of this work package is to understand better the possibility of delivering the DAE target of 30 Mbps per household using an advanced wireless solution in the 3.6 GHz band and to estimate how much radio spectrum may be required to achieve this.

[2] 'NGA networks have been defined in EC Recommendation 2010/572/EU on regulated access to NGAs as meaning "wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput), as compared to those provided over already existing copper networks. In the context of this report NGAs also include wireless networks capable of providing similar performance to wired NGA networks such as fibre to the cabinet (FTTC) or hybrid fibre coaxial (HFC) cable networks

2 The role of wireless technology in meeting broadband targets

2.1 The need for high speed broadband

Broadband connection speeds have been steadily increasing in recent years, a trend that is set to continue in response to both market demand and regulatory initiatives such as the European Union's Digital Agenda for Europe (DAE)[3]. For example, Cisco's widely regarded Visual Networking Index (VNI) projects average broadband speeds in Western Europe to rise 150% between 2013 and 2018, from 19.3 Mbps to 49 Mbps[4]. This growth is largely driven by applications such as streaming video, which requires sustained and reliable access to high bit rates to maintain an acceptable quality of service.

For the purposes of this paper, NGA refers to network access platforms capable of delivering high speed broadband at speeds of 30 Mbps or higher. These predominantly use wired technologies, including digital subscriber line (DSL), fibre or cable (DOCSIS 3.0), however the infrastructure to support such platforms may not be available in certain areas and the latest wireless technologies (such as LTE-A) could provide a viable substitute where this is the case.

Wired technologies such as very high speed DSL (VDSL) can currently deliver speeds approaching 100 Mbps and are generally uncontended between the street cabinet and the customer premises (although contention does exist on the fibre backhaul and sometimes also within the street cabinet). Performance is however very dependent on distance from the cabinet (speed degrades significantly at distances beyond about 200 metres) and crosstalk between copper connections can further reduce speed as the number of connections increases. Nevertheless, VDSL where available is usually capable of delivering 50 Mbps or more and future improvements to VDSL technology have the potential to increase this to 200 Mbps or more.

Cable networks using hybrid fibre coaxial (HFC)[5] technology are capable of even higher speeds (1 Gbps or more) but much of the available capacity is reserved for TV channels. Current advertised bit rates tend to be in the range 50 - 250 Mbps. Unlike VDSL, the connection from the street cabinet to the customer premises is contended (since cable networks use a tree architecture to connect to users rather than the star architecture used by VDSL – see Figure 2-1 below). For example, we understand UPC's Irish cable network has a contention ratio of 8:1[6].

Providing uncontended access to large numbers of users via a radio network would result in very inefficient spectrum utilisation, since even at peak times most users are unlikely to be using more than a small portion of the headline bit rate they have available to them. This is explained further in the following section.

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[3] See http://ec.europa.eu/digital-agenda/

[4] See http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html. Note the term "average speed" is not explicitly defined in the VNI but is assumed to refer to the headline advertised rate offered to subscribers.

[5] HFC uses fibre to connect the cable head end to street cabinets and co-axial cable for onward connectivity to customer premises

[6] See www.siliconrepublic.com/comms/item/25636-asai-upholds-magnet-fastes

2.2 Impact of network contention on broadband speed

The term “contention” refers to the sharing of available bandwidth between multiple users and is a feature of all broadband networks, either in the access network or the backhaul. Contention works on the principle that a significant proportion of broadband subscribers will not simultaneously require access to the highest instantaneous data speeds. For example, NGA networks are intended to provide access at speeds of 30 Mbps or more, sufficient to carry several simultaneous high definition video streams, however the likelihood of multiple households accessing such content at the same time is relatively low.

In practice, the average bit rate per user across a network is likely to be at least an order of magnitude lower than the peak rate that is available. This is apparent, for example, in the Cisco VNI projections, which in addition to the broadband speed projections referred to above also project total busy hour traffic levels across geographic regions. For 2018, Cisco estimates that total busy hour IP traffic across Western Europe will reach 202 Terabits per second, which is approximately equivalent to 1 Mbps per household. Even allowing for day-to-day and geographic variation in traffic demand, it is clear that dimensioning a network to be capable of delivering a headline rate of 30 Mbps or more to all users simultaneously all of the time would lead to massive over-provision of capacity.

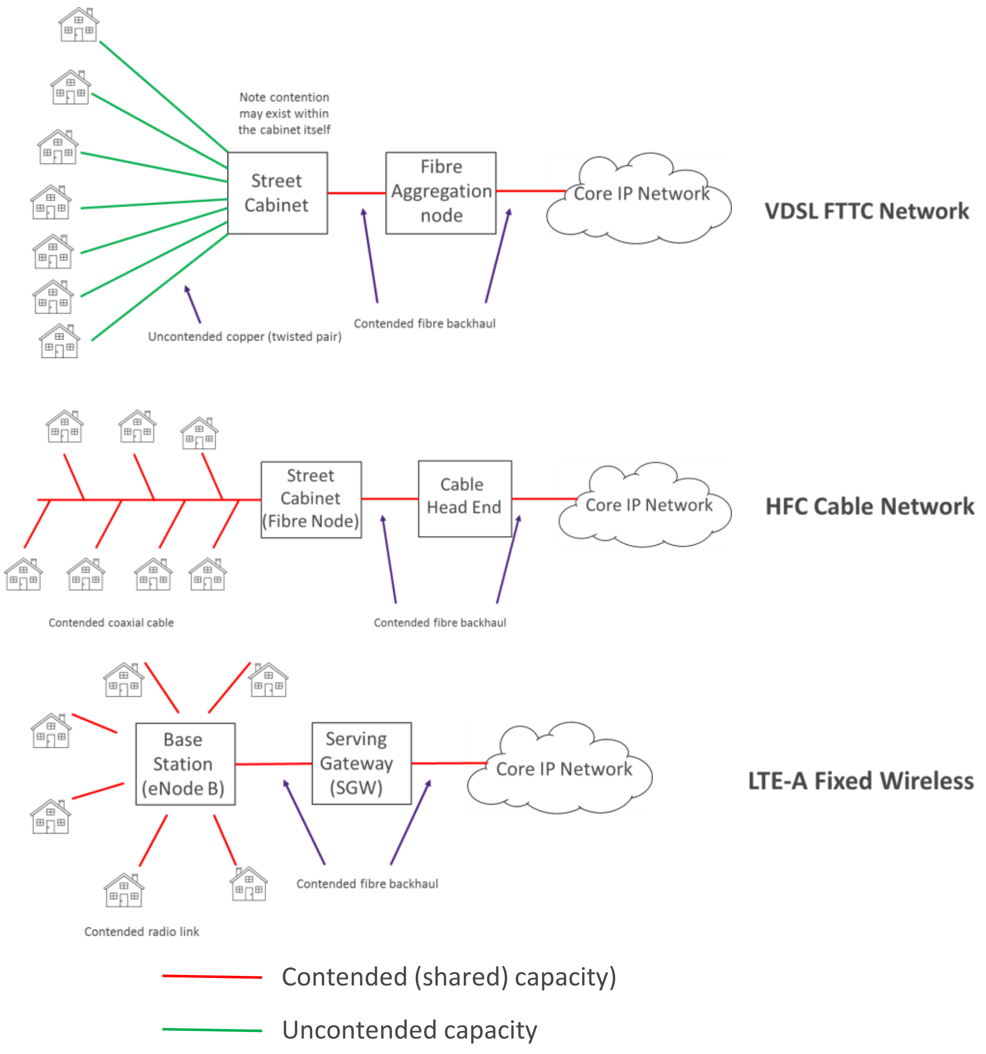
Contention ratios in wired networks vary depending on the technology. Older ADSL connections typically had contention ratios as high as 50:1, whereas cable networks are typically 8:1 and VDSL services are uncontended from the street cabinet to the subscriber (though contention may exist within the cabinet itself). However both cable and VDSL services have additional contention on the fibre backhaul, which is likely to be shared between multiple street cabinets. This would also apply to the backhaul used to connect wireless base stations.

The OECD’s Communications Outlook report for 2011 reported contention ratios for some of the exiting Irish FWALA operators. Irish Broadband was quoted as having ratios of 48:1 on its 3 Mbps service and 12:1 on its 7.6 Mbps service. Digiweb’s reported contention ratios were up to 36:1 for residential users and 18:1 for businesses. In 2010, Three was required to provide a maximum contention ratio of 18:1 as part of its contract under the National Broadband Scheme

The impact of contention on actual speeds can in practice be relatively small, as illustrated by figures published recently by Ofcom in the UK which compare networks’ maximum speeds with those during the busiest time of day. For BT’s ADSL service (which is uncontended from the street cabinet), the range of speeds fell from 9.7-12.1 Mbps to 8.9-11.3 Mbps (a reduction of 7-8%), for VDSL (FTTC) the range fell from 62.6-65.5 Mbps to 60.1-62.9 Mbps (reduction of 4%) and for Virgin Media Cable (which we believe has similar contention to UPC’s Irish network) from 62.7-62.9 Mbps to 54.1-57.7 Mbps (reduction of 9-14%). It can be seen that the impact is greatest in the cable networks which are contended from the street cabinet, although even here the impact is still relatively small and unlikely to affect significantly the customer experience.

The figure below compares the network architecture for typical VDSL, cable and fixed wireless networks, highlighting where contention exists. Note all networks have contention in the backhaul and only VDSL provides an uncontended connection to the premises

Figure 2-1: Traffic contention in VDSL, cable and fixed wireless networks



Source: Plum Consulting

2.3 Digital Agenda for Europe (DAE) Broadband Targets

The DAE is one of the initiatives under the EU's "Europe 2020" programme, which sets out the EU's growth strategy for the coming decade. The DAE was launched in May 2010 and contains a large number of actions grouped into a number of priority areas. Specific goals of the DAE include population coverage and speed targets for fixed broadband connectivity. In particular, the DAE sets targets for universal availability of 30 Mbps over fixed broadband networks by 2020 and for 50% of households to have access to at least 100 Mbps. Such speeds require access to a next generation access (NGA) technology using a wired or wireless solution.

Each year the European Commission (EC) publishes a DAE "scoreboard" which includes an update on the progress that has been made towards the 2020 target. The latest (2014) scoreboard[7] reported that NGA coverage across the EU had doubled over the three year period, to 2013, to 62%, but coverage in rural areas was only 18%. In Ireland total coverage was reported to be 54% and rural coverage less than 6%. Conversely, the penetration of high speed broadband (>30 Mbps) in Ireland was found to be higher than the EU average, at 9% of population compared to 6% for the EU overall. This suggests a strong demand for high speed broadband in Ireland. Advanced wireless networks operating in the 3.6 GHz band could potentially provide an alternative delivery platform in areas where non-radio platforms are not available, or provide additional choice and competition elsewhere, providing the target 30 Mbps headline data rate set by the DAE can be achieved.

It should be noted that the 30 Mbps target relates specifically to the downlink data rate. All current consumer broadband platforms are asymmetric and generally deliver much higher speeds in the downlink direction than in the uplink. For example, eircom's fibre to the cabinet broadband service reportedly delivers typical downlink speeds of 60 Mbps or more but less than 20 Mbps in the uplink[8]. This reflects consumer traffic profiles, where downlink demand tends to be far greater to support applications such as on-demand video. The 30 Mbps and 100 Mbps targets refer to the headline or advertised speeds rather than guaranteed minima. In practice some reduction in speed at the busiest times would be expected, but such reduction is unlikely to be more than 10-15% in most circumstances, as indicated by the recent Ofcom reports for cable networks with an assumed contention ratio of 8:1[9]

2.4 Meeting DAE Targets using wireless technology

The DAE target of ubiquitous availability of 30 Mbps broadband is particularly challenging for wireless technology, due to the limited availability of radio spectrum and the wide variation in achievable speed depending on the quality of the radio link. There is a growing international consensus that the preferred technology to deploy for both mobile and fixed wireless broadband services in the future is LTE – Advanced (LTE-A), the latest variant of the IMT-2000 family of wireless standards[10], We have therefore assumed, that driven by the business case, LTE-A would be used as the preferred technology for future advanced wireless networks. This does not however preclude the deployment of alternative technologies so long as these comply with the relevant licence conditions proposed by ComReg in Document 15/70, for example the relevant BEM's and signal levels at borders of regions etc. and we note that ComReg has no intention to mandate a specific technology.

In a wireless network, the capacity from a base station depends on the amount of radio spectrum available, the technology deployed, quality of the radio link that can be achieved and the number of sectors that can be accommodated. A sectorised base station uses directional antennas to split the coverage from the mast into typically three or four angular segments, rather than providing omnidirectional coverage from a single antenna. Since the available spectrum can be re-used on each sector, the base station capacity increases in line with the number of sectors.

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[7] Report available at https://ec.europa.eu/digital-agenda/en/news/scoreboard-2014-trends-european-broadband-markets-2014. The next report is due to be published in May 2015

[8] Source: http://testmy.net/host-max/eircom (speed test aggregator site)

[9] This is based on UPC Ireland's network – the contention ratio for Virgin Media's UK network is not available but is assumed to be similar.to the reported 8:1 ratio on the UPC Ireland network

[10] The current status of wireless technologies suitable for deployment in the 3.6 GHz band is addressed in detail in WP2

At the network level, additional capacity can also be provided by adopting a higher density of smaller cells (sometimes referred to as cell splitting). However either additional base stations or additional spectrum will incur costs for the network operator, hence when designing a network it is sensible to factor in a reasonable degree of contention to reflect the likely peak time demand across the network, rather than attempting to guarantee the full advertised bit rate to all users all of the time.

Subject to sufficient radio spectrum being available, LTE-A has the potential to deliver bit rates of hundreds of Mbps, however in practice the actual bit rate that can be guaranteed to an individual subscriber may be much lower, especially in a mobile environment. This is due to factors such as:

- Number of users connected to a base station: in mobile networks it is not possible to control the number of users within a particular cell coverage area and at busy times the available capacity may be contended over a large and fluctuating number of users, limiting the bandwidth available to each individual
- Quality of the radio signal path: there are often obstructions (terrain, buildings, etc.) between the network base station and the user terminal which significantly attenuate the signal and reduce the bit rate that can be delivered.
- Sensitivity of the terminal device. The performance of antennas in handheld mobile devices is significantly compromised by the need to provide omnidirectional coverage (so the device does not have to be pointed towards the base station) and the limited space in which to accommodate the antenna.
- Effect of interference between adjacent cells and sectors: because LTE-A networks generally use the same carrier frequencies throughout the network, adjacent cells and sectors will interfere with one another, particularly towards the edge of their coverage area, reducing the available bit rate.

For all of the above reasons, achieving a consistently high bit rate with a conventional handheld or desktop mobile device is unlikely to be feasible without either a very large amount of spectrum (100s of MHz per operator) or a very large number of base stations. However, LTE can also be deployed in a fixed user equipment (UE) configuration using external, elevated directional antennas, serving a fixed number of subscribers per cell and this approach will largely overcome the above limitations. In the following chapters we analyse in more detail how an advanced wireless technology such as LTE-A can be deployed to provide an effective NGA solution and consider how much radio spectrum might be required to achieve this in typical deployment scenarios.

3 LTE as an NGA Solution

3.1 Introduction

In this section we consider how an advanced wireless technology such as LTE-A might be deployed to provide a high speed fixed broadband service and what factors are likely to influence the performance available with a given amount of radio spectrum and infrastructure. We start by reviewing the bit rates that can be achieved with LTE technology.

3.2 Quantifying the available bit rates

The bit rate attainable over an LTE-A radio link depends on various factors, including:

- The quality of the radio link (path loss)
- The radio spectrum bandwidth available (channel width)
- Split between uplink and downlink traffic
- Base station and terminal antenna performance
- Deployment of capacity enhancement techniques such as multiple input multiple output (MIMO) antennas.

Each of these is considered in the following sections.

3.2.1 Path Loss

The quality of the radio link (principally the extent of signal attenuation or path loss) is key to the data transmission capacity because it determines the spectrum efficiency, i.e. the volume of data traffic in Mbps that can be carried per MHz of radio spectrum. LTE-A uses Adaptive Modulation and Coding (AMC) to maximise the data throughput (in bits per second or bps), depending on the signal to noise ratio (SNR) of the received signal, which in turn depends on the quality of the radio link. In the latest 3GPP standards (Release 12) the modulation schemes specified are QPSK (which conveys up to 2 bps per Hz of bandwidth), 16QAM (4 bps per Hz), 64QAM (6 bps per Hz) and 256QAM (8 bps per Hz). The coding rate (proportion of data bits to coded bits)[11] typically varies between 1/8th and 4/5ths. The base station selects an appropriate modulation and coding scheme (MCS) based on data received from the user equipment about the quality of the received signal. This data is referred to as the Channel Quality Indicator (CQI), of which there are 15 specific values, each corresponding to a particular modulation and coding scheme.

The lowest CQI value corresponds to a spectrum efficiency of only 0.15 bps per Hz whilst the highest is over 7 bps per Hz[12]. For a 20 MHz channel, typically used in higher frequency bands, this means

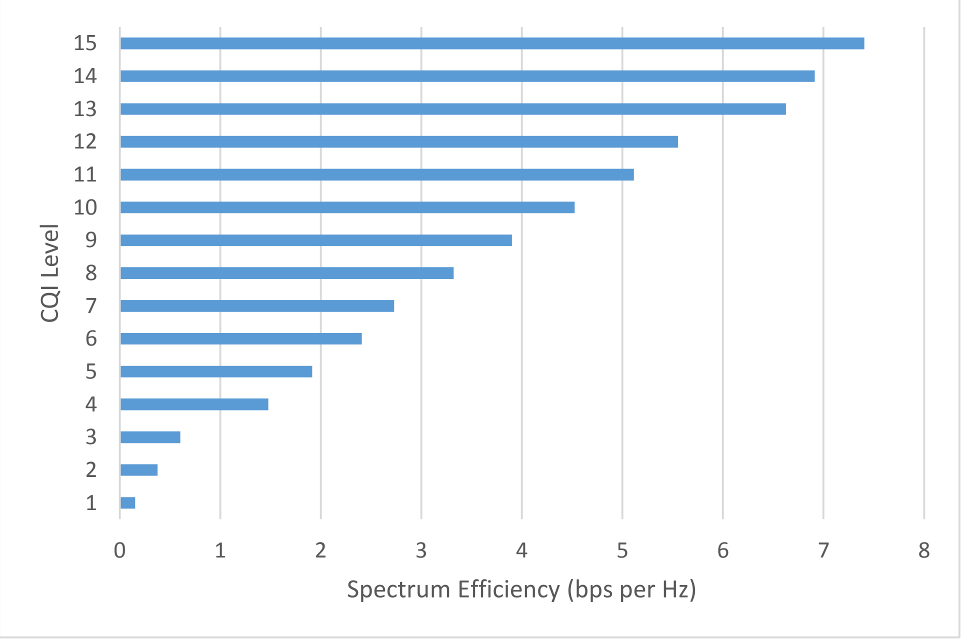
[11] Coding (Forward Error Correction) adds additional bits that can be used to correct errors in the received bits.

[12] Note these “raw” efficiency values relate to gross bit and do not take account of signal processing overheads or TDD uplink / downlink split. They also do not allow for any MIMO gain.

the maximum bit rate available in the absence of MIMO gain[13] will be between 3 Mbps and over 100 Mbps[14], depending on the quality of the radio path between the base station and terminal. Note that for a given bit rate the tolerable path length is significantly higher for a fixed wireless network than for a mobile network, reflecting the higher gain and elevation of the antenna.

The figure below shows the spectrum efficiency in bps per Hz corresponding to each defined CQI level[15].

Figure 3-1: Spectrum efficiency of LTE radio link as a function of CQI level



3.2.2 Channel Width

The LTE standards define a range of radio frequency (RF) channel widths, namely 1.4 MHz, 3 MHz, 5 MHz, 10 MHz. 15 MHz and 20 MHz[16]. The latest version of the standards also provides the option to aggregate up to five RF channels, enabling total bandwidths of up to 100 MHz to be realised. We estimate that the overall spectrum efficiency likely to be achieved in a fixed wireless network is approximately 4 bps/Hz (this is discussed further in section 3.2.7 below), hence the corresponding bit rates for the six channel width options would be 5.6, 12, 20, 40, 60 and 80 Mbps, per channel, respectively. Only the highest option (20 MHz) would be capable of supporting multiple simultaneous high bit rate services (30 Mbps) from a single transmitter. Spectrum efficiency is also higher for the wider channel width as the signalling overhead is lower in percentage terms. For these reasons we consider 20 MHz to be the minimum spectrum bandwidth required to provide a wireless NGA platform.

[13] The impact of MIMO is addressed in section 3.2.5

[14] Corresponding to CQI levels 1 and 15 respectively

[15] source: 3GPP standard 36.213

[16] Source: Table 5.6-1in 3GPP/ETSI technical standard TS36.101. For further information on LTE standards please refer to the Plum report 2 on Rollout considerations and timelines

Channel aggregation may be used to increase the peak bit rate to individual users and/or extend the reach of the base station, although the benefits of aggregation are somewhat reduced in a fixed network environment as the overall spectrum efficiency is much higher than in a mobile environment (i.e. likely higher CQI at the cell edge).

3.2.3 Split between uplink and downlink traffic

In a TDD network, a portion of time will be dedicated to support uplink traffic and this will further reduce the downlink throughput. The LTE standards define seven specific TDD frame configurations[17], each of which has a particular downlink/uplink ratio, as shown below.

Table 3-1: Downlink / Uplink Ratio for TD-LTE frame configuration options

Configuration option	0	1	2	3	4	5	6
Downlink/Uplink Ratio	1:3	1:1	3:1	2:1	7:2	8:1	3:5

Feedback from TDD network operators suggests the downlink to uplink ratio is likely to be in the range 3:1 to 7:1 and research carried out by Sandvine and Nokia Siemens Networks (NSN)[18] suggests global internet traffic patterns have similar ratios in the range 3:1 to 5:1. According to NSN, the most widely deployed configuration is option 2, i.e. a downlink / uplink ratio of 3:1. This would also be consistent with the preferred sub-frame configuration noted in Report 1[19]. We have therefore used this assumption in our analysis, i.e. the assumed downlink capacity is reduced by 25% to accommodate the uplink traffic.

An additional overhead must also be factored in to allow for various control signals and the guard interval between the transmit and receive time frames[20]. This varies according to the precise network configuration; we have assumed a value of 20% (towards the upper end of the range) in our analysis

3.2.4 Base station and CPE antenna characteristics

Section 3.2.1 above highlights the importance of signal quality (low path loss) in achieving a high spectrum efficiency and bit rate The distance between the base station and CPE device is a key determinant of path loss, but in a fixed network environment the characteristics and location of the base station and CPE antennas also play an important role. Macro base stations of the type typically deployed in FWA networks generally have sectored antennas which provide multiple beams each of 90 or 120 degrees width. This has two advantages – firstly the antenna discrimination enables the radio channel to be re-used on each of the 3 or 4 sectors (increasing capacity accordingly) and secondly the directional sector antennas have considerably higher gain than an omnidirectional

[17] Table 4.2-2 of 3GPP standard TS36.211

[18] NSN White Paper "TD-LTE Frame Configuration Primer", Nov 2013

[19] Section 2.2.3 of "Potential Rights of Use in the 3.6 GHz Band: Report 1, Technical Analysis"

[20] For example the Physical Downlink Control Channel (PDCCH) accounts for 7% of the gross data rate and downlink reference signals used to support MIMO account for a further 5 – 14% depending on the MIMO mode (note however that we have assumed no MIMO gain in our capacity estimations). The guard period depends on the required transmission range but is likely to have a smaller impact– e.g. for 10 km would be less than 1%.

antenna would provide, meaning that, amongst other things, a higher path loss can be tolerated for a given bit rate.

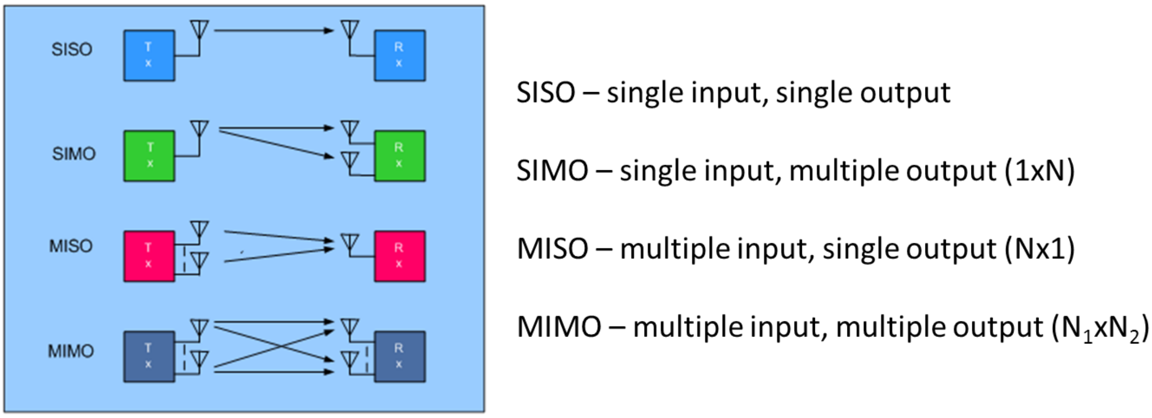
The CPE antennas used in fixed networks are also directional and are mounted externally, typically on a rooftop or other elevated position. Once again the antenna gain leads to an increase in the tolerable path loss, but there is also a further benefit in that there is a much higher probability of a line of sight path between the base station and antenna than would be the case for a mobile network, where user terminals are often shielded by buildings, trees and other clutter. This means that a reliable service can be provided over much larger distances than would be the case for a mobile network, especially in an urban or suburban environment. This higher prevalence of line of sight paths between base station and customer premises has a significant impact on network planning, which is discussed further in section 3.2.6.

In a fixed network configuration, polarisation discrimination can also be used to reduce interference between adjacent cells and sectors which might otherwise reduce network capacity, e.g. by deploying orthogonal polarisations on adjacent sectors), or to provide MIMO gain. In the latter case it may be necessary to adopt a two-frequency re-use pattern (whereby adjacent sectors deploy different frequency channels) to minimise inter-sector interference

3.2.5 Impact of MIMO deployment

MIMO uses multiple antennas at the base station and/or user equipment to create multiple radio paths which can significantly increase the throughput available in a radio network. The concept is illustrated in the figure below:

Figure 3-2: Multiple antenna configuration



The principal benefit of MIMO (i.e. multiple antennas at both ends of the link) is that multiple radio paths are created and each of these can carry data. In theory, doubling the number of antennas has the potential to double the transmission data rate, however this depends on the radio paths having perfect spatial separation, which in practice is unlikely to be realised. For example, trials undertaken by Ericsson[21] suggest that at the higher CQI levels deployed in a fixed wireless network the improvement resulting from doubling the number of paths (in this case from 2 to 4) is of the order of 50%, rather than the theoretical 100%.

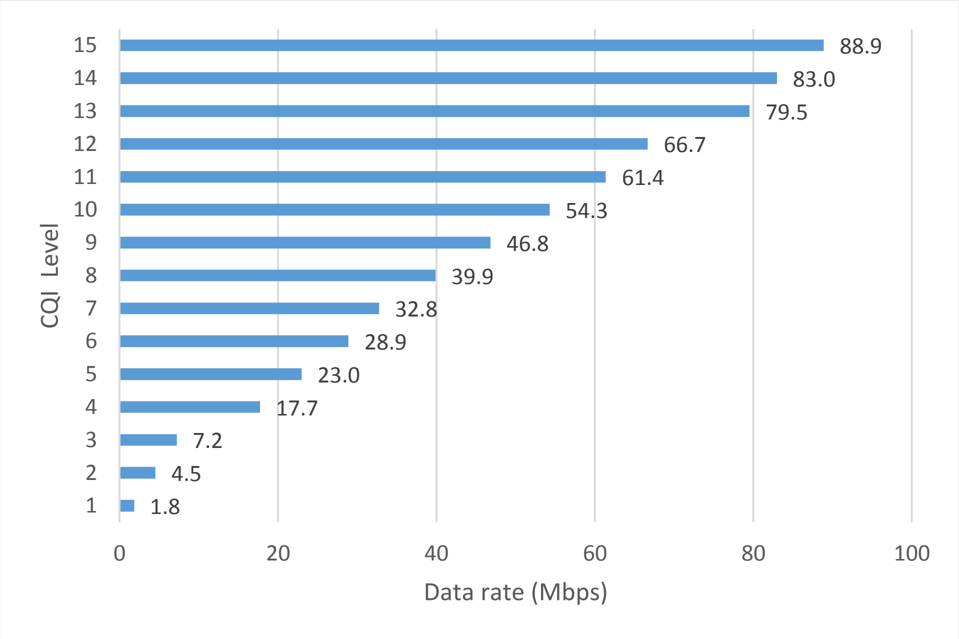
[21] "Field trials of LTE with 4×4 MIMO", Johan Furuskog, Karl Werner, Mathias Riback and Bo Hagerman, Ericsson Review, 2010

The LTE standards can support up to 8 antennas at each port (i.e. 8x8 MIMO). Current 3.5 GHz CPE antenna systems such as those being trialled in Ireland support two antennas, so we assume in the medium term that 2x2 MIMO would be deployed, resulting in a 50% increase in throughput.

The benefits of MIMO based on spatial multiplexing are likely to be more limited in a free space environment, such as we envisage for FWA deployments, due to the limited extent of multipath propagation. An alternative would be to deploy dual polarisation to provide MIMO gain similar to that provided by 2x2 MIMO, however we have assumed in our capacity calculations that a more effective approach would be to use polarisation discrimination to minimise inter-sector interference, by deploying orthogonal polarisation on adjacent cell sectors. We have therefore not included MIMO gain in our capacity estimations.

Taking this into account and factoring in the downlink throughput loss due to processing overheads (20%) and uplink throughput (25%) yields the following estimated throughput as a function of CQI for a single 20 MHz TDD channel:

Figure 3-3: Downlink data rate as a function of CQI level, taking account of signal processing overheads and TDD guard interval



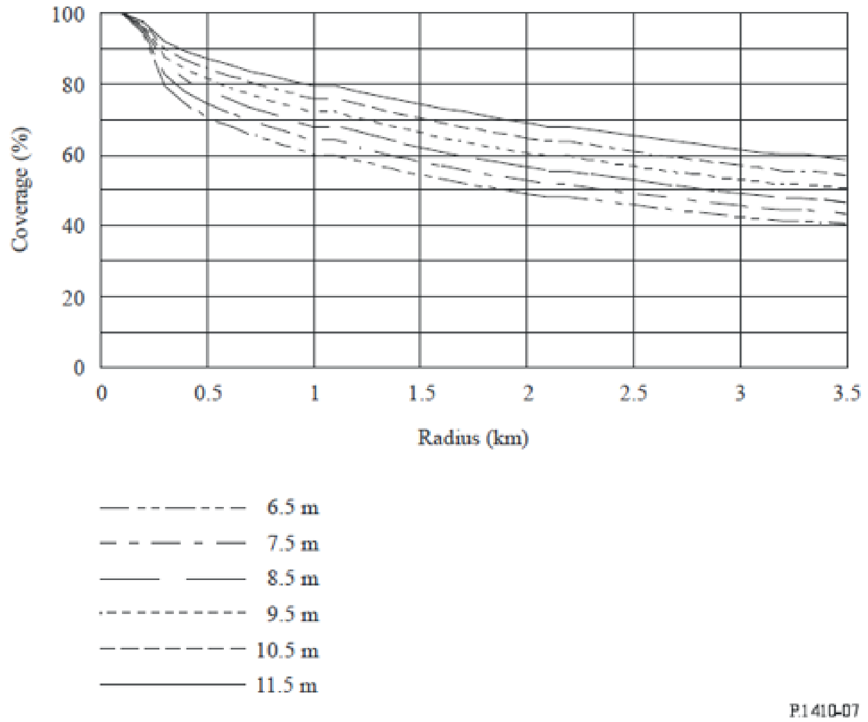
It can be seen that only CQI levels of 7 or higher are sufficient to deliver the target 30 Mbps headline speed. Note however that a single user operating at this CQI level would consume virtually all of the available capacity for a single radio channel at peak usage. Whilst maintaining such a high CQI in a mobile network would be extremely challenging due to the effects of clutter and inter-cell interference, the situation in a fixed wireless network deploying directional rooftop antennas is much more favourable, particularly if a line of sight path can be achieved for the majority of CPE installations. This suggests taking a rather different approach to network planning to that which would be used for a conventional mobile network, as we discuss in the following section

3.2.6 Network Planning Considerations

In a conventional mobile network or a fixed access network where users do not generally have clear line of sight visibility of the base station, the range over which a high speed connection can be provided may be severely constrained by building and other clutter which attenuate the radio signal. The effect tends to be much more pronounced in urban and suburban areas, where the additional clutter losses may reduce the viable path to as little as 1-2 km, compared to 8 km or more in relatively clutter free rural areas.

In a fixed wireless network, where a line of sight exists, the path loss will be very much lower and a high quality signal (corresponding to the highest CQI and spectrum efficiency) can be achieved over distances of 10 km or more. Hence the most important consideration becomes the probability of achieving a line of sight to a base station, rather than the distance to the base station (though the latter does have a bearing on the former). In practice this probability will be very site dependent, however work has been undertaken within the ITU Radiocommunications sector (ITU-R) to generate indicative probabilities as a function of antenna height and distance for a typical suburban environment. The values are presented in ITU-R Recommendation 1410-07 and are reproduced below:

Figure 3-4: Modelled cumulative coverage for transmitter at height of 30 m and receiver at heights of 6.5, 7.5, 8.5, 9.5, 10.5 and 11.5 m (source: ITU-R Rec 1410-07)



It can be seen that at a distance of 3.5 km from the base station at typical rooftop heights, there is a 40-60% probability that a line of sight will exist. The Recommendation also notes that line of sight probability almost doubles if two base stations are within a similar distance, suggesting that a lattice of overlapping cells with a spacing of 3 – 4 km should enable a line of sight path to be realised for a large majority of connections. Hence a relatively high overall spectrum efficiency should be achieved.

For example, assuming that 80% of FWA connections can achieve a line of sight path and operate at the highest CQI level, whilst the remaining 20% have non-line of sight paths and operate at the lowest viable CQI level to provide 30 Mbps yields the following overall spectrum efficiency:

- 80% of connections achieve 89 Mbps / 20 MHz (based on highest CQI level 15)
- 20% of connections achieve at least 32.8 Mbps / 20 MHz (based on minimum CQI level of 7)
- Overall throughput spectrum efficiency = (0.8x89 + 0.2x32.8) = 78 Mbps / 20 MHz, or 3.9 bps/Hz.

LTE technology incorporates advanced scheduling and interference management capabilities that enable a single frequency re-use factor to be deployed, i.e. the same radio channels can be deployed on all base station sectors. This helps to maximise capacity and spectrum efficiency by enabling all an operator's available radio spectrum to be used at all locations in the network.

We have assumed that in a fixed network deployment the impact of inter-sector interference would be minimised, e.g. by deployment of orthogonal polarisation on adjacent sectors[22], but also assumed no MIMO gain as spatial multiplexing is likely to be less effective in a predominantly line of sight environment. An alternative approach would be to use dual polarisation on all sectors, effectively providing a 2:1 MIMO gain, along with adoption of a two-frequency re-use pattern to minimise inter-sector interference. The impact on capacity would be neutral, since the higher re-use factor could be offset by the MIMO gain.

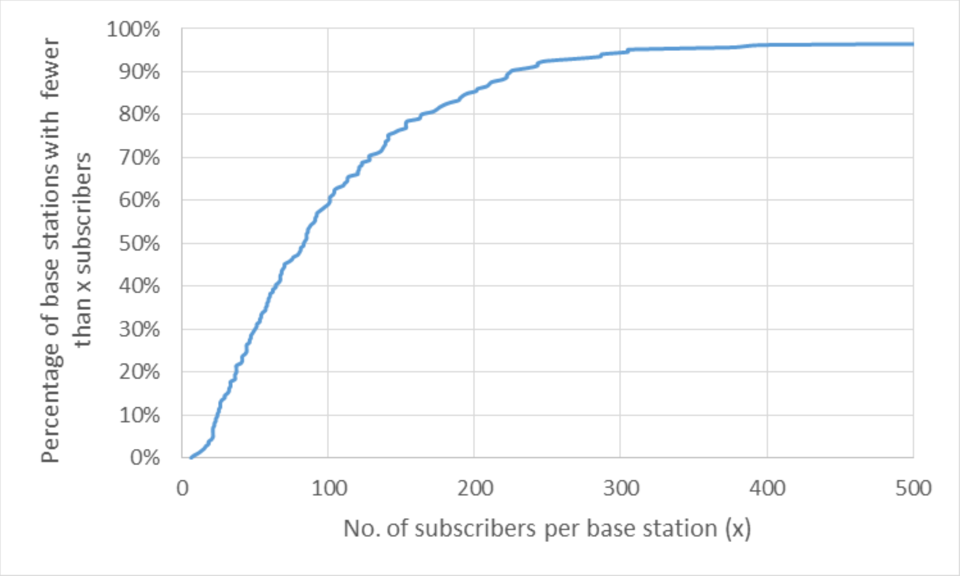
3.2.7 Estimating Base Station Throughput and Capacity

The data throughput capacity based on the above spectrum efficiency value for a typical four sectored base station would be 4 x 78 = 312 Mbps. The capacity in terms of the number of users that can be reasonably supported will depend on the assumed headline bit rate and contention ratio. For an uncontended service providing 30 Mbps, only 10 users per base station could be supported, rising to 52 if 100 MHz were available. Given the current distribution of users per base station on existing FWALA services (see below), it is questionable whether this would provide an economic business case.

However, if a similar contention ratio to today's cable networks (of the order of 8:1) were to be applied the capacity would increase to 83 users per 20 MHz carrier (=312 x 8 / 30), which suggests that an NGA service could be provided with similar base station subscriber loadings to today's FWALA systems using two or three 20 MHz LTE-A carriers.

[22] Such an approach is described, for example, in "Performance improvement of fixed wireless access networks by conjunction of dual polarization and time domain radio resource allocation technique" by Alexander Vavoulas et al of University of Athens, International Journal of Communication Systems, 2010, which suggests potential throughput improvements of up to 95%.

Figure 3-5: Subscribers per base station for exiting FWALA services



4 Case Studies of Potential FWA Deployments in Urban, Suburban and Rural environments

4.1 Introduction

In the following sections we consider the implications of using a fixed wireless network to deliver high speed broadband at various locations in Ireland. The objective is to consider the potential radio spectrum and network infrastructure requirements (base stations) to serve a particular proportion of the population in each case. For simplicity we have assumed a single wireless network and have considered two contention options, namely fully uncontended (all users guaranteed a minimum of 30 Mbps at all times) and contention similar to existing cable networks (i.e. 8:1).

In the analyses we have made the following assumptions:

- LTE-A technology (based on 3GPP Release 12 or later) used throughout
- Base stations comprising four 90 degree sectors
- Rooftop mounted customer premises antennas
- Line of sight visibility of at least one base station for 80% of consumer premises antennas, enabling operation at the highest spectrum efficiency and bit rate
- A minimum CQI level of 7 for the remaining 20% of connections
- Single frequency re-use, i.e. all available spectrum is used at all base stations
- Orthogonal polarisation deployed on adjacent base station sectors
- No MIMO gain

Currently the market share of wireless broadband in Ireland is approximately 4% nationally. This is high by global standards and we therefore do not expect to see any significant increase in this share in the future, especially in urban and suburban areas where VDSL and cable provision is widely available. However it is possible that the higher speeds available with LTE-A technology could enable wireless to compete more effectively and that a higher market share could be achieved over time. In our modelling we have therefore considered three potential market scenarios, namely

i) All households served by wireless broadband (this is extreme scenario and is included for reference purposes only)

ii) The current 4% share is maintained nationally

iii) The wireless market share increases but differs according to the extent of local competition – we have assumed a 10% share in large urban / suburban areas, 30% in smaller urban / suburban areas and 50% in rural areas

4.2 Case 1: Large Urban / Suburban Area

For this example we have chosen Dublin City and the surrounding area, which according to Irish census data has a total of 468,000 households. If all of these households were to receive an uncontended wireless broadband service at 30 Mbps, the implications for both spectrum and infrastructure would be enormous, as illustrated in Figure 4-1 below. It can be seen that even if all of the available 3.6 GHz spectrum were to be used, over 2,000 base stations would be required to serve the Dublin area. Of course, this is very far from a realistic situation, since in reality only a small proportion of broadband subscribers are served by wireless.

As discussed in section 3.2.7 above, we would expect wireless networks to be planned with a contention ratio similar to those currently found in cable networks, which would lead to an eight-fold increase in the number of subscribers that can be accommodated per base station. Applying the current 4% market share and 8:1 contention assumptions results in a much more realistic infrastructure requirement, as illustrated in Figure 4-2.

Figure 4-1: Spectrum and Infrastructure requirement to deliver uncontended wireless broadband to all households in the Dublin area

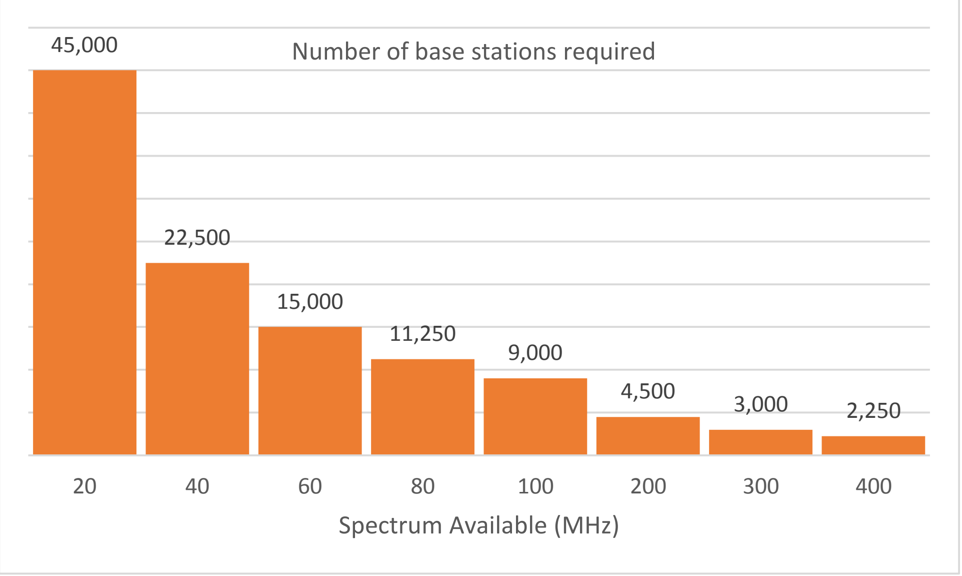
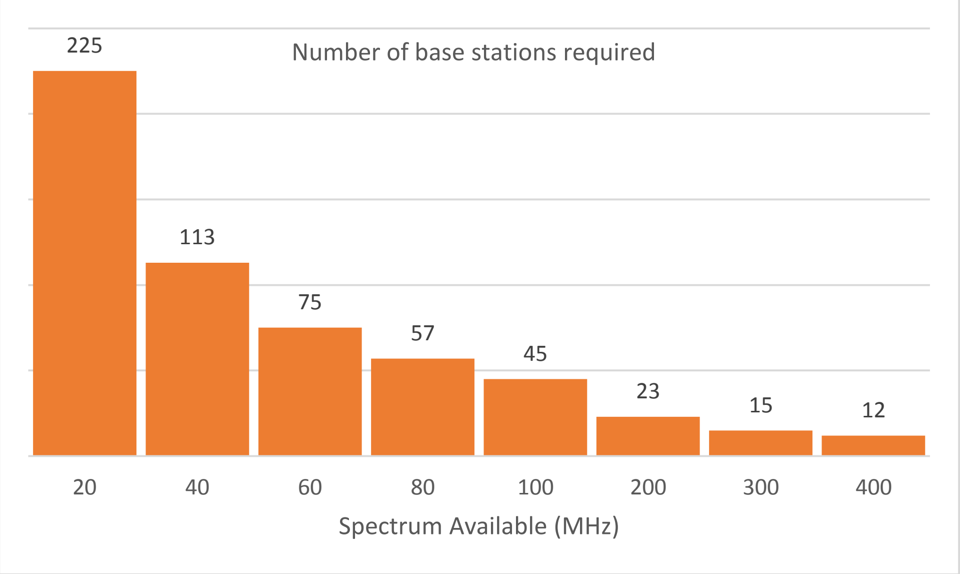


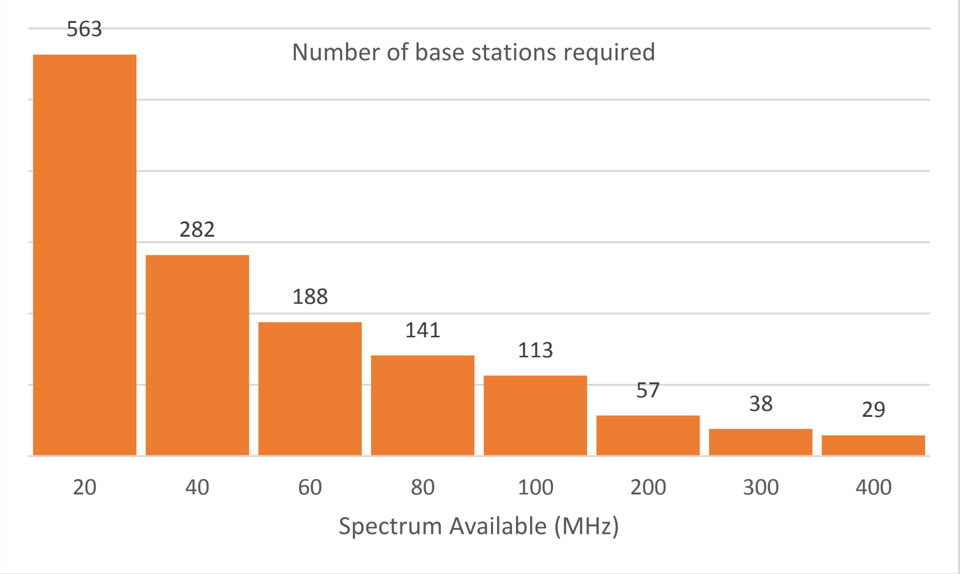
Figure 4-2: Spectrum and Infrastructure requirement to deliver wireless broadband to 4% of households in the Dublin area assuming a contention ratio of 8:1



In this case the number of base stations required falls to below 50 even if only 25% of the available 3.6 GHz spectrum is available (i.e. 100 MHz). Our analysis of current FWALA systems indicates there are already more than 50 base stations in the Dublin area. If all of these were to be upgraded to LTE-A technology we would expect that projected demand could be met with as few as four 20 MHz frequency channels, though additional spectrum may provide operators with more scope to compete against wired alternatives by offering higher headline speeds and/or lower contention ratios. Note that this estimate assumes all the wireless traffic is carried by a single network, in the case of two or more networks the spectrum requirement per operator would be accordingly lower, in the range 40 – 60 MHz.

Finally, a higher growth scenario has been considered, based on a 10% market share for fixed wireless access, This would require an estimated 110 base stations to cover the Dublin area with 100 MHz available, as illustrated below:

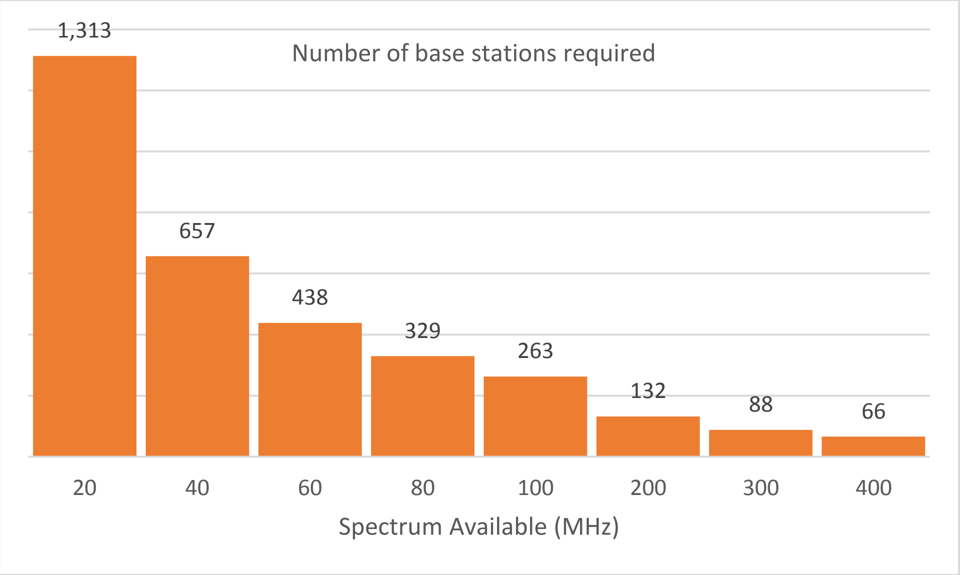
Figure 4-3: Spectrum and Infrastructure requirement to deliver wireless broadband to 10% of households in the Dublin area assuming a contention ratio of 8:1



4.3 Case 2: Small Urban / Suburban Area

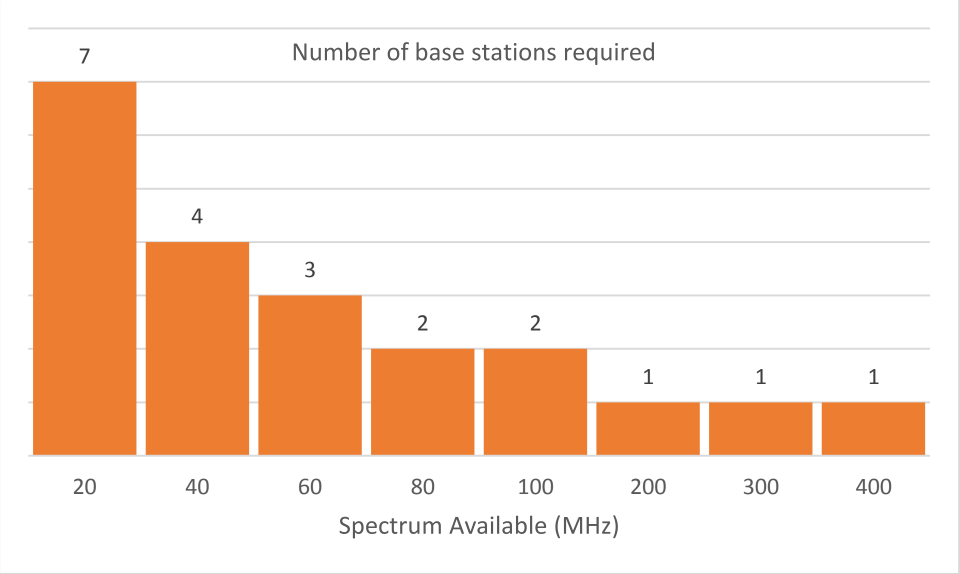
In this case we have chosen the town of Dundalk, which has approximately 14,000 households and currently appears to be served by four FWALA base stations. If every household in the area were to be served by FWA on an uncontended basis the infrastructure requirement would be as follows:

Figure 4-4: Spectrum and Infrastructure requirement to deliver uncontended wireless broadband to all households in Dundalk town



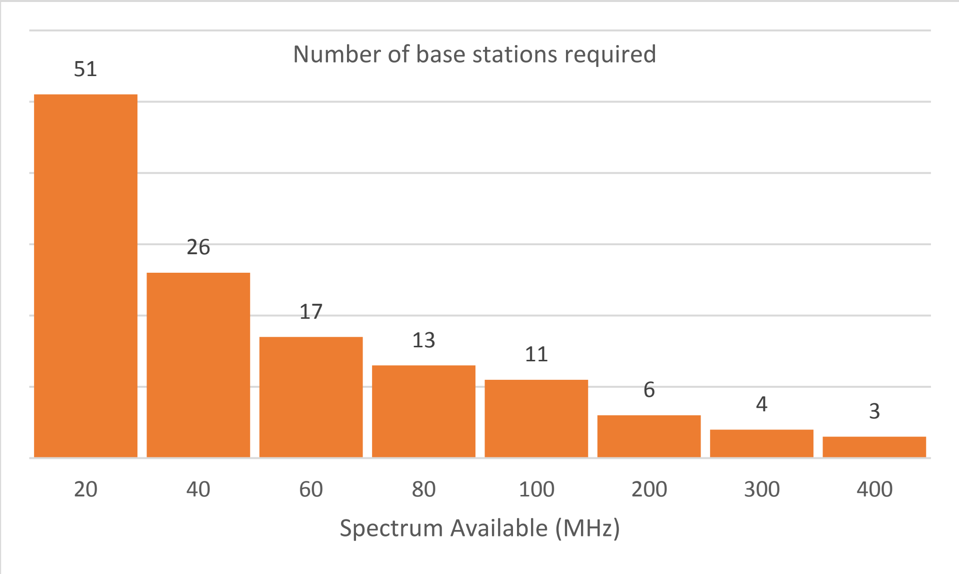
Applying the current 4% market share and 8:1 contention ratio assumptions to Dundalk yields the following infrastructure / spectrum relationship, implying that a viable high speed service could be delivered with a similar number of base stations to the existing FWALA services using as few as two 20 MHz carriers. A third carrier would provide a margin for potential future growth and better capability to compete with increasing speeds offered by cable and VDSL providers.

Figure 4-5: Spectrum and Infrastructure requirement to deliver wireless broadband to 4% of households in Dundalk town assuming a contention ratio of 8:1



A potential higher growth scenario has also been considered. The more limited range of competing offerings compared to Dublin could lead to a somewhat higher market share, so the following analysis relates to an upper estimate of 30% of households:

Figure 4-6: Spectrum and Infrastructure requirement to deliver wireless broadband to 30% of households in Dundalk town assuming a contention ratio of 8:1



In this case it appears that eleven base stations would be sufficient if 100 MHz were available. To put this into context, according to ComReg's Siteviewer tool there are currently 39 mobile sites serving the Dundalk town area, equivalent to approximately ten per operator.

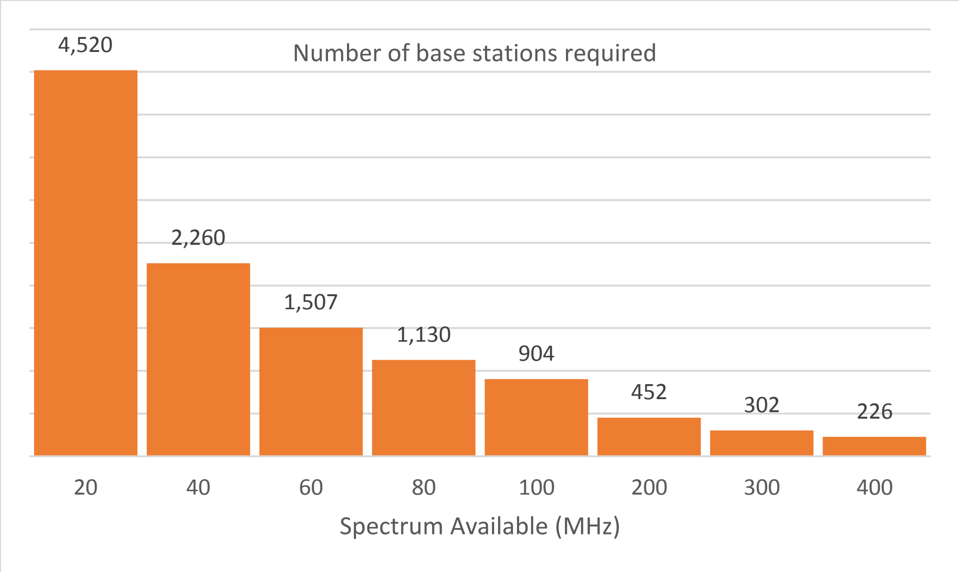
4.4 Case 3: Predominantly Rural Area

For the rural example we have considered County Donegal, which has a rural population[23] of approximately 47,000 households spread over an area of 4,860 sq. km. Again applying the 4% market share, 8:1 contention assumptions yields the following relation between infrastructure and spectrum:

In the extreme scenario of every household being connected to wireless broadband the required number of base stations would be as follows:

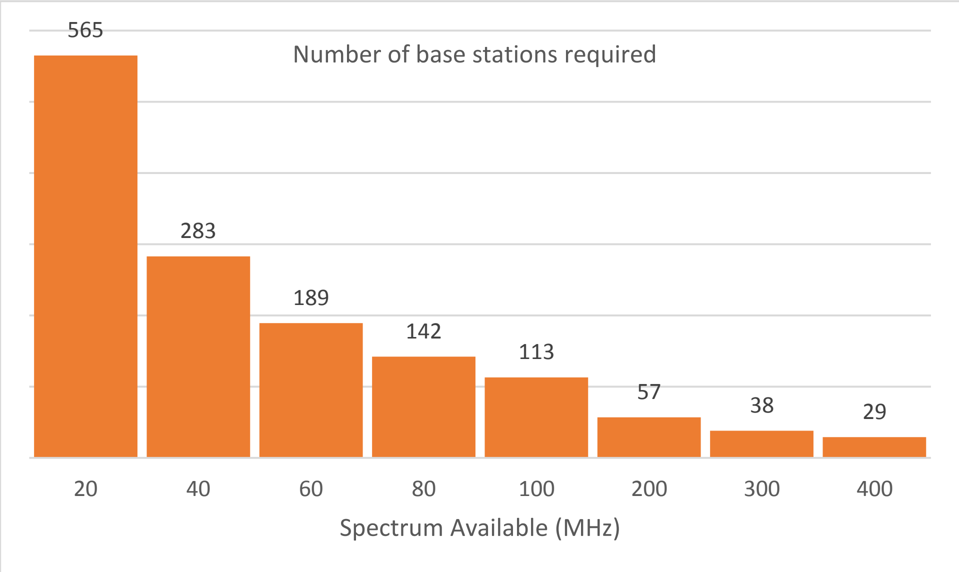
[23] Rural population excludes households in the three principal towns (Letterkenny, Donegal Town and Buncrana)

Figure 4-7: Spectrum and Infrastructure requirement to deliver uncontended wireless broadband to all households in rural Donegal



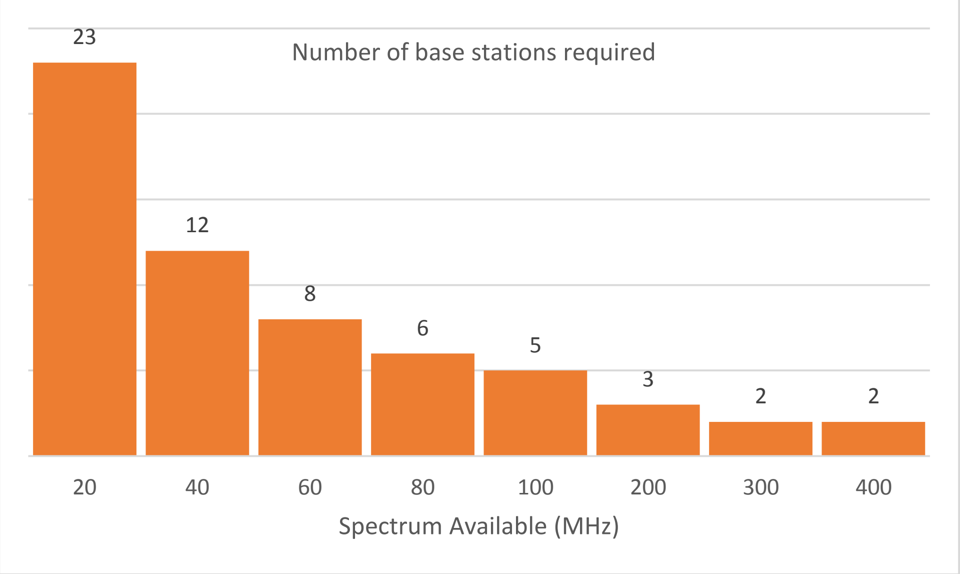
If all households are served but with an assumed 8:1 contention ratio the number of base station requires falls significantly, as illustrated below:

Figure 4-8: Spectrum and Infrastructure requirement to deliver wireless broadband to all households in rural Donegal with an 8:1 contention ratio



Applying the current 4% market share and assuming 8:1 contention yields the following requirement:

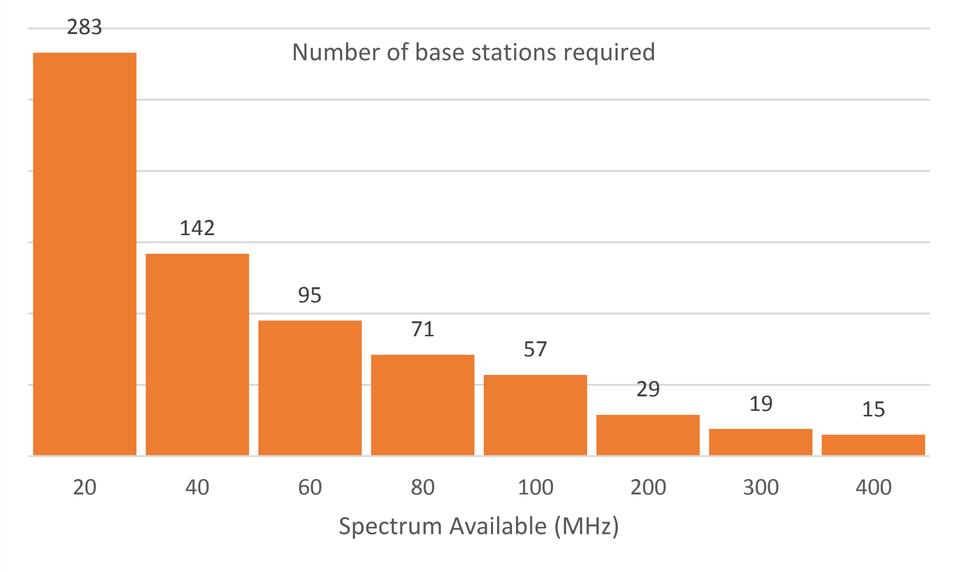
Figure 4-9: Spectrum and Infrastructure requirement to deliver wireless broadband to 4% of households in rural Donegal assuming a contention ratio of 8:1



This result suggests that with three or more 20 MHz carriers, fewer than ten base stations would be required to meet anticipated demand. There appears to be relatively little take-up of FWALA currently in this area outside the main town of Letterkenny, so new infrastructure would be required to provide an advanced wireless services across the county. Given the mountainous nature of the local terrain it is likely that coverage, rather than capacity, may be bigger determinant of the infrastructure required.

Given the likely limited availability of alternative broadband platforms in rural areas (many of which may not be served by cable broadband), it is possible that the take-up of wireless broadband in such areas could be substantially higher than in more populous areas over the long term. We have therefore analysed the implications of 50% of rural Donegal households subscribing to high speed wireless broadband. The results are shown below:

Figure 4-10: Spectrum and Infrastructure requirement to deliver wireless broadband to 50% of households in rural Donegal assuming a contention ratio of 8:1



It can be seen that with 100 MHz available the number of base stations required is 57. By comparison, ComReg's Siteviewer tool indicates a total of 224 mobile base stations in rural Donegal, equivalent to 56 per operator. Since it is likely that mobile infrastructure is more coverage than capacity driven in such a sparsely populated area, this suggests that a fixed wireless network configured to deliver coverage to all of the populated areas of Donegal, having access to 100 MHz of spectrum and sufficient fibre backhaul capacity would be capable of serving up to half the population with a high speed broadband service.

4.5 Summary of Results

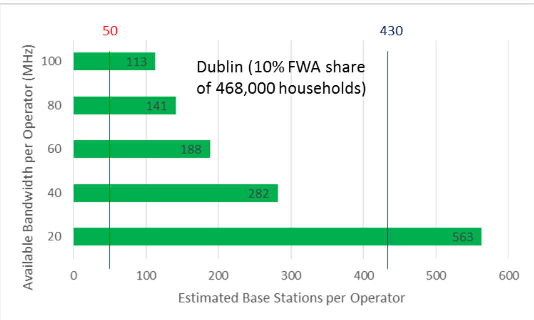
The table below shows the results for each location and scenario are presented below, in terms of the number of base stations required by a single wireless network having access to various amounts of radio spectrum. For comparison, the current approximate number of fixed wireless (FWALA) base stations (where known) and mobile stations per operator (based on ComReg Siteviewer data) are also shown.

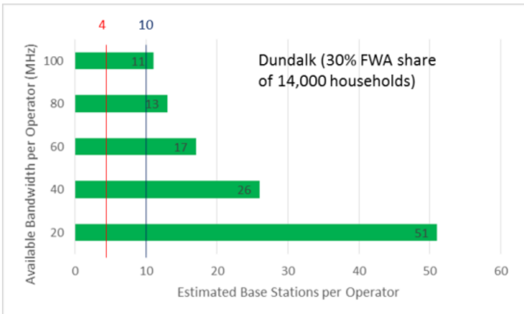
Table 4-1: Estimated numbers of base stations required as a function of available spectrum

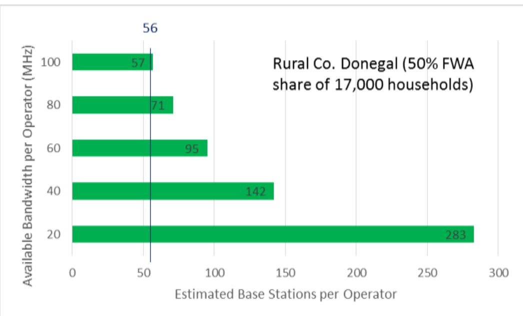
Region	Contention Ratio	BB Market Share	Number of base stations required based on quantum of spectrum available					FWA stations currently deployed	Mobile stations per op currently deployed
			20 MHz	40 MHz	60 MHz	80 MHz	100 MHz		
Dublin City and Suburbs (468,000 households)	8:1	4%	225	113	75	57	45	50	430
	8:1	10%	563	282	188	141	113		
	1:1	100%	55,625	2,8133	1,875	1,407	1,125		
Dundalk Town (14,000 households)	8:1	4%	7	4	3	2	2	4	10
	8:1	30%	51	26	17	13	11		
	1:1	100%	1,313	657	438	329	26		
Rural Country Donegal (17,000 households)	8:1	4%	23	12	8	6	5	n/a	56
	8:1	50%	283	142	95	71	57		
	8:1	100%	565	283	189	142	113		
	1:1	100%	4,520	2,260	1,507	1,130	904		

The results for the mid-range scenario are shown graphically in the figure below.

Figure 4-11: Estimated number of Base Stations per Operator in typical urban, suburban and rural locations







Estimated current no. of FWALA base stations per operator (where available)

Estimated current no. of mobile base stations per operator

5 Conclusions and Recommendations

Our analysis suggests that a total of up to 80 MHz would be required by a single network to cater for a future high speed wireless broadband service compatible with the DAE 30 Mbps target, based on current FWALA infrastructure density and market share (4% of the total broadband market). This estimate is also based on the assumption that there would be a single wireless operator in each area. In a multi-operator environment and with the same overall wireless market share, 40 – 60 MHz per operator is likely to be sufficient. These estimates are based on the following assumptions:

(i) the wireless network is configured using directional rooftop antennas with an 80% probability of a line of sight path to a network base station,

(ii) The long term market share of wireless broadband access will not grow significantly beyond its current level

(iii) A contention ratio between the base station and customer premises of 8:1 will be sufficient to provide an acceptable end-user experience with minimal deviation from the headline speed offered

(iv) Interference between adjacent sectors is minimised, e.g. by use of orthogonal polarisation on adjacent base station sectors.

In the event of advanced wireless services attaining a higher share of the overall broadband market (reflecting the improved performance using LTE-Advanced or similar state of the art technology), we estimate that with 100 MHz in total and an infrastructure density comparable to one of today's mobile cellular networks, advanced wireless services could serve up to 30% of all broadband subscribers in a typical suburban area and up to 50% of all subscribers in sparsely populated rural areas. We have not however considered the economic viability of supporting such infrastructure and the associated backhaul requirements.

On the basis of our analysis we would consider that in the order of 100 MHz in a given area would be sufficient to provide a high speed (30 Mbps or more) broadband service with a similar infrastructure density to existing wireless services, with any additional spectrum dependent on local demand. This amount of spectrum is also sufficient to support more than one operator where demand exists, or to allow a single operator the scope to offer the highest possible headline speeds by taking full advantage of the carrier aggregation capabilities of LTE-Advanced technology.

The 20 MHz[24] minimum block size is recommended to maximise spectrum efficiency (since signal processing overheads are proportionately higher for narrower channels) and to ensure that there is sufficient capacity at each base station to support multiple simultaneous high speed connections. For licensing purposes, a block size of 5 MHz could be specified, but with a recommendation that where possible operators acquire contiguous spectrum comprising multiples of 20 MHz.

Continued deployment of legacy fixed wireless technologies such as WiMAX or wireless DOCSIS would likely result in a higher spectrum demand to provide a similar service offering, reflecting the lower spectrum efficiency of these technologies in their current form. It is difficult to quantify the

[24] Where this is not practical, e.g. due to adjacency to the State Services allocation, where an operator wishes to deploy an unsynchronised network requiring the internalising of guard bands or where an operator wishes to deploy a technology requiring a bandwidth that is not a multiple of 20 MHz, block sizes should be multiples of 5 MHz

impact in precise terms as we do not have sight of the detailed deployment characteristics, however various papers have indicated WiMAX as having a spectrum efficiency 30 - 40% lower of LTE[25].

[25] See, for example Priyanka et al, "WiMAX vs LTE", University of Maryland, March 2012 or Dr.-Ing. Carsten Ball, LTE and WiMAX Technology and Performance Comparison", Nokia Siemens Networks, April 2007

6 Glossary

ACLR	Adjacent Channel leakage Ratio
AMC	Adaptive modulation and coding
CPE	Customer Premises Equipment
CQI	Channel Quality Indicator
BEM	Block Edge Mask
BS	Base station
BWA	Broadband Wireless Access
CC	Component Carriers
CEPT	European Conference of Postal and Telecommunications Administrations
CoMP	Coordinated Multipoint
DAE	Digital Agenda for Europe
DL	Downlink
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
EC	European Commission
ECC	Electronic Communications Committee
ECC PT1	Electronic Communications Committee Project Team 1
ECC WG FM	Electronic Communications Committee Working Group Frequency Management
ECP	European Common Proposal
ECS	Electronic Communication Systems)
eiCIC	Enhanced inter-cell interference coordination
EIRP	Effective Isotropic Radiated Power
eMBMS	Evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B (LTE Base Station)

ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FFS	For Further Study
FWA	Fixed Wireless Access
FWALA	Fixed Wireless Access Local Area
FTTC	Fibre to the cabinet
Gbps	Gigabits per second
GNSS	Global Navigation Satellite System
HeNB	Home evolved Node B (LTE Femtocell)
HetNet	Heterogeneous network (supports interaction between different types of cells and technologies)
HFC	Hybrid Fibre Coaxial (cable broadband technology)
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IMT-A	International Mobile Telecommunications Advanced (4th generation mobile)
IMT-2000	International Mobile Telecommunications (ITU 3rd generation mobile standard)
IP	Internet Protocol
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union – Radiocommunications
I/N	Interference to Noise Ratio
LTE	Long Term Evolution (4th generation mobile technology standard)
LTE-A	LTE Advanced (latest version of the LTE standard)
LTE-LAA	Licensed Assisted Access LTE (version of the LTE standard)

LTE-U	Unlicensed LTE (version of the LTE standard)
Mbps	Megabits per second
MCL	Minimum Coupling Loss
MIMO	Multiple Input Multiple Output
MFCN	Mobile Fixed Communications Networks
MoU	Memorandum of Understanding
NGA	Next Generation Access
NTIA	US National Telecommunications and Information Administration
OECD	Organisation for Economic Co-operation and Development
OFDMA	Orthogonal Frequency Division Multiple Access
PCI	Physical Layer Cell Identities
PSSR	Public Sector Spectrum Release (process for spectrum award in UK)
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RF	Radio Frequency
RRC	Radio Resource Control
SCFDMA	Single Carrier Frequency Division Multiple Access
SCH	Shared channel
SDL	Supplemental downlink
SRTM	Shuttle Radar Topography Mission
TDD	Time Division Duplex
TD-LTE	Time Division- Long Term Evolution
TD-SCDMA	Time Division – Synchronous Code Division Multiple Access
TTI	Transmission Time Interval
UE	User equipment

UL	Uplink
UT	User terminal
UTC	Coordinated Universal Time
VDSL	Very high speed digital subscriber line
WRC	World Radio Conference
WRC-15	World Radio Conference 2015
WiMAX	Wireless Microwave Access (wireless broadband technology)
3D	3 Dimensional
3GPP	3rd Generation Partnership Project (body responsible for LTE-A standards)