From: [redacted]
To: NBP Mapping
Subject: National Broadband Plan State intervention - Unable to access fibre
Date: 16 September 2019 12:20:45
Attachments: image.png
image.png

Hi there,

My business premises eircode is [redacted] I am [redacted]

I am on a small side road with another house, with the fibre passing along both ends of the side road, but not down the side road.

This is the map on https://fibrerollout.ie/rollout-map/
Image.png

It is only 400 metres according to google maps from the N67 to my house.
image.png

Eir refuse to deal with me, simply because the https://fibrerollout.ie/rollout-map/ shows that they have not passed my business

What can be done about this?

I badly need fibre as I deal with high quality images and need to send them to clients and newspapers etc.

Kind Regards,
[redacted]

--

Best Regards,

[redacted]

[redacted]

[redacted]

Click icons & images

[redacted]

From: [redacted]
To: NBP Mapping; [redacted]
Subject: Broadband
Date: 26 September 2019 18:35:07
Attachments: eir broadband speed test Sept 2019.JPG
speed test 26 Sept 2019.JPG
Speed test.JPG

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Hello
My name is [redacted] from [redacted], Leitrim, my postcode is [redacted]

Attached is our broadband speed tests. We are considered to be in the Blue area - Eircode [redacted] is in the **BLUE AREA**
Your premises is in an area where eir has delivered high speed broadband services as part of its 300k rural rollout.
I dont know what your proposals are but I am looking forward to your response, as I have corresponded with eir for a long time and have not have any satisfaction with them. I pay 146euro per month to eir.
Thanking you
[redacted]

eir

SPEEDTEST

PING
11
ms

DOWNLOAD
5.7
Mbps

JITTER
13
ms

UPLOAD
4.0
Mbps

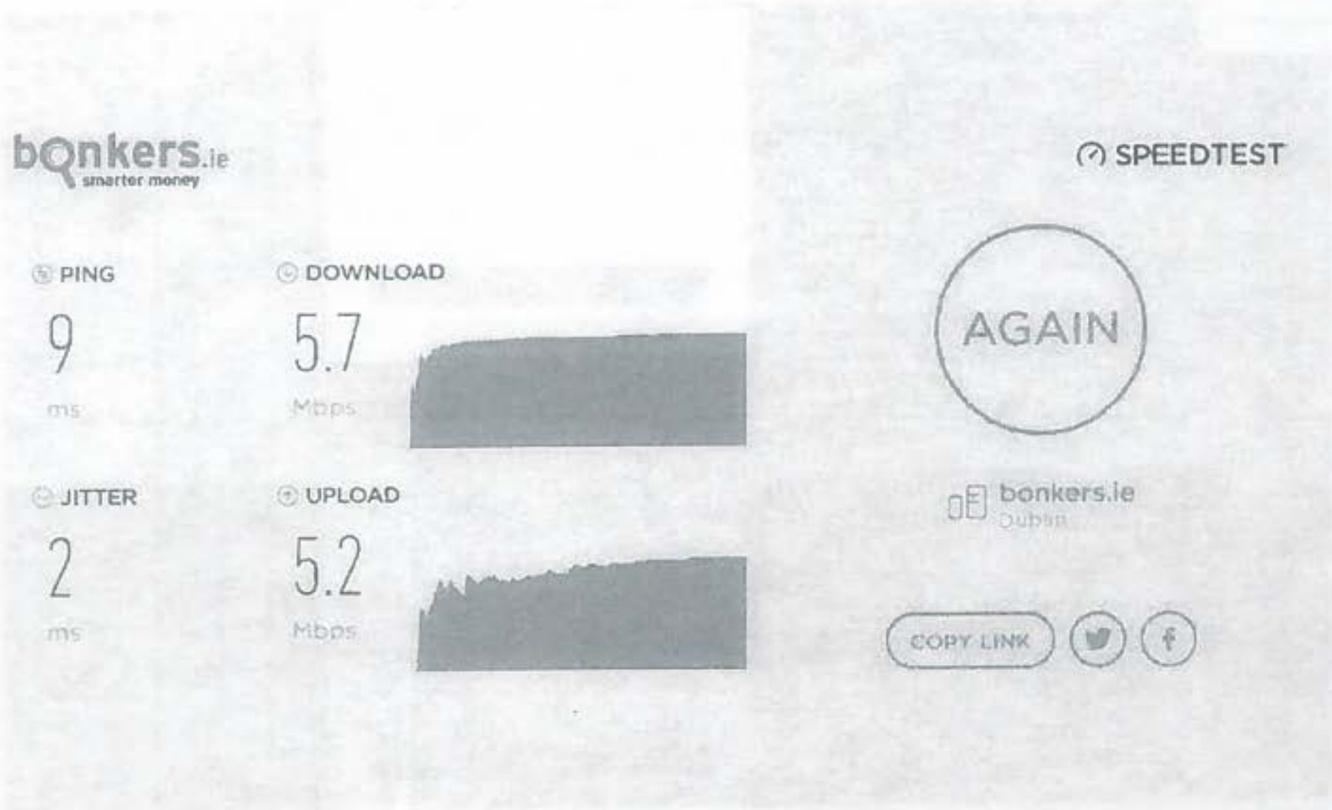
AGAIN

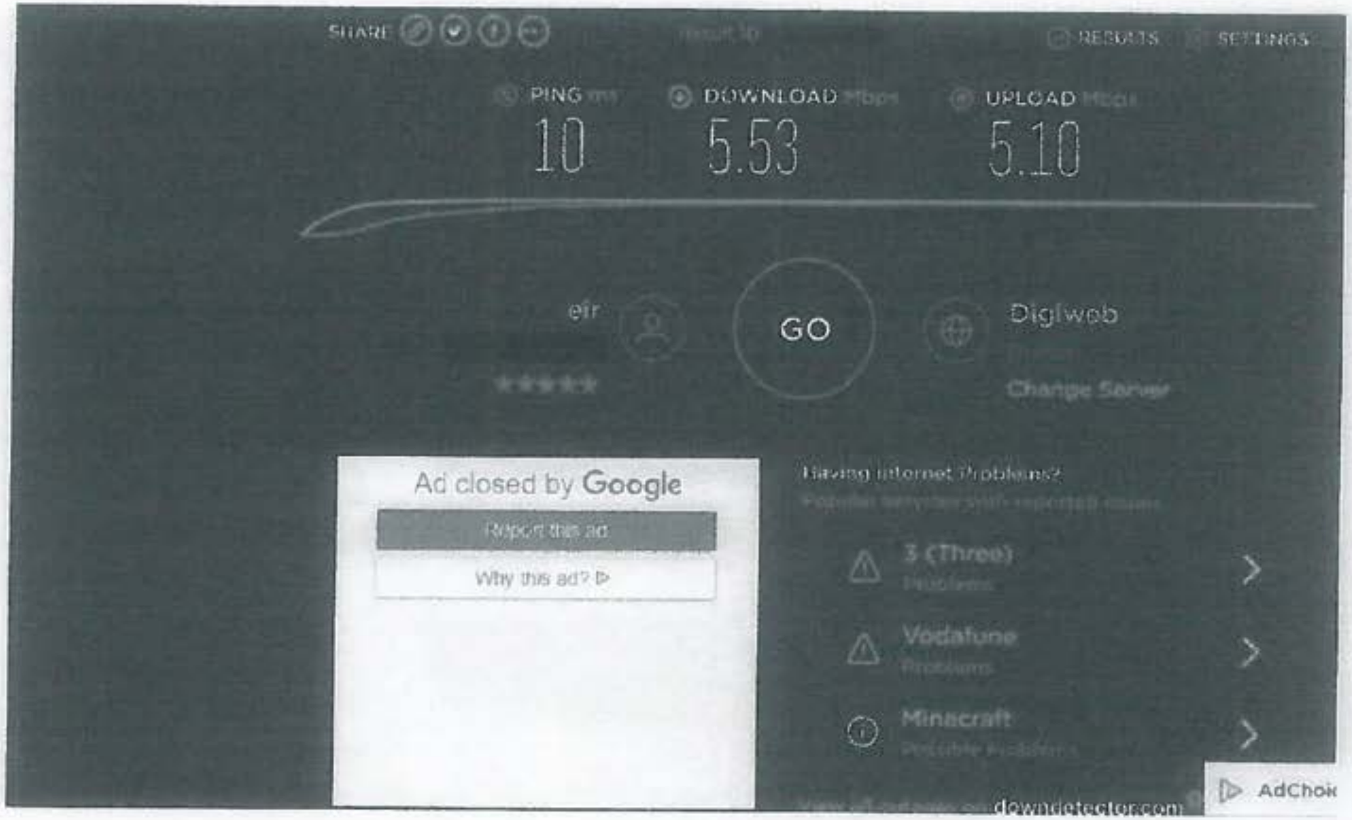
Eir
Dublin

COPY LINK

eir
[redacted]

Eir
Dublin


bonkers.ie
smarter money
SPEEDTEST
PING
9
ms
DOWNLOAD
5.7
Mbps
JITTER
2
ms
UPLOAD
5.2
Mbps
AGAIN
bonkers.ie
Dublin
COPY LINK


SHARE
RESULTS
SETTINGS
PING ms
10
DOWNLOAD Mbps
5.53
UPLOAD Mbps
5.10
eir
GO
Digiweb
Change Server
Ad closed by Google
Report this ad
Why this ad?
Having Internet Problems?
3 (Three)
Vodafone
Minecraft
downdetector.com
AdChoi

Gary Brazil

From: nbpmapping@dccae.gov.ie
Sent: 19 September 2019 10:35
To: NBP Mapping
Subject: New Submission

Follow Up Flag: Follow up
Flag Status: Completed

Conclusion of the Mapping Exercise

[redacted]

[redacted]

National Broadband Plan

Conclusion of the Mapping Exercise

Submissions: nbpmapping@dccae.gov.ie

The Department of Communications Climate Action and Environment is running a consultation on the National Broadband Plan Map.

We would like to hear from you if you have a problem accessing a high speed broadband service for your home or business.

Issues may include placing an order, getting connected, and/or getting the service you have ordered.

Name:
[redacted]

[redacted]

[redacted]

[redacted]

Location on NBP Map
Light Blue

Detail of correspondence with service providers:
Has a service with Eir but it is below the minimum speeds for FTTH. Only getting Fibre to the Cabinet even though they are in the blue in light blue area.

Detail of issue experienced:
Currently with Eir to get the issue resolved but has had no replies even though they have been in contact with Eir on numerous occasions

In some cases queries may need referral to operators after the consultation has concluded.

Has permission been given to pass on details supplied to the relevant operator(s) in the course of investigating any issues?

Yes

[redacted]

From:	[redacted]
Sent:	17 September 2019 10:44
To:	NBP Mapping
Subject:	Access to HSB
Follow Up Flag:	Follow up
Flag Status:	Completed

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Dear [redacted],

I am writing to tell you that Eir has not connected my home and other homes in the immediate area to HSB.
Fibre broadband was supplied to two roads that connect to mine,close to [redacted] but not to ours.
[redacted]
My understanding was that the government's mission was to deliver HSB to all rural areas but this has not been achieved in the case of this small road.

I would be grateful if you could acknowledge this feedback.

Yours faithfully,

[redacted]

From: [redacted]
To: NBP Mapping
Cc: [redacted]
Subject: FW: connection speeds
Date: 26 September 2019 16:12:08
Attachments: image1.png

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Hi,

Ref [redacted]

Eir code [redacted]

I have attached a recent screen shot of our broadband. As you can see the result is very poor.
In our business we require good broadband for a lot of day to day work including credit card payments.
If there is anything that can be done to promt improvement in this we would be very greatful.

Kind Regards

[redacted]

17:33
SPEEDTEST
DOWNLOAD Mbps
UPLOAD Mbps
4.86
5.29
Ping 20ms
Jitter 6.7ms
Loss 0%
Understanding results
Do This To Fix Slow WiFi Now
This tiny device can double internet speeds & supercharge your Wi-Fi signal.
TheGadgetReviewGuy
GO
eir

Imagine

Response to:-
National Broadband Plan
Conclusion of the Mapping Exercise for the Intervention Area Pre-Deployment
26th JULY 2019

[redacted]

20th September, 2019

Contents

Table of Figures

1 Overview

Imagine's response to the DCCAE consultation concerning the National Broadband Plan, Conclusion of the Mapping Exercise for the Intervention Area Pre-Deployment, 26th July 2015

For the purpose of facilitating and ensuring compliance with the State Aid Guidelines governing the proposed intervention in the NGA market, this document sets out Imagines commercial investment in existing NGA high speed broadband infrastructure in the market, where Imagine has already invested and is further expanding its network to meet demand in existing coverage areas and our plans for further commercial investment in new areas.

Considering the passage of time, the fundamental change in technology and the award of spectrum, secured funding and the new deployed network and service in the market this submission should be considered as completely separate and different than any previous submission from Imagine.

1.1 State Aid Guidelines

For reference we include here the primary sections of the State Guidelines relevant to this response:

EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks (2013/C 25/01)

> (20) Applying this principle to the broadband sector, the Commission considers that in areas where private investors have already invested in a broadband network infrastructure (or are further expanding the network) and are already providing competitive broadband services with an adequate broadband coverage, setting up a parallel competitive and publicly funded broadband infrastructure cannot be considered as an SGEI within the meaning of Article 106(2) TFEU (31)
>
> However, where it can be demonstrated that private investors are not in a position to provide in the near future (32) adequate broadband coverage to all citizens or users, thus leaving a significant part of the population unconnected, a public service compensation may be granted to an undertaking entrusted with the operation of an SGEI provided the conditions of the SGEI communication cited above are fulfilled. In this respect, the networks to be taken into consideration for assessing the need for an SGEI should always be of comparable type, namely either basic broadband or NGA networks
>
> (45) Regarding the *incentive effect* of the measure, it needs to be examined whether the broadband network investment concerned would not have been undertaken within the same time frame without any State aid. Where an operator is subject to certain obligations to cover the target area (61), it may not be eligible for State aid, as the latter is unlikely to have an incentive effect
>
> (61) This may, for instance, apply to mobile LTE (long-term evolution) or LTE advanced operators with coverage targets under their licence conditions in the target area. Similarly, if an operator designated with an universal service obligation (USO) receives

> public service compensation, no additional State aid can be granted to finance the same network
>
> (55) For the purposes of State aid assessment, the present Guidelines distinguish between basic and NGA networks.
>
> (56) Several different technology platforms can be considered as basic broadband networks including asymmetric digital subscriber lines (up to ADSL2+ networks), non-enhanced cable (e.g. DOCSIS 2.0), mobile networks of third generation (UMTS) and satellite systems.
>
> (57) At the current stage of market and technological development (69), NGA networks are access networks which rely wholly or partly on optical elements (70) and which are capable of delivering broadband access services with enhanced characteristics as compared to existing basic broadband networks (71).
>
> (69) Due to rapid technological development in the future other technologies may also be able to deliver NGA services.
>
> (71) The final connection to the end-user may be ensured both by wired and wireless technologies. Given the rapid evolution of advanced wireless technologies such as LTE-Advanced and the intensifying market deployment of LTE or Wi-Fi, next generation fixed wireless access (e.g. based on possibly tailored mobile broadband technology) could be a viable alternative to certain wired NGA (FTTCab, for example) if certain conditions are met. Since the wireless medium is 'shared' (the speed per user depends on the number of connected users in the area covered) and is inherently subject to fluctuating environmental conditions, in order to provide reliably the minimum download speeds per subscriber that can be expected of an NGA, next generation fixed wireless networks may need to be deployed at a certain degree of density and/or with advanced configurations (such as directed and/or multiple antennas). Next generation wireless access based on tailored mobile broadband technology must also ensure the required quality of service level to users at a fixed location while serving any other nomadic subscribers in the area of interest.
>
> (58) NGA networks are understood to have at least the following characteristics: (i) deliver services reliably at a very high speed per subscriber through optical (or equivalent technology) backhaul sufficiently close to user premises to guarantee the actual delivery of the very high speed; (ii) support a variety of advanced digital services including converged all-IP services; and (iii) have substantially higher upload speeds (compared to basic broadband networks). At the current stage of market and technological development, NGA networks are: (i) fibre-based access networks (FTTx) (72); (ii) advanced upgraded cable networks (73), and (iii) certain advanced wireless access networks capable of delivering reliable high speeds per subscriber (74).
>
> (63) For the purpose of identifying the geographical areas as white, grey or black as described below, the aid granting authority needs to determine whether broadband infrastructures exist in the targeted area. In order to further ensure that the public intervention does not disrupt private investments, the aid granting authorities should also verify whether private investors have concrete plans to roll out their own infrastructure in the near future. The term 'near future' should be understood as referring to a period of 3 years (79). If the granting authority takes a longer time

horizon for the deployment of the subsidised infrastructure, the same time horizon should also be used to assess the existence of commercial investment plans.

(64) To verify that there are no private investors planning to roll out their own infrastructure in the near future, the aid granting authority should publish a summary of the planned aid measure and invite interested parties to comment.

(65) There exists the risk that a mere 'expression of interest' by a private investor could delay delivery of broadband services in the target area if subsequently such investment does not take place while at the same time public intervention has been stalled. The aid granting authority could therefore require certain commitments from the private investor before deferring the public intervention. These commitments should ensure that significant progress in terms of coverage will be made within the 3-year period or for the longer period foreseen for the supported investment. It may further request the respective operator to enter into a corresponding contract which outlines the deployment commitments. This contract could foresee a number of 'milestones' which would have to be achieved during the 3-year period (90) and reporting on the progress made. If a milestone is not achieved, the granting authority may then go ahead with its public intervention plans. This rule applies both for basic and for NGA networks.

Design of the measure and the need to limit distortions of competition

(78) Every State measure in support of broadband deployment should fulfil all compatibility principles described above in Section 2.5, including the common interest objective, the existence of market failure, the appropriateness and the incentive effect of the measure. As regards limiting the distortions of competition, besides the demonstration of how a 'step change' is achieved in all cases (in white, grey and black areas) (90), the following necessary conditions must be fulfilled to demonstrate the proportionality of the measure. Failure to meet any of these conditions would most likely require an in-depth assessment (91) which could result in a conclusion that the aid is incompatible with the internal market.

> (a) Detailed *mapping and analysis of coverage*. Member States should clearly identify which geographic areas will be covered by the support measure in question (92), whenever possible in cooperation with the competent national bodies. The consultation of the NRA is encouraged but optional. Best practice examples suggest creation of a central database of the available infrastructure at a national level thereby increasing transparency and reducing the costs for the implementation of smaller, local projects. Member States have the freedom to define the target areas, however, they are encouraged to take into account economic conditions in the definition of relevant regions before launching the tender (93)

(92) This mapping should be done on the basis of homes passed by a particular network infrastructure and not on the basis of the actual number of homes or customers connected as subscribers.

(93) For instance, target areas that are too small might not provide sufficient economic incentives for market players to bid for the aid, while areas that are too big might reduce

the competitive outcome of the selection process. Several selection procedures also allow different potential undertakings to benefit from State aid thereby avoiding that one (already dominant) operators' market share is further strengthened by State aid measures by favouring large market players or discouraging technologies which would mainly be competitive in smaller target areas.

(94) In case where it can be demonstrated that existing operators did not provide any meaningful information to a public authority for the purposes of the required mapping exercise, such authorities would have to rely only on whatever information has been made available to them

1.2 Background:

Imagine was a participating member of the Next Generation Broadband Task Force. As an Irish company with considerable expertise and experience in both the Fixed and Mobile industries across Europe and the Irish communications market over the last 25 years, Imagine informed the task force on the then existing capabilities and future expected development of wireless technology and the importance of wireless infrastructure in Ireland in meeting EU objectives as set out in the DAE. Of critical importance was the developing Global standards for FWA including 4G LTE wireless technology and the distinction between dedicated FWA to provide fixed versus mobile services

While at the time Imagine had the required 3.5Ghz licenced spectrum to deploy FWA services its investment in the market was frustrated, pending the conclusion of a consultation on the future reallocation use and award of the 5G 3.5Ghz spectrum by 2017. Reflecting our commitment to the NGA market opportunity, pending conclusion of the Spectrum Award in early 2017, in mid 2016, Imagine deployed a commercial high speed broadband service using an LTE Fixed Wireless broadband network of 55 sites across areas previously identified as uncommercial by existing operators

This deployment of high speed broadband services was noted in a Statement by the Minister and on the Departments web site in the section Commercial Investment in high speed broadband.

> *"Imagine have started to deploy high speed enhanced broadband services using advanced LTE Fixed Wireless technologies particularly in rural and other more remote areas previously considered not to be commercially attractive."*[1]

Originally launched on a 2T2R architecture, eventually servicing some 18k customers this network provided the live trial and base case for the subsequent upgrade of the network through the industry roadmap, infrastructure and CPE releases, which provide significant increase in both capacity and throughput, and to the current latest release LTE Advanced Pro and 5G ready infrastructure deployed in the current network.

It is noteworthy that the capacity and throughput enhancement envisaged in the industry roadmap provided by Imagine, in its response to the mapping process in 2015, were not only

[1] Source https://www.dccae.gov.ie/en-ie/news-and-media/press-releases/Pages/Minister-Naughten-TD-welcomes-.aspx

achieved but were substantially surpassed within the expected timeframe.

In July 2017 Imagine successfully secured the 60Mhz of 5G 3.5Ghz spectrum across regional Ireland, in the ComReg competitive spectrum auction award process, required to deploy its national LTE-A Fixed Broadband network.

In early 2018 Imagine engaged with stakeholders and the Department in relation to the proposed investment by Brookfield and our planned commercial investment in the market. The announcement of the proposed investment in May 2018 was followed by an acknowledgement of Imagines commercial investment in high speed broadband in the market by the Minister:

> ***"Minister Naughten TD welcomes Imagine announcement of €120m in investment***
>
> ***Imagine announcement of €120m in investment funding to assist in commercial roll out of high speed broadband welcomed by Minister for Communications Denis Naughten TD"***
>
> *May 11, 2018*
>
> *Minister for Communications Denis Naughten TD has welcomed the announcement today by Imagine Communications Group Limited of a €120 million investment and 50.1% share acquisition by Canadian investment firm Brookfield. Imagine states the cash injection will assist the company in rolling out high speed broadband infrastructure to rural and regional areas, following the approval of the transaction by competition and regulatory authorities.*
>
> *Minister Naughten stated:*
>
> *"I warmly welcome today's announcement from Imagine. This investment was made possible following the release of the valuable 3.6 GHz spectrum. In October 2016, I signed Regulations which allowed ComReg to auction spectrum in the 3.6GHz band* to provide an 86% increase in total spectrum available for mobile and fixed wireless services. A strong, future proofed broadband network delivered under the National Broadband Plan will underpin and support these key investments by telecommunications companies, such as Imagine, in LTE and 5G evolutionary technologies. Our shared goal is to connect Ireland to the digital age, and this investment will result in rural and regional Ireland getting access to high speed broadband services in the short term. It will also provide the backbone for the roll out of 5G in rural Ireland over the next decade."*[3]
>
> **(Wireless Telegraphy (3.6GHz Band Licences) Regulations, 2016 (S.I. 532 of 2016)*

Subsequent to the announcement, conscious of the importance of high speed broadband particularly in rural Ireland, our ongoing support for the government and NBP objectives and seeking to avoid any further delay to the conclusion of the NBP procurement process, Imagine continued our engagement with Department which sought agreement on the basis on which Imagine would continue its commercial rollout of 5G ready infrastructure in parallel with the NBP process.

[3] https://www.dccae.gov.ie/en-ie/news-and-media/press-releases/Pages/Minister-Naughten-TD-welcomes-.aspx

In January 2019 Imagine informed the Department of its forthcoming announcement of its investment and commercial rollout of highspeed broadband infrastructure [redacted]

At the formal commercial launch on the 13th of February 2019 Imagine provided details of its commercial rollout of 5G NR ready infrastructure and its intention to be the first operator to deliver 150Mb fixed broadband services to the majority of the 1.6m premises outside areas already serviced by cable, with the priority to provide services to the majority of the 540,000 premises where there was previously no planned commercial alternative. The announcement included details of our planned rollout of an initial 155 sites by June 2019. See Attached Press Release

The commercial investment and *"rollout of high speed broadband across underserved areas of the country"* is acknowledged on the Departments website under *"Commercial Investment"*[4]

A key principle of the NBP is to support and stimulate commercial investment.

Since the publication of the NBP in 2012, the commercial telecommunications sector has invested over €2.75 billion. This was primarily on upgrading and modernising networks which support the provision of high speed broadband and mobile telecommunications services.

Significant additional investment is expected over the coming years. Today over 1.78m or 75% of premises in Ireland can access commercially available high speed broadband services.

Various players in the market have ramped up the speed of their rollout, for example:

- *SIRO is investing €450m to provide fibre broadband to 500,000 premises across 51 towns on an open access basis. In February 2019 it announced further investment in its high speed broadband deployment in Donegal*
- *Virgin, currently serving 900,000 premises, is investing high speed broadband rollout to a further 100,000 premises.*
- *In February 2019 Imagine announced plans to invest €300 million a high speed broadband deployment across Ireland. The announcement follows on from an announcement in 2018 of a partnership with global asset management group Brookfield and €120m funding to roll out high speed broadband across underserved areas of the country.*
- *In February 2019 eir announced that its new FTTH investment of up to €500m over a 5 year period, to upgrade eir's legacy copper network across 180 towns and cities. This is in addition to eir's deployment of high speed broadband to 300,000 rural premises under its Commitment Agreement with the Department.*

On the 6th September 2019 Imagine announced that it had delivered on its announced initial plan and commitment to quickly deliver high speed broadband of up to 150Mb with details of the availability of services across 155 sites covering over 800k premises including 234k of the

[4] https://www.dccae.gov.ie/en-ie/communications/topics/Broadband/national-broadband-plan/commercial-investment/Pages/Commercial-Investment.aspx

540k premises identified in the proposed intervention. See Press Release contained in the appendices.

1.3 LTE Advanced Pro evolution to 5GNR 5G

As envisaged under the State Aid Guidelines since the commencement of the NBP process, there has been a step change in the development of next generation wireless technology. Driven by the rapid evolution of "smartphone" and "tablet" capability and the global demand for high speed data center IP infrastructure to meet consumer demand, the development and deployment of LTE and accelerated migration to LTE A infrastructure has been unprecedented. Reflecting demand, take up of 4G services was at a rate of 10 times faster than 3G. This market demand driven environment has significantly accelerated the requirement for ever increasing network capacity and increased speed and a global ecosystem of infrastructure and device development. Current "LTE Advanced" standards are today delivering high capacity and throughput capabilities of 300Mb and above which are way beyond legacy fixed technologies such as FTTC and comparable with current FTTH offerings of 150Mbps. Further planned releases which include Massive MIMO and adaptive beamforming will further increase capacity and throughput speeds up to 1Gbps. The evolution from LTE-A to 5G, and vendor roadmaps over the next 5 years, envisage the convergence of fibre and wireless with speeds of over 10Gbps already being demonstrated by vendors today.

1.3.1 Evolution to 5G

5G is the next generation wireless technology with 5G NR (New Radio) defined by 3GPP standards as the new air interface developed for the 5G network. This is an evolution of the existing LTE Advanced standards.

Enabled by faster connections, higher throughput, and more capacity 5G will facilitate:

- Enhanced Mobile Broadband (eMBB),
- Ultra Reliable Low Latency Communications (URLLC), and
- Massive Machine Type Communications (mMTC)

The targets for 5G capabilities are for it to deliver:

- 100 x data rate
- 100 x connected devices
- < 1ms latency
- 90% less power consumption
- Use of new spectrum bands including bands < 6 GHz for core services and > 6 GHz for supplementary services e.g. small cell capacity

A view of the evolution of LTE towards 5G NR is provided in Figure 8 Imagine Evolution Path to 5G. The equipment currently being deployed by Imagine is 5G NR hardware capable and can be software upgraded to 5G. The remaining infrastructure e.g. masts, backhaul network, core network etc. will be reused as 5G NR technology is introduced to supersede the LTE network.

The transition from LTE Advanced to 5G NR and full 5G is by way of a combination of software upgrades and additions of adjunct hardware into existing platforms.

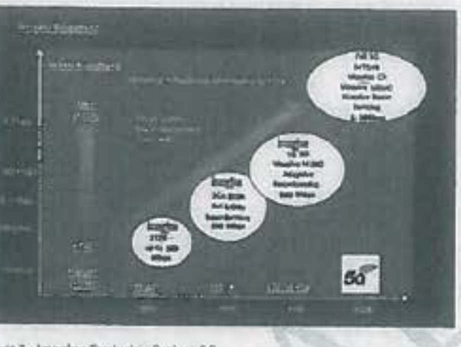


Figure 1: Imagine Evolution Path to 5G

TDD LTE

With the increasing demand for capacity combined with the constraint of the limitation of spectrum, of particular importance has been the development and take up of the Time Division protocol variant of LTE (TD-LTE) designed to maximise the use of spectrum in the most efficient way to deliver higher bandwidth services. Derived from fixed wireless and early 4G WiMax protocols and standards, TD-LTE uses the same channel for downloading and uploading data where the spectrum resources are allocated proportionally in the time domain to reflect and cater for normal broadband usage profiles the demand for downloading data far exceeds the demand for uploading. TD-LTE significantly increases the capacity of a network to deliver high speed broadband services and is a key factor driving the convergence of fixed and wireless networks.

Requiring ever increasing bandwidth the frequency bands 3.4-3.6 GHz and 3.6-3.8GHz were adopted as LTE-A bands 42 and 43, which is one of the pioneer bands for 5G. Ireland was one of the first countries in the world to release the 5G 3.5Ghz spectrum in 2017

International Position

By the beginning of August 2019, there were 304 commercially launched LTE-Advanced networks in 134 countries. Overall, 335 operators are investing in LTE Advanced (in the form of tests, trials, deployments or commercial service provision) in 141 countries.

Many operators with LTE-Advanced networks are looking to extend their capabilities by adding 3GPP Release 13 or Release 14 LTE-Advanced Pro features, e.g. those making use of carrier aggregation of large numbers of channels, or carriers across TDD and FDD modes, LAA, massive MIMO, Mission Critical Push-to-Talk, LTE Cat-NB1/NB-IoT or LTE-M/Cat-M1.

Figure 1 - Countries with launched LTE-Advanced networks 2019

According to GSA research from August 2019, at a European level some 106 operators in 41 countries are investing in 5G.

While LTE advanced 4G networks are already capable of providing low latency 300Mbps services and will already benefit from the increased capacity of Massive MIMO, 5G will provide the opportunity to offer Ultra Low Latency at speeds in excess of 1Gbpsand expected to exceed 10Gbps. As recognised under the Digital Agenda for Europe and by Governments, in addition to Fibre infrastructure high capacity low latency superfast 5G infrastructure is considered to be a key driver of the future digital economy, the achievement of a Gigabit Society and a solution to the digital divide

LTE- Advanced / 5G Fixed Broadband

Beyond enhanced mobile services with the existing high capacity, throughput and low latency of LTE Advanced and the evolution to 5G, FWA (LTE-A/ 5G Fixed Broadband) has emerged as a competitive and future proofed alternative to FTTx to deliver high speed broadband services and for many operators a key driver of 5G infrastructure investment.

A recent report by Analsys Mason[4] identifies that 5G FWA offers organic revenue growth to mobile operators at a time when the main services offer none and shows a total addressable market of about 290 million premises worldwide by 2023.

Identifying both complimentary and challenger commercial opportunities the report clearly identifies the commercial opportunity for holders of mid-band 3.5Gz spectrum holders as an alternative to FTTx in high cost/ suburban/ rural areas. The report identifies the primary opportunity accounting for 205 million of the potential 290 million premises, for challengers in high cost FTTC regulated monopoly markets with weak wholesale broadband competition, where there is poor last mile physical infrastructure and FTTP deployment is slow and cost per premises exceeds $1200.

In the case of Ireland, the report identifies the commercial market opportunity for a challenger to existing fixed operators at 310,000 Premises.

"5G alters the economic-geographical boundary between fixed and wireless deployment and creates sufficient capacity to shift the economic-customer segmentation boundary between the 'demanding' and the 'undemanding'. FTTP is likely to continue to be a technically superior solution - higher bandwidths up and down, more robust, lower opex –but initial costs will be high. Moreover, it is debatable whether its superiority matters to most end users."

In terms of capacity average of 200Gb per month for a fixed user versus 10Gb for mobile does present an issue and even with the estimated customer usage of 1TB per month by 2024 identifies that Aggregate bandwidth per subscriber required to carry that data load is still under 8Mbps.

In relation to committed data and actual usage, research carried out by the Wall Street Journal found similar results across 34 testers who ran five, six or seven streams at once. The users with speeds of 100 Mbps or higher who had seven streams going used only about 7.1 Mbps of capacity on average. People who paid for even faster speeds still streamed video at about the same speed as everyone else, resulting in their using a smaller portion of their available bandwidth. One person with a 300 Mbps connection streamed at a median of only 7.2 Mbps using a mere 2% of the capacity they pay for.[5]

Notably given the recent inaccurate assertion of the requirement of 6k sites to provide nationwide 5G fixed broadband nation, based on a misinterpretation on a ComReg report for 5G mobile coverage, the report is helpful in establishing that "Coverage is based almost entirely on existing macrocells, because mMIMO makes 3.5GHz coverage about 80–90% as extensive as 1800MHz. We do not think 3.5GHz 5G will make a major difference to the underlying historical

[4] "5G fixed-wireless access: the market opportunity for operators and vendors"

[5] See the Wall Street Journal article included with the appendices

trend in cell sites and will certainly not require more than local and tactical use of small cells unless there are power constraints."

While the report highlights a number of challenges and investment decisions for Mobile operators based on a hybrid Mobile and FWA deployment, who have to consider not only the allocation of 60Mhz of valuable spectrum to fixed users but also the impact of heavy data fixed broadband users on its mobile services, a dedicated LTE-A/5G Fixed broadband operator does not face the same constraints.

It should also be noted that in addition to the hybrid model the analysis is based on assumption of the use of Indoor and self-installed CPE which reduces spectral efficiency and impacts service variability. As identified by the Author the use of external CPE with high gain antennas ensures a higher quality service, which increases spectral efficiency and overall network capacity and performance.

The Imagine business model and consequential network design and deployment is based on a fully dedicated LTE-A/5G Fixed Broadband network using a dedicated 60MHz of 3.5Ghz spectrum. With customers professionally installed using only high gain external CPE and only connected if a minimum high modulation threshold signal can be achieved the Imagine network achieves the highest spectral efficiency, optimum capacity, throughput and performance achievable based on the theoretical optimum performance metrics and the highest quality of service and customer user experience. By definition of the design and implementation with a 77% 256Qam and 99% 64 modulation the Imagine LTE-A network is one of the best performing LTE Networks in the industry.

In the context of this submission and the NBP objectives the following extracts from an Analysys Mason report* are insightful and helpful (Text highlighted for emphasis)

> *Given the substantial funding requirement to meet the DAE 100Mbit/s coverage target and, ultimately, the EC's Gigabit Society vision the need for cost-efficient technologies has never been more critical. Another key consideration is the time taken to deploy broadband networks given the 2025 target and the need to avoid the risk of a significant digital divide in rural areas. It is vitally important for EU countries to explore alternative NGA technologies and undertake detailed cost modelling, including market consultation, to devise the most cost-efficient approach to meet the DAE 100Mbit/s coverage target and Gigabit Society vision.*
>
> *In its "Call for a Gigabit Society" report Vodafone highlights the importance of investing in **future-proof fixed and wireless technologies such as FTTP, cable and 5G networks.** Investing in copper and satellite technologies to meet short-term goals might not achieve the Gigabit Society vision, as these technologies are not expected to achieve 1Gbit/s broadband speeds in the foreseeable future. Copper and satellite technologies are not as **future-proofed as FTTP and FWA.** Investing in future-proof technologies thus becomes extremely important as a long term aim.*
>
> *Previous mobile developments have involved competing broadband technologies for 3G through to 4G which to some extent limited the full potential of economies of scale benefits. 5G is different in that network operators have a very clear upgrade path to the future, with significant industry support towards 5G standards developed by the 3GPP body. One such benefit is lower cost for electronics devices (e.g. chipsets for user devices and network equipment) which could result in lower user-device and network deployment cost. The future-proof 5G platform allows technology upgrades rather than technology 'overhaul', reducing long-term costs.*
>
> *Wireless connectivity has a role to play as a complement to, rather than a substitute for, fibre to the premises (FTTP). Telefónica in Spain and Deutsche Telekom in Germany are examples of network operators with plans to deploy significant FTTP network infrastructure, but which have also indicated plans to deploy an FWA solution as a complement to their existing networks; other similar operators are likely to follow this lead over time. This suggests that FTTP and 5G networks can be used as effective complements to each other. Governments across Europe (e.g. France and the UK) have already devised and published 5G network strategies despite having invested heavily in FTTx5 network infrastructure via their NBPs. A dense fibre network allows wireless masts to have fibre backhaul, resulting in synergy benefits (i.e. cost savings).*
>
> *The economics of wireless infrastructure could be beneficial in certain circumstances to help achieve the DAE targets. A mix of fibre-based and FWA solutions could be used to address the rural broadband challenge in a timely manner; the nature of the technology mix being highly dependent on the total (private plus public) funding being available. **There are already examples across Europe that demonstrate that FWA is an NGA technology that can satisfy the DAE 30Mbit/s coverage targets.** Open Fiber in Italy and Relish in the UK are using FWA solutions based on a 3GPP solution as part of NBP delivery.*
>
> ***Given the future-proof nature of the 3GPP technology platform, FWA deployment (using both 3GPP 4G and 5G) can potentially play a role in helping meet NBP and DAE targets.** The extent to which FWA plays a role will be critically dependent on local market conditions (e.g. the extent of population 'clustering' in rural and remote areas, suppliers' strategic choices, government budgets, the procurement process and State-aid policy implementation"*

* "Analysys Mason White paper on EU broadband plan challenges and opportunities"

Delivering NGA services using FWA TD LTE Advanced and 5G NR infrastructure will have a significant impact on the competitive NGA market, the areas and number of premises to which NGA service can be delivered commercially, the reduction of areas and premises requiring State Intervention and the ultimate cost of the Intervention to the State and the Irish taxpayer. Imagine are the only FWA operator with sufficient spectrum to deliver NGA services on a national basis using TD LTE Advanced and 5G NR infrastructure.

5G Spectrum

The forthcoming ComReg Spectrum Multi-Band auction has a mixture of TDD and FDD spectrum available and it is our intention to participate in that auction to add further spectrum resources to our existing spectrum portfolio

1.4 Existing Network

1.4.1 Scale of operation End to End

The Imagine network, as well as the organisation, is designed and built to be scalable. Central to this is the Core Network which currently is a full function, fully featured LTE Core. The Core, as well as all other elements used are carrier grade and sourced from world leading suppliers such as Huawei and it is fully redundant, resilient and fault tolerant. As capacity and sites connected grow within the network Core capacity is selectively upgraded to add additional throughput capability as required to ensure continued smooth operation. The Core we have in place from Huawei is scalable to handle extremely large numbers of sites and customers.

Our backhaul network is predominantly fibre and complimented by secure licenced microwave links where fibre connections are not yet available. The backhaul network, end to end, is completely uncontended and generally operates with zero (or close to zero) packet loss ensuring low latency and maximum operational efficiency. As our network grows, planned backhaul evolution will introduce additional alternate path routing for sites further improving availability.

As part of our initial investment, as well as the very significant investment in our LTE Core, we have put in place a full suite of network management tools to monitor in real time the operation of all elements in the network from our Core all the way through our RAN equipment and also including full remote management of CPE. This ensures we have real-time accurate monitoring and control of all network elements.

At this time, and with substantial network assets in place and operating, the incremental addition of sites is a comparatively straightforward process. Each new site as it is added to the network is centrally managed from our core and is seamlessly inserted into our operational management and reporting systems. Additional backhaul links are similarly straightforward.

1.4.2 Imagine Organisational Capability

As an established operator with over 12 years of experience in rollout and operation of fixed wireless networks, Imagine has the full capability to build operate and maintain the network and service our customers needs.

Currently, we have 254 permanent staff in the organisation and we are a fully self contained communications company with resources spanning the complete range of activities from Network Design, Build, Operate, Manage and Maintain to complete customer service and care and the full complement of support services needed to run the company. Our internal resources, while growing steadily, are complemented by external partners who provide us with additional temporary resources during periods of intense activity as well as fully outsourced services for selected activities.

The company project manages the entirety of the roll-out and contracts to vendors or to third party suppliers certain activities such as site planning, drive-testing of sites, site testing and acceptance and ongoing optimisation of the network.

All Imagine Engineering and Field staff as well as any sub-contractor staff are fully trained and vendor certified in the planning and deployment of LTE/5G and associated IP and backhaul equipment.

This is overseen by a number of highly experienced senior Engineering and project management staff with experience in multiple mobile and broadband network deployments in Ireland and internationally to oversee the evolution of the network.

Further information outlining in more detail some of the organisational capabilities, partnerships management approaches and risk management issues are laid out later in this document.

1.4.2.1 Operation

Imagine to date has deployed LTE-A to 172 base stations across the Regions. This super-fast broadband infrastructure uses advanced 4G Time-Division Long-Term Evolution (TD LTE Advanced) which uses LTE spectrum in a more efficient way to deliver high-capacity, high-speed broadband service to users. This infrastructure is deployed using Imagine's current (3400-3800 MHz) spectrum in the 3GPP defined LTE bands 42 and 43. Imagine's spectrum position, combined with the advanced capability of TD LTE Advanced deployed for fixed wireless using high channel bandwidths (initially 2x20MHz), enables the company to deliver high-speed NGA services of up to 150Mbps to a large population over a comparatively wide area.

As the evolution of high-speed wireless networks and global standards-based infrastructure migrates towards 5G NR, Imagine's network technology will continue to benefit from ongoing development to meet the industry anticipated increasing demand for high speed broadband services, capacity and speed.

1.5 Existing Network Coverage

Imagine recently announced that it had completed Phase One of its 5G Ready fixed Broadband network. Already this is delivering reliable high speed service broadband (up to 300Mbps) and is available to over 800k premises across rural Ireland.

1.6 Service Quality and Usage

1.6.1 Service Quality

Service Assurance is based on well proven installation practices based on more than 10 years of experience of planning, connecting and managing outdoor installations in fixed wireless deployments. All CPE installations are carried out by Imagine staff or sub-contractors who are trained and experienced. Imagine do not permit self-installation by users or via dealers. All installations are subject to passing an installation acceptance. This ensure predictability and service quality for the customer and the network overall.

Proactive management of quality metrics is carried out post installation to ensure the signal quality metrics are maintained both for the individual customer and on a network wide basis.

Deploying the TD-LTE network as a fixed wireless solution provides predictability and control over the RF metrics of customers with only those with acceptable metrics being accepted onto the network in order to maximise the capacity of the system to connected users. By only using outdoor antennas we maximise coverage and ensure the highest possible metrics are achieved.

Strict management and control of the process by which customers get access to the network and the number of users per sector ensures the highest modulation, capacity and network performance and ensures the quality of service provided customers

As is discussed in more detail in Section 2.7.5 we have shown, with data from our live network that the network does deliver a *"minimum download speed of 30 Mbit/s when they demand it"* and furthermore provides a service far in excess of this minimum speed for a significant number of users and for a significant amount of the time. It has been shown that, even at peak times, user demands are being fully met with spare resources available in the network.

1.6.2 Usage of the Service

In addition to looking at achievable speeds during peak times for a given number of subscribers it is also necessary to consider the capability of the network to support the total volume of data demanded by the subscribers.

Today, in the existing Imagine TD LTE network the average monthly usage of each customer is between XXXX with an average monthly demand across the network of XXXX per customer.

The latest ComReg Quarterly Market report shows that, at XXX per month Imagine customers download a greater volume than the average user at 194GB and that the Imagine network carries more traffic than VDSL and FTTP networks at 168.7GB and 193.7GB respectively and approximately the same as Cable at 251GB.

This clearly demonstrates the ability of the existing network to meet and exceed current demands from Customers within our coverage footprint.

1.7 Network Capacity and Growth

As a commercial investor in the market, we have already deployed capital to create the network which is now in place and available to serve these customers. In line with normal commercial investment criteria, we are satisfied that the coverage and capacity currently available in the network is sufficient to serve current market demand. As take-up of the network increases, and customer usage similarly increases, we stand ready to inject further capital into further network capacity as required to maintain the competitiveness of our service to our customers and to maintain our customer experience at an appropriately high level. There are many tools at our disposal to maintain and improve the customer experience including (but not limited to):

- Network densification – adding further sites into the overall network to improve available capacity
- Small Cells – deploy small cells to selectively create pockets of capacity in particular areas of higher demand
- Increase Spectrum Holdings – add further spectrum into our radio network. This is particularly in reference to the forthcoming ComReg Multi-Band Spectrum Auction

These, and other options available to us, are discussed in more detail in Section 2.7.9 in this document.

1.8 Expansion of Existing Network Footprint

For the purpose of assisting the Department to the extent that possible, reasonable and practical within the constraints of standard industry practice for the deployment of a Fixed Wireless infrastructure, Imagine have identified a coverage footprint across XXX sites where we fully intend to deploy commercial NGA network infrastructure and provide NGA service to homes and businesses within coverage. This future coverage map is attached as Q6 in the appendices to this document.

It is our intention to continue to expand our existing network coverage over the coming c. 2-3 years to gradually evolve from our current coverage towards this future coverage area by adding additional sites into the network. This gradual expansion of our network will be primarily commercially driven and in response to market demand for high speed broadband service. This expansion of our network is in line with our overall commercial investment programme and is fully funded.

At this point in time we are not prepared to commit to signing a Commitment Agreement with DCCAE and therefore we have decided not to submit these future expansion plans for consideration in this phase of the mapping exercise. - albeit we are prepared to share, and have provided you with, our current view of the eventual extent of our intended coverage in the map referred to earlier.

XXX

We will continue to assess further areas beyond this footprint where business case requirements are met and where we will therefore further extend our footprint by rolling out additional sites. This process will be further assisted and influenced by current discussions with other retail and wholesale operators. Discussions including extending and "in filling" coverage in areas where other NGA networks are being deployed will also inform our planned infrastructure deployment. The outcome of these discussions could lead to a faster and more extensive rollout of the Imagine Infrastructure.

As this process evolves, we will identify those further areas where we intend to deploy infrastructure and will inform the department on an ongoing basis in relation to continuing to evolve the mapping process

1.9 The Existing Imagine Network and State Aid Guidelines

In line with standard operator practice we normally model our coverage plots with a 76% probability at the cell edge and an area probability of 90%, based on our service offering of up to 150Mbps across the network. See above

A map showing this coverage plot is in

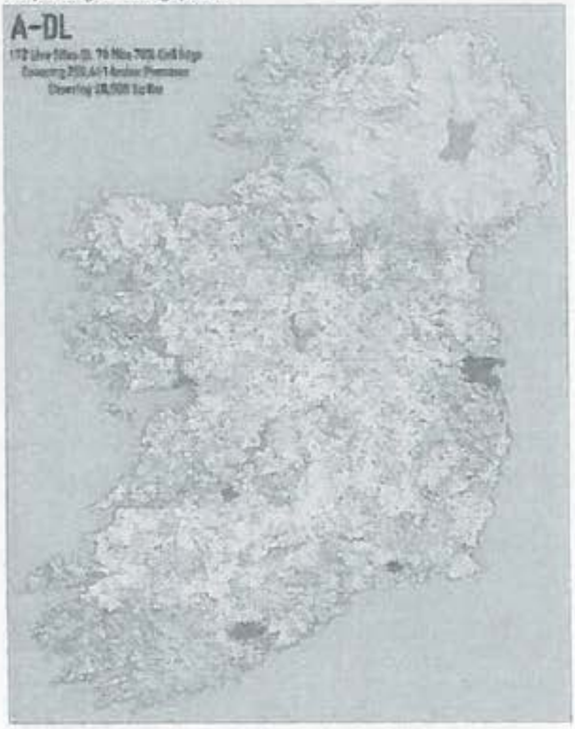


Figure 2 : 76% Cell Edge Coverage Profile below. The profile shows that, using these criteria 259,411 'Amber' homes are within the current coverage footprint of the existing Imagine network.

Figure 2 76% Cell Edge Coverage Profile

In the interests of completeness and to maintain a consistency of approach throughout the process we believe it is also helpful to examine what the resultant coverage profile of the existing network is if a less restrictive view is taken of the Departments requirements for the UL requirement. We have therefore produced a further coverage plot showing the SAG requirement of 76% Cell Edge probability, 90% Area Probability with 30Mbps DL and 2Mbps UL as being a more reasonable representation of what a commercial operator would feel is required to be deployed to customers.

Figure 3 : 76% Cell Edge probability, 90% Area Probability 30Mbps DL 2Mbps UL

We are aware however that you have specified that you require such radio plots to be calculated using higher than normal thresholds – specifically, you require that the Cell Edge probability should be set at 95% with a corresponding area probability of 99% with a minimum service to the customer of 30Mbps. We should make clear at this juncture that we do not consider such restrictive radio coverage metrics to be either necessary or appropriate for commercial network deployments as they are overly restrictive. In any event, notwithstanding, we have run such coverage plots for you using your criteria and this is displayed in Figure 4 : 95% Cell Edge Coverage Profile 30Mbps below.

Figure 4 . 95% Cell Edge Coverage Profile 30Mbps

This plot shows that there are 273,044 'Amber' homes with the existing footprint of the Imagine network.

Further to the SAG requirements of 30Mbps download you have included an additional requirement that Uplink capability must meet or exceed a minimum of 6Mbps and since this is a

further limiting factor on the plot above we have also included a coverage plot showing this further restriction and it is shown in Figure 5 - 95% Cell Edge Coverage Profile 30Mbps DL 6Mbps UL below.

Figure 5 - 95% Cell Edge Coverage Profile 30Mbps DL 6Mbps UL

Combining these DL and UL restrictions gives rise to the coverage profile shown and includes 229,101 'Amber' homes within the existing network coverage.

Taking a particular view of these various coverage profiles will alter the number of 'Amber' premises deemed to be within coverage of our existing network. Across these various coverage plots, the quantum of 'Amber' homes within coverage of our existing deployed network ranges from 229,101 to 359,195.

Specific technical details for the network and the requested coverage plot file formats accompany this response document for each scenario.

As recognised by the EU and set out in the SAG, the rapid development and deployment of LTE Advanced infrastructure in the last few years has provided a step change in the technologies available to deliver NGA services to European citizens. This will only be enhanced by the evolution to 5G.

The Imagine LTE Advanced network not only meets the guidelines set out in SAG, it exceeds the required performance in terms of capacity, speed and user experience that could be envisaged in the SAG to be available in *any other* European market. With our spectrum holdings we can fully exploit the potential of the TD-LTE Advanced network to deliver the very best high speed services possible using 60MHz (up to 3x20MHz) channels (and up to 100MHz channels in 5G NR with the appropriate spectrum), with the most efficient frequency plans to minimise co-channel interference which can reduce overall network capacity. Additionally, the full benefit of current performance enhancements such as Beamforming, MIMO (and future planned LTE Advanced releases and eventually 5G NR) can offer peak speeds of 300Mbps and Imagine along with many other operators have already commenced trials of higher-order carrier aggregation and Massive MIMO systems with peak speeds approaching or exceeding 1Gbps.

Imagine's spectrum position, harnessed to provide ultrafast NGA fixed broadband services, provides Ireland with a significant advantage over other European markets in addressing the digital divide, meeting the objectives set out in the NBP of delivering high speed broadband to all citizens by 2020 and deriving the benefit of the digital dividend. Imagine intend to provide wholesale access to our network to other operators and service providers on a competitive basis ensuring customers benefit from competitive and innovative services.

Imagine believes that its TD-LTE Advanced and 5G NR network will be an essential component in the integrated and effective solutions required to meet the expected targets set out in the National Broadband Plan (NBP) and that the NBP's targets can only be delivered on time and cost effectively to all consumers if a combination of new FTTH, FTTC and Fixed Wireless infrastructure is deployed.

The Imagine service is dimensioned and specified to deliver a comparative or better service and user experience than competing NGA service offerings and is provided to customers on the same or equivalent terms and conditions as other NGA services. The Imagine network is fully flexible to meet evolving consumer demand and is dimensioned to meet expected growth in data consumption and demand.

Already planned TD-LTE Advanced releases and roadmap developments through 5G NR will further enhance overall speed and capacity providing a future proofed solution. Additional capacity to meet demand in an area will be provided by overlapping multi-base station

deployments and additional overlay sectors where required. Further information is provided later in this submission outlining the available strategies to meet growing customer numbers and increasing customer demand.

As has been already communicated to DCCAE, Imagine has completed Phase 1 of it's National Network with 172 sites live and providing service to Customers all across Regional Ireland. At this time, we have extended high speed NGA grade broadband to c. 800,000 homes (passed) including c. 260,000 'Amber' homes (passed) within the currently identified intervention area depending on the interpretation of the required radio metrics as outlined in the various plots provided in Section 1.5 Existing Network Coverage. Again, at this time the service proposition we offer customers within coverage is a standard 150Mbps broadband service with no effective limitation to use for normal domestic consumption. This service far exceeds the minimum service threshold required to no longer categorise these homes as 'Amber' in NBP terms.

In this context, we are mindful of paragraph 20 of SAG Guidelines[1] where it states:

> *"...the Commission considers that in areas where private investors have already invested in a broadband network infrastructure (or are further expanding the network) and are already providing competitive broadband services with an adequate broadband coverage, setting up a parallel competitive and publicly funded broadband infrastructure cannot be considered as an SGEI within the meaning of Article 106(2) TFEU..."*

Accordingly, in our view that it is unavoidable to now remove these homes from the NBP Intervention Area so that the NBP does not find itself in contravention to SAG rules.

We look forward to our ongoing engagement with the department to ensure that the full benefit of the Imagine TD-LTE Advanced and 5G NR infrastructure can be fully exploited to deliver the objectives set out in the Governments NBP.

[1] EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks (2013/C 25/01)

2 Imagine's Response for Existing NGA Networks

E. Information Required if a submission is made

E.1 Submissions with respect to existing NGA networks

Appendix A1 of Assessment Criteria

A1.1.1 A description of the overall network architecture

2.1 A description of the overall network architecture

Imagine's existing TDD LTE Advanced Network Architecture is currently deployed on 172 sites is based on standard elements and sub systems as defined in 3GPP standards for LTE Advanced Pro. The existing LTE solution is compliant to 3GPP Release 14 (LTE Advanced Pro) with additional Release 15 features enabled as required[8] The key elements of the end-to-end architecture are shown in Figure 6, and are briefly

- LTE User Equipment (UE)/ Customer Premises Equipment (CPE) - External CPE connected to indoor router
- LTE Radio Access Network (RAN) - eNodeB equipment
- Backhaul network - Gbps fibre optic transmission links and Point-to-Point microwave radio
- Layer 2/3 IP core Routers and switches.
- LTE Evolved Packet Core (EPC), including MME, S-GW, P-GW, HSS & PCRF.
- Applications Servers VoIP, email etc.
- OSS - Network management, billing & provisioning

Full End to End build operate and maintain technical solution and capability, including:

- eNodeB equipment and sector antennas.
- Outdoor cabinets to house the eNodeB BBU equipment, transmission equipment, fibre optic equipment, routing, switching and power system equipment
- Rectifiers and battery back-up for eNodeB, backhaul and L2/3 IP network equipment
- Radio planning and network drive test tools.
- Network management solution- UE ACS solution, U2000 and PRS.
- Customer Premises Equipment, installation tools and systems.
- Additional solutions to provide extended coverage
- Full OSS / BSS

[8] Huawei RAN Roadmap

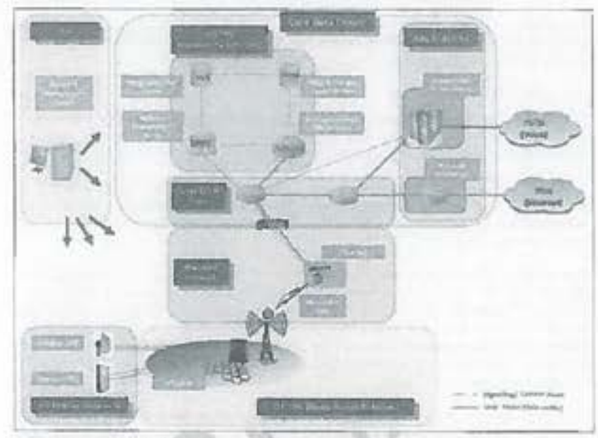


Figure 6 . Imagine LTE Architecture

The network is designed to provide the optimum balance of coverage and capacity within the target coverage area, to provide a commercial service of up to 150Mbps Download and 14Mbps Upload. As of September 2019 this includes 172 live sites of an initial nominal plan across XXX sites. Voice services are offered to all customers with a single voice line per customer using a G.711 codec, dimensioned to support 100mE per line and with 1% blocking (Erlang B).

[redacted]

Enhanced performance is achieved through the use of LTE Advanced and Advanced Pro features such as MIMO, Carrier Aggregation, 256QAM, CoMP and Multi-user Beamforming.

Imagine deploys carrier aggregation as follows

- 3x 20 MHz downlink CA for the ASFN, S333 and S33 architectures,
- 2 x 15 MHz CA for the S15/15 soft split architecture
- In the uplink, 2CA is currently supported

In addition to carrier aggregation the current network deployment also supports both DL 4x2 MIMO and Beamforming TM 7/8 whereby the base station transmits 4 streams and the UE receives these on two receiver elements. The additional base station capacity results in a higher number of supported users per sector.

The equipment currently being rolled out is 5G NR hardware capable and will be software upgraded to 5G NR. The remaining Infrastructure e.g. masts, backhaul network, core network etc will be reused when 5G NR technology is introduced to supersede the LTE network.

2.1.1 RAN Architecture Roadmap

Whilst the existing Imagine LTE Advanced network can continue providing high speed broadband for the foreseeable future it is also 5G NR hardware capable and thus able to evolve and provide further enhanced capabilities as 5G industry standards are deployed.

In the immediate short term the architecture of the planned network will remain the same as the existing TD-LTE Advanced Pro architecture as described in detail in section 2.1Imagine will increase capacity and throughput delivered via the ongoing evolution and development of enhancements to LTE and the eventual evolution of the network to a 5G NR RAN and associated core network

The equipment currently being rolled out by Imagine is 5G NR hardware capable and can be software upgraded to 5G. The remaining infrastructure e.g. masts, backhaul network, core network etc, will be reused as 5G NR technology is introduced to supersede the LTE network. networks will heterogenous and not just 5G as according to Analysys Mason *"5G is not the only gigabit wireless show in town."* Imagine is developing its plans to complement the LTE and 5G architecture through the implementation and integration of other RAN technologies such as mmWave, V-Band Point to Multi-Point, Mesh networks and Open RAN

In line with stated industry practice the migration to 5G will be an evolution of LTE A ... Imagine will commence the migration to a 5G architecture based on 5G NR radios and a 5G Core - either Non-Standalone (NSA) using the existing LTE Advanced core or Standalone (SA)

In the short to medium term the most significant development will be the introduction of M-MIMO based on 64T 64R AAU to the LTE Advanced Pro Architecture

2.1.1.1 Massive MIMO

Massive MIMO, available in 3GPP release 14 is a key enabler for 5G based on the extension of existing LTE Advanced capabilities such as Beamforming and MIMO using large smart antenna arrays such as 64T 64R to deliver:

- **Increased Network Capacity** – through MU MIMO where multiple users are served with the same time and frequency resources , M-MIMO is expected to provide up to 2-3x the capacity of the legacy 2T2R configurations.
- **Improved Coverage** – improving the data rates and user experience across the network, even at the cells edge and with 3D beamforming adjusts the coverage to deliver service in locations that have relatively weak network coverage.

Trials of the Huawei eRAN 15 AAS614 64T64R Massive MIMO base station began in June 2019 and are progressing well with positive results to date. Testing is ongoing with a view to determining the optimal deployment and operational practices and live deployment is expected to take place from Q4 2019 onwards.

Figure 7 : Capacity and Coverage Gain of Massive MIMO

2.1.2 Evolution to 5G

5G is the next generation of mobile technology with 5G NR (New Radio) defined by 3GPP standards as the new air interface developed for the 5G network. It is generally agreed that there are three main uses for 5G - They are

- Enhanced Mobile Broadband (eMBB)
- Ultra Reliable Low Latency Communications (URLLC), and
- Massive Machine Type Communications (mMTC)

Enhanced Mobile Broadband (eMBB) is an evolution from 4G LTE mobile broadband services, with faster connections, higher throughput, and more capacity and will be the primary driver of initial deployments of 5G. Neither URLLC nor mMTC not expected to be deployed widely before 2021.

The targets for 5G capabilities are for it to deliver:

- 100 x data rate
- 100 x connected devices
- < 1ms latency
- 90% less power consumption
- Use of new spectrum bands including bands < 6 GHz for core services and > 6 GHz for supplementary services e.g. small cell capacity

A view of the evolution of LTE towards 5G NR is provided in Figure 8. These developments will be available to Imagine and are expected to be easily deployable with a combination of software upgrades and relatively simple additions of adjunct hardware into existing platforms.

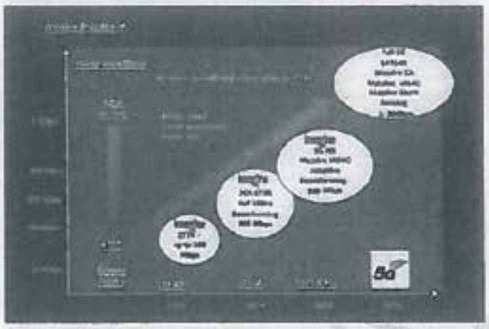


Figure 8 : Imagine Evolution Path to 5G

The equipment currently being rolled out by Imagine is 5G NR hardware capable and can be software upgraded to 5G. The remaining infrastructure e.g. masts, backhaul network, core network etc. will be reused as 5G NR technology is introduced to supersede the LTE network.

2.1.3 5G Architecture

The 5G architecture will be based on the standard elements and sub systems, as defined in the relevant 3GPP standards 5G. The key elements of the end-to-end architecture are shown in Figure 10, and are briefly:

- 5G User Equipment (UE) -Indoor and outdoor customer devices.
- 5G Radio Access Network (RAN) -eNodeB equipment.
- Backhaul network - Point-to-Point microwave radio and Gbps fibre optic transmission links.
- Layer 2/3 IP core- Routers and switches.
- 5G NSA or SA Core
- Application Servers- VoIP, email etc.
- OSS - Network management, billing & provisioning.

The overall 5G technical solution encompasses all equipment necessary to build out the network, including

- eNodeB equipment and sector antennas
- Outdoor cabinets to house the eNodeB BBU equipment, transmission equipment, fibre optic equipment, routing, switching and power system equipment.
- Rectifiers and battery back-up for eNodeB, backhaul and L2/3 IP network equipment.
- Radio planning and network drive test tools.
- Network management solution- UE ACS solution, U2000 and PRS

- Customer Equipment installation tools and systems.
- Additional solutions to provide extended coverage

As the RAN equipment currently being rolled out is also 5G NR hardware capable it can be software upgraded to 5G NR. The remaining infrastructure e.g. masts, backhaul network, core network etc. will be reused when 5G NR technology is introduced to supersede the LTE network. The existing TD LTE Advanced Pro architecture will remain and continue to be supported during the evolution process. The LTE EPC core that Imagine runs is also 5G ready and can operate as a 3GPP Release 15 compliant 5G NSA core.

There are several alternative migration paths defined by 3GPP and supported by the vendors as shown below. Imagine is working closely with several vendors to determine the optimum path.

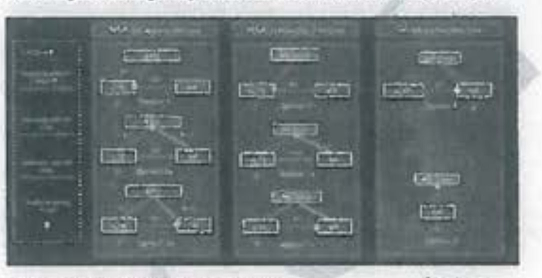


Figure 9 : Example of Migration from 4G to 5G

The 5G core will also evolve from the 4G EPC in terms of its underlying implementation

- Control and User Plane Separation (CUPS) of the 4G EPC i.e.

  The SGW and PGW functions are split into a control and data plane component.

  - SGW → SGW-C and SGW-U
  - PGW → PGW-C and PGW-U
- Reorganising the 4G EPC functions into service orirented functions and Service Oriented Architecture (SOA) as shown below

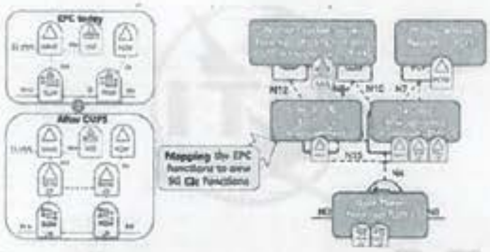


Figure 10 4G EPC to 5GS architecture evolution

A final step in the evolution of the 5G core architecture is that it will be implemented using Network Function Virtualisation (NFV) based platforms resulting in improved functionality, lower cost and more flexible solution that can grow according to the needs of the services demanded by the users.

Whilst Imagine's existing LTE EPC Core is capable of being upgraded to support 3GPP Compliant 5G NSA, Imagine is also evaluating the longer-term solution and migration to an NFV based 5G SA platform from vendors such as Affirmed and Mavenir

2.1.3.1 Small Cells

Imagine has completed testing of small cells and is using several utilities and infrastructure operators to provide structures on which to locate the units. These will be deployed as multiple additional cells in a macro cell area or where the density of households does not support the cost of a full macro site deployment or solve local coverage anomalies.

2.1.3.2 Other RAN Technologies

In addition to planning the evolution to M MIMO and 5G Imagine has initiated several projects to investigate how best to implement and integrate other new developments in RAN technology including mmWave, V Band Point to Multi-Point, Mesh networks, and Open RAN which will enable the network to evolve in a heterogeneous manner. These are described in more detail in section 2 7CPE Devices (UE) Roadmap

Imagine's detailed specification for the UE devices is based on 3GPP specifications from Release 12 for LTE-A and release 15 for dual mode, and requirements developed by the GTI 3 5/3.6 GHz TD-LTE interest group of which Imagine is a founding member.

As Imagine move towards the deployment 5G NR the CPE roadmaps are showing a clear migration path to native 5G CPE via dual mode LTE-A and 5G devices.

Native 5G NR CPE are available today (indoor only) with outdoor due in early 2020. Imagine are working with companies like Nokia for the delivery of such devices.

Dual mode LTE A and 5G NR CPE will be available from Q1 2020 from at least two vendors (Zyxel and Gemtek). These will be tested on the Imagine network at the back end of 2019 with a view for deployment in 2020

As an example the basic roadmap for the Gemtek UE is outlined below:

[redacted]

Further details on CPE devices are given in section 2 5.

A1.1.2. A description of the access network technology and the specification of the access equipment (including the relevant telecoms standards with which the equipment complies):

2.2 Existing network access technology and access specification

The existing Imagine access network is based on the relevant telecom standard 3GPP Release 14 using Huawei eRAN solutions based on the DBS5900 TD-LTE Advanced eNodeB.

The DBS5900 TD-LTE Advanced eNodeB consists of the Remote Radio Unit RRU5258 and Base Band Unit BBU5900.

One or more RRU (Remote Radio Unit) modules constitute the radio frequency (RF) component of a distributed E-UTRAN NodeB (eNodeB). The RRU can be mounted on the tower at the antenna

(reducing feeder length and loss, improving system coverage), onto a pole, stand, or concrete wall. Remote radio units (RRU) demodulate the receive RF signals, modulate, amplify and control the power of the transmit RF signals, and monitor and maintain the performance of the overall RAN interface.

A single RRU5258 RF module supports up to four carriers, 8T8R transmission and receive ports, MIMO and single user/multiuser beamforming. The key specifications for the RRU5258 are as follows:

[illegible]	[illegible]
LTE Frequency Band	3.6GHz (Band 42, Band 43)
Transceiver Bandwidth (MHz)	200 MHz
Transmission Power (W)	8*30W (240W)
Transmission Mode	8T8R
Power Input	-48V DC
Weight	25 kg

Table 1 : RRU5258 Specification

The RRU5258 RF equipment is connected to the BBU5900 base band unit using fibre optic feeder cables that comply with the 10Gb per feeder CPRI specification. These can be used to a maximum distance of 10km.

The BBU5900 is a 2U rack mounted chassis (86mm x 442mm x 310mm) that houses the UMPT universal main processor and interface board, multiple UBBP e6 base band processing and interface units, cooling fans and power regulation unit.

Imagine's network uses key performance enhancement features which significantly increase the access networks performance, capacity and coverage capability of an LTE-Advanced network deployed in a fixed wireless configuration. Some of these features are in Table 2, below – *"Huawei TD-LTE Advanced eRAN Features*

[illegible]	[illegible]
8T8R	Using 8 transmit and 8 receive ports increases the system diversity gain by 6db over legacy 2T2R systems. This increase in gain results in better coverage and higher MCS levels to UE's increasing system performance.
High Power RRUs (240 W)	8 x 30W (240W) is double the power of legacy equipment and increases the system performance by 3dB, providing better coverage and higher MCS levels to UE's increasing system performance.
Adaptive MIMO	DL MIMO, in accordance with the 3GPP Release 10 specifications involves multiple data streams between the UE and the eNodeB. This feature significantly improves downlink system throughput and coverage performance and enables the doubling of peak download speeds over SISO systems. Unlike most mobile devices the fixed wireless UEs are currently capable of physically supporting 4 transmit/receive antennas necessary for higher order MIMO operation.
Carrier Aggregation	Carrier Aggregation in accordance with the 3GPP Release 10 specifications increases the bandwidth, and thereby increases the bit rate and throughput available. Imagine utilises different RF configurations as described in section 2.7.3 all of which deploy carrier aggregation allowing peak speeds of up to 420 Mbps
256 QAM MCS	With the deployment of CAT12 UE devices 256 QAM is available. 256QAM provides 25% more throughput than legacy 64QAM. All imagines sites incorporate 256 QAM.
Beamforming	Beamforming achieves increased SINR by adjusting the phase of signals transmitted on different antennas providing constructive addition of the signals at the receiver. This increase in signal levels to a UE increase the MCS and overall performance, while decreasing the noise and interference to other UE's in the area.
UE Category 12 support	UE category 12 CPE devices provide many enhanced features as well as a maximum DL 603 Mbps data rate and UL 102 Mbps data rate.
CoMP	Intra Site CoMP provides the ability of a CPE at a certain optimised threshold to use any spare resources that may be available on another sector on the same site. Increasing the CPE's performance.
Enhanced Scheduling	Under the conventional AMC scheme, the eNodeB chooses an MCS for a UE based on the reported CQI. As a result, the MCS will mainly change according to the reported CQI. However, the UE measurement error and channel fading affects the accuracy of the reported CQI to some extent. MCS selection based on an inaccurate CQI can cause a failure to reach the block error rate (BLER) target in DL transmission. Enhanced Scheduling provides a closed-loop feedback mechanism to guarantee that the actual BLER reaches the BLER target increasing system performance
CQI	The CQI adjustment scheme introduces a closed-loop mechanism to compensate for CQI measurement errors. When an eNodeB selects the MCS for DL transmission, in addition to the CQI and transmit power, the eNodeB also considers the difference between the target BLER and the actual BLER. Note that the actual BLER is calculated based on the closed-loop ACK/NACK that the eNodeB received in DL transmission. In addition, the closed-loop mechanism used in the CQI adjustment scheme allows the eNodeB to instruct a UE to change the BLER target for CQI reporting, which maximises system throughput.
Interference Rejection Combining (IRC)	Interference Rejection Combining (IRC) is a receive-antenna combining technique to effectively overcome inter-cell interference. The method can be used with receive diversity and can be used for MIMO decoding in any scenario improving the system performance in the presence of interference providing enhanced network coverage and better service quality (higher throughput) at the cell edge.
Security Mechanism	The eNodeB provides encryption for RRC signalling and user data. The encryption function consists of ciphering and deciphering performed at the Packet Data Convergence Protocol (PDCP) layer. After receiving the UE context from the EPC, the eNodeB initiates the initial security activation procedure. During RRC connection setup, an encryption algorithm is selected, and an encryption key is generated based on the RRC protocol.

Table 2 Huawei TD-LTE Advanced eRAN Features

2.2.1 Planned network access technology and access specification

In the immediate short term the specification of the planned access equipment (including the relevant telecoms standards with which the equipment complies) for the remainder of the 460 site nominal rollout will remain as described in section E1- A1.1.2 for the existing network.

In the medium term the basic specifications of the access equipment will include the Huawei AAU5613 64T64 supporting Massive MIMO and 5G NR as follows.

Figure 11 : C-Band 64T64R

[redacted]

Figure 15 5G Features Roadmap

A1.1.3. A description of the backhaul network technology (national and metro) and the specification of the backhaul equipment (including the relevant telecoms standards with which the equipment complies).

2.3 Existing Backhaul Solution Technology

The Imagine existing backhaul solution is based on a network of interconnected managed multiple 1Gbps/10Gbps fibre connections, which are supplemented by high capacity licensed point-to-point microwave links where fibre is unavailable at the base station site. The backhaul links are always dimensioned to be fully uncontended.

The fibre and microwave backhaul terminate into Huawei ATN910C-B 10Gbps switches

Figure 12 : Sample - Imagine Backhaul Network Design Example

2.3.1 Fibre Backhaul Partners

Imagine have engaged and interconnected with all the significant managed fibre service providers in Ireland that provide wholesale services to operators. The main suppliers that Imagine use for backhaul network on fibre services are BT Ireland, eNet, ESBT, Virgin Media and Open Eir. Each of these suppliers already provide multiple Gbps fibre connections to Imagine, all interconnected at Imagine's data centre in Interxion. There are also some smaller providers that provide individual links when managed services are not available from these main suppliers and these too are interconnected at Interxion.

2.3.1.1 BT Ireland Overview

BT Ireland Wholesale has been providing wholesale services to the Irish wholesale market since 2006. Imagine sites are connected by BT to Imagine's data centre in Interxion. The standard installation is an Etherway (Adva CPE) product delivering service at a LAN port at the listed bandwidth (Etherflow) with either 1 Gbps (standard) or 10 Gbps (optional) facing the WAN. BT already has a presence at Interxion and can provide multiple 10 Gbps handoff ports at this location.

The BT Etherflow product is made up of two components – an Etherway access at each end of a point-to-point circuit and an Ethernet Virtual Connection defining the service end-to-end. BT Etherway access provides the physical connectivity or access to the BT network. BT Etherway Access is provided as Ethernet over fibre at speeds of up to 10 Gbps. BT Ethernet Virtual Connection defines the connectivity between the two (or more) end sites - enabling the creation of point-to-point and point-to multipoint networks.

Because BT Etherflow is offered in increasing speed increments with a gentle step change, it enables a 'right size' solution and so avoid the cost of network over-extension. BT Etherflow offers bandwidth increments between 512 kbps and 10 Gbps although Imagine always configure a minimum of at least 1Gbps on each fibre connection.

2.3.1.2 ESBT Overview

ESBT are a wholesale telecommunications provider with over 15 years of telecoms experience. ESBT own and operate an extensive telecoms network throughout Ireland with international fibre connectivity to the UK. ESBT also owns and manages a portfolio of 400 + telecommunications towers and sites nationwide, ESBT provide transmission service for mobile and wireless operators, private communications companies and emergency services.

ESBT has used ESB's extensive electricity transmission network to deploy its 1300 km fibre optic network, on overhead lines and in underground ducting. ESB Telecoms' fibre network consists of 48 pair single mode fibre (SMF) compliant with ITU G.652.

ESBT offers access to its network at either its Points of Presence (POP) or directly at the customer's chosen location. For complete, end to end solutions from customer premises to Internet gateways and beyond, ESBT has entered Strategic Relationships with Other Licensed Operators, Internet Services Providers and Data Centre operators.

2.3.1.3 eNet Overview

eNet was formed in 2000 to develop open access networks for the delivery of affordable, state of the art fibre broadband services. eNet's national managed layer 2 ethernet circuits are uncontended end-to-end capacities. It delivers clear bandwidth from end user site to Carrier POP. There is no contention in eNet's network. eNet's standard national managed service has the following features:

- Protected ring to e-net co-location
- Diverse interconnects to protected national backhaul
- National backhaul to dual core NTU's in e-net POP, Dublin

- Supports all standard Ethernet interface handoff types
- Microwave Backhaul Technology

2.3.1.4 Open Eir Overview

Open Eir is the wholesale division of the incumbent Eir. Its fibre reach into Ireland is unrivalled. Imagine is fully interconnected with OpenEir and has interconnection configured at the Interxion data center.

Imagine has access to the full backhaul network of Open Eir using their WUP (Wholesale Uncontended Product).

OpenEir's WUPs provide dedicated, high-bandwidth, point-to-point leased lines with no contention, in a choice of two speeds: 1 Gbps and 10 Gbps. A full technical description can be found in the documentation section on the Open eir website: www.openeir.ie/products

WUPs are delivered over a physical optical fibre circuit using OpenEir's core Wavelength Division Multiplexing (WDM) network.

The WUP circuits feature an Ethernet presentation as standard and other options such as Synchronous Digital Hierarchy (SDH) are available.

WUP's can be provided from all serving WDM nodes.

2.3.1.5 Virgin Media Overview

Virgin Media Ireland is Liberty Global's telecommunications operation in Ireland. It is the largest digital cable television provider within the Republic of Ireland. Virgin media offers broadband internet, digital television and digital (VoIP) telephony to 1 million customers. Through its wholesale division Imagine has access to Virgin backhaul network and is full interconnected at the Interxion data centre. Virgin offers 1Gbps to 10Gbps uncontended protected circuits from its extensive national network.

2.3.2 Fibre link sizing

The capacity of each fibre PoP is dimensioned to be greater than the sum of the capacity required for all connected sites to that PoP. i.e. the capacity of the fibre PoP is over 100% of the required capacity from each connected site or sites. Each fibre PoP has multiple Gbps capacity which is increased in multiples of 1Gbps or 10Gpbs as required to ensure the backhaul at all times remains fully uncontended / uncongested.

A proactive monitoring and alarm system manage managed by the Imagine NOC looks at capacity in the backhaul network on a near real-time basis. Once capacity reaches 70% this triggers an upgrade.

2.3.3 Point to Point Microwave Links Overview:

Imagine deploy the latest generation all IP transit associated Aviat CTR and WTM Carrier Ethernet microwave links, Ceragon FibeAir IP 20C equipment. These devices use the latest microwave technologies such as 4096 QAM, 4x4 MIMO, concurrent ACM (Adaptive Coding and Modulation), XPIC (Cross Pol Interference Cancellation) and adaptive dual carrier operation to give throughput, latency and packet loss performance equivalent to fibre backhaul across the whole network.

These Microwave links provide similar performance to fibre links. Today Imagine deploy microwave links with capacities from 600Mbps 2Gbps with latency of c 0.6ms for 30 km links and 99.999% availability. This is dependent on distance and configured for the capacity required. Imagine only use fully licensed frequency bands (e.g. 6GHz to 80GHz) according to ComReg's microwave link length policy.

The following assumptions are used to dimension the Microwave backhaul network:

All sites in the plan require new backhaul (i.e. we do not assume existing capacity is sufficient). Sites are planned with at least enough capacity to service the cumulative capacity to service any of the nodes that are connected to them.

Imagine's backhaul network is fully uncontended end-to-end. Capacity on all links is continually monitored by the Imagine NOC and upgraded where required to avoid any contention.

Except for access sites co-located with the fibre POP, access sites will be connected to the fibre POP via a licensed point point microwave link.

All licensed microwave point-to-point links will have an initial capacity of at least 600 Mbps configured using either:

- 2 x 56 MHz Channel XPIC
- 1 x 250 to 1000 MHz Channel (eBand 80 GHz)

Sites are configured with enough capacity to carry the cumulative capacity required to service any nodes that are connected to them.

As the network grows, microwave backhaul capacity can be readily increased using any of the following options on a case by case basis to give the optimum solution:

- Increase microwave capacity using 2x XPIC configuration
- Increase microwave capacity using multi band aggregated technology
- extend fibre connection to access sites
- increase fibre capacity from 1 x Gbps to N x Gbps or N x 10Gbps as applicable

The detailed specification for the Aviat and Ceragon microwave point to point links, including relevant standards compliance is given in Appendix D. A sample of the backhaul architecture design is shown in Appendix E – "Network Template Microwave Backhaul"

It should be noted the throughput per site quoted refers only to downlink traffic. Since the TDD LTE base stations are configured with an asymmetrical TDD ratio of 3:1 (DL:UL) as mandated by the liberalised 3.5Ghz license and is set to match the typical usage profile of Internet services demanded by

customers, the downlink traffic is typically at least an order of magnitude greater than the uplink traffic (not unusual to see figures > 10:1) and is therefore the limiting factor that determines the dimensioning of the backhaul links.

It should also be noted that all fibre connections used in the backhaul network are also fully symmetrical in that whatever Gbps capacity is quoted is the capacity in each of both the downlink and uplink directions and is dimensioned so that there is no packet loss or contention on any of the links. Backhaul network efficiency is a key KPI on the network and monitored real time.

A1.1.4. *A design for the national backhaul network including any traffic and capacity assumptions.*

2.4 Current National Backhaul Infrastructure and Design.

Imagine's current LTE Advanced EPC core network is installed in our data centre located at Interxion in Parkwest, Dublin. The Imagine core is at the center of all downstream backhaul links and onward routing to the Internet and is the focal point for the national backhaul infrastructure.

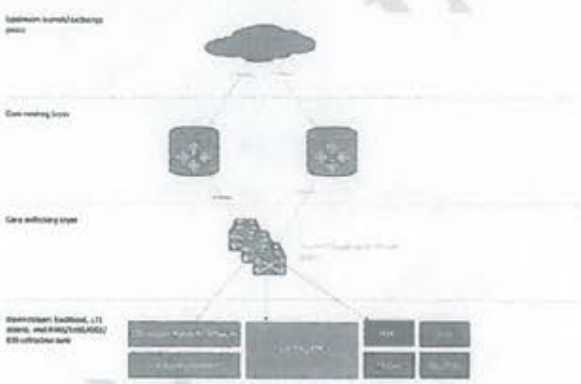


Figure 13 : Imagine Core

Imagine has over 260 existing sites with existing backhaul links which include a mix of Imagine's own microwave network to over 60 fibre hub sites. These provide leased fibre capacity from these hubs to the core in Dublin. The backhaul capacity for these sites currently ranges from 1Gbps to 10 Gbps.

2.4.1 LTE Backhaul Infrastructure and Design

At all times Imagine's policy for backhaul is to avoid over-subscription and contention. To this end, we dimension each segment on the path between a base station and the core network to provide enough bandwidth for that fully loaded eNodeB.

The backhaul transmission network for the LTE network consists of Imagine's own microwave links connecting each base station site to a fibre PoP site. The minimum capacity of these microwave link is 550 Mbps but can reach 2Gbps if appropriate.

Imagine have identified in excess of 500 fibre PoPs nationally including those from its key suppliers ESB Telecom (XX), eNet (XX), BT Ireland (XX) and Eir (XX).

The fibre PoP sites combine the traffic from groups of 2-10 sites onto fibre links that are backhauled to the LTE Advanced EPC core network over leased fibre backhaul links. The line rate of the fibre links to Imagine's core are 10Gbps, with sub-line rates applied on a VLAN basis depending on the number of downstream sites.

In some cases, the traffic from multiple hub sites may be combined at regional hubs for onward transmission to the LTE EPC core network. The capacity of the fibre backhaul links will range from 1 Gbps to 10 Gbps and can be easily extended to multiple 10 Gbps links combined using a Link Aggregation protocol.

The average number of microwave links that are aggregated at a fibre PoP is three. Therefore, on average 25% of all sites in a region will be PoP sites with fibre connections. As the availability of fibre connections in remote and rural locations increases to bring fibre directly to the base station site the number of sites per fibre will be reduced with the eventual goal of all eNodeB sites being connected via fibre.

Actual capacity figures for the differing radio configurations are discussed in the relevant RAN section of this submission. This dictates the capacity required and the technical solution that is deployed.

2.4.2 Fibre Hub Configurations

Based on the number of eNodeB sites being combined, and availability of fibre at suitable mast structures and/or colocation of eNodeB at fibre PoP sites there are several scenarios for the fibre PoP configurations as follows:

Scenario 1: Where the fibre provider is co-located with a suitable tower or building which can serve as the microwave hub.

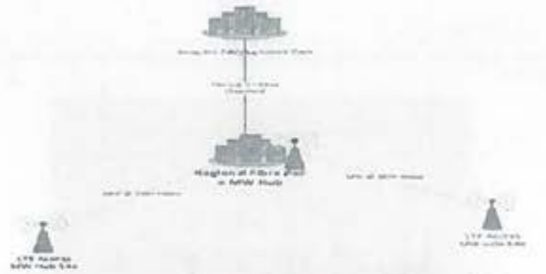


Figure 14 : Scenario 1 Microwave to co-located Fibre POP

Scenario 2: Individual sites with no dependants directly connected via leased fibre to the Imagine core.

Figure 15 : Scenario 2 Site co-located Fibre POP

Scenario 3: Regional hubs which combine fibre connections from local hubs and microwave connections from local sites.

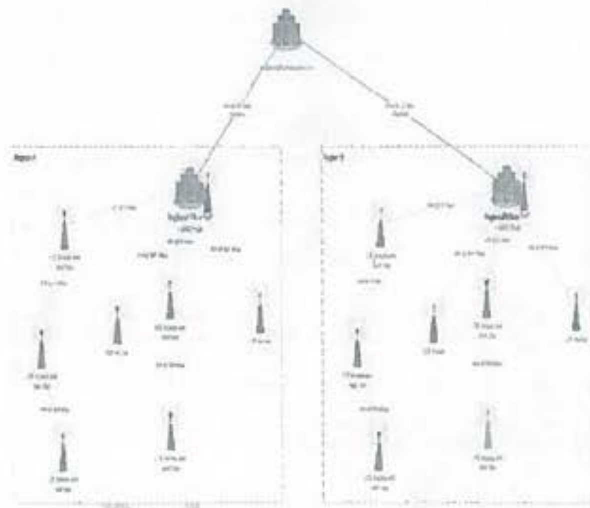


Figure 16 : Scenario 3 Tier 2 Regional Fibre POP Site

Scenario 4: If no suitable structure is available to serve as a microwave hub at the fibre POP, Imagine will factor in the costs associated with creating a separate microwave hub and connecting this to the fibre POP via short hop high capacity microwave. (Hub Scenario 4a) or via a dedicated fibre dig (Hub Scenario 4b)

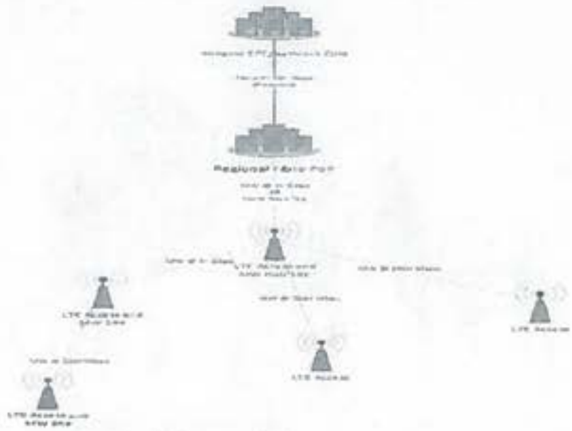


Figure 17: Scenario 4 Microwave Hub to Fibre POP

2.4.3 Fibre Hub Locations

As an example, Figure 18 - eNodeB connected to Fibre POP shows the eNodeB sites connected to a POP location.

Figure 18 - eNodeB connected to Fibre POP

A full list of existing sites by sector and associated backhaul is given in the appendix to this document.

A1.1.5. *The specification of all types of customer premises equipment which the operator plans to use.*

2.5 Customer Premises Equipment

Imagine only deploy Cat 12 specification CPE's on its network on new installations. Even though there are some legacy Cat 6 and Cat 4 CPE currently deployed in the network, these are being migrated and replaced by Cat 12. Full specifications and product specs for these legacy CPE's have been given in previous submissions.

In this submission the specifications of Cat 12 will be presented as this is the CPE category that is being installed on the Imagine network today. It is interesting to note over the years the actual delivery of CPE categories has beaten roadmap predictions of only few years ago as demand globally has been ahead of expectations.

Imagine have decided not to use Indoor CPE in its current deployment due to the uncertain nature of the quality of install and the resulting stability of signal quality. Experience of over 20K customers installed has shown that professional installs of outdoor CPE gives the best signal quality and predictability of service while maximising the efficiency of the base station and hence network. According to Analysys Mason report of March 2019 (5G fixed wireless access, the market opportunity for operators and vendors) outdoor antenna are perhaps 5 times, more efficient than those in smartphones.

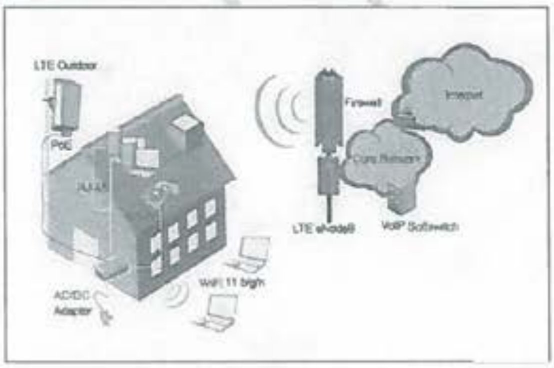


Figure 19 Typical outdoor CPE installation

In its planning Imagine has assumed an install height of Xm for the CPE height.

It should also be noted that the 8m height is used in the link budget to determine the maximum range of the service and therefore it is not the case that every CPE device in coverage must be at a height of 8m in order to obtain the required signal strength and quality to meet the service metrics.

In other words the entire rollout is not dependent on every connection requiring a height of Xm. In 2019 Imagine now have in excess of 20K customers deployed and this has shown that average heights are much less than XM with only those on cell edge needing to go near that level. XM installs are really the exception rather than the rule. In fact with the densification of the network lower height installs are required to use natural shielding of interference (from CPE and overlapping cells) and optimise the reflections to get high modulations including 256QAM and make use of MIMO at the CPE.

The basis of this assumption that typical roof ridge heights for residential buildings are as follows:

- Two storey dwelling: 8.2m
- Storey and a half dwelling: 7.2m
- Single storey dwelling: 6.2m

For typical installations therefore it is possible by various techniques such as the use of wall brackets with poles to which antenna is fixed.

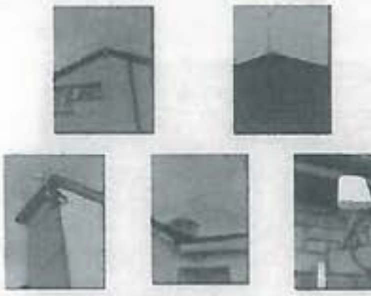


Figure 20 - Typical examples of Installations

2.5.1 Specifications of CPE's deployed.

Imagine's detailed specification for the UE devices is based on 3GPP specifications from Release 12 for LTE-A and release 15 for dual mode, and requirements developed by the GTI 3.5/3.6 GHz TD-LTE Interest group of which Imagine is a founding member.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Figure 21 : Deployed CPE Specifications

In addition to Cat 12 CPE, Imagine today also have access to Cat 13 and Cat 18 CPE which are commercially available from various vendors. However the additional LTE features that are enabled by these higher spec CPE's give no added capacity or advantage to the LTE-A solution and are not deployed in the production network. They also tend to be a lot more expensive

2.5.2 CPE Roadmaps

Figure: GEMTEK CPE Roadmap towards 5G

Figure 22 : GemTek CPE Roadmap to 5G

As Imagine move towards the deployment 5G NR the CPE roadmaps from vendors are showing a clear migration path to native 5G NR CPE via dual mode LTE-A and 5G devices. These native 5G NR CPE are available today for test (and in volume from Q1 2020) . Dual mode LTE-A and 5G NR CPE will be available from Q1 2020 from at least two vendors (Zyxel and Gemtek). These will be tested on the Imagine network at the back end of 2019 with a view for deployment in 2020 as part of the 5G NR evolution.

Figure 23 : Gemtek Dual Mode CPE specification

In the attachments are the product specs from GemTek and Zyxel for the dual mode devices and a native 5G NR CPE from Nokia

Full specifications of the Cat 12 devices and dual mode LTE-A and 5G NR devices as well as a native 5g NR Indoor device are attached in Appendix C as follows:

Full specifications of the Cat 12 devices n Appendix C as follows:

- Appendix C1 Gemtek Cat 12 Product Spec.pdf
- Appendix C2 ZenTel Cat 12 Product Spec.pdf
- Appendix C3 Zyxel Dual Mode LTE A 5G NR .pdf
- Appendix C4 GemTek Wireless CPE Roadmap
- Appendix C5 Nokia 5G Indoor CPE.pdf

2.6 Coverage Data

A1.1.6. Coverage data, in the form of a Polygonised (vector) dataset with 'DOWNLOAD SPEED' attribute attached to the polygon

Please see attached files below for the above information:

- ***Section 2.2 Q6 Coverage Data DL Outdoor UE Prediction ESRI Shapefiles***
- ***Section 2.2 Q6 Coverage Data DL Outdoor UE Prediction TAB***

In order to further address the issues around the Cell Edge probability and the requirement for 6Mbps uplink Imagine has provided multiple coverage maps for consideration and to compare the benefits of each as follows.

	[redacted]		
	- 150Mbps DL - 6Mbps UL - 76/90% Cell Edge/Area probability	- 30-6Mbps DL/UL - 95/99% Cell Edge/Area probability	- 30-2Mbps[1] DL/UL - 76/90% Cell Edge/Area probability
Current "172" sites	✓	✓	✓
Planned "XXX" sites	✓	✓	✓

1 Uplink to be order of magnitude better than DSL technology – should be between 1 2 Mbps and endure that uplink does not constrain coverage

In producing these maps Imagine has used a CPE Antenna with 17dB gain (ZMTel CAT 12 UE). Whilst in some specific install cases it can offer an improved service overall it provides a more conservative coverage plot since in most instances it gives a reduced coverage range than the 14dB gain (Gemtek CAT 12UE) due to the higher sensitivity to noise.

A1.1.7. Any other relevant information that could assist the DCENR in assessing the concrete nature of submission.

2.7 Radio Access Network Performance

2.7.1 Capability of the Existing Network

Four years on from its previous submissions Imagine now has 172 sites deployed, 259,411 'Amber' homes covered and over XX,000 satisfied high speed broadband customers with an up to 150Mbps service. Imagine can, with confidence therefore, describe the performance of its existing network not in terms of what it is expected to do but what it actually does backed up with KPI and performance measurements from a live network. In fact Imagine customers enjoy levels of monthly usage higher than all existing FTTx networks and as high as the Cable networks.

High speed, high quality services are achievable because Imagine maximises the efficiency of the system through...

- Exclusive use of outdoor devices – higher gain, no indoor losses, no mobility
- Monitoring and managing Sector Capacity (no. of users per sector) and customer usage (GB per month)
- Actively managing heavy users via an acceptable usage policy to give priority to normal users
- Closing sectors for sale when capacity limit is reached
- Managing devices – monitor for abnormal behavior, degradation in signal metrics or disproportionate use of resources

2.7.2 Overview

In its response to the DECNR 2015 Supplementary Information Request[9] and multiple subsequent follow up clarifications and consultations Imagine provided much detail on the performance capabilities of its then planned LTE Advanced network. In various responses from the department and its consultants many incorrect conclusions were drawn and assertions made in terms of how the network would actually perform. Indeed, Analysys Mason[10] made statements such as the following.

"the solution proposed will not be implemented in the timeframe proposed in May 2015"

and

[9] National Broadband Plan High Speed Broadband Map Supplementary Information Request, 27th March 2015

[10] Analysys Mason, Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

"Imagine is not proposing a credible NGA solution

Although the technology proposed by Imagine is capable of providing NGA services, the site configuration and the network solution Imagine is proposing, incorporating that technology is not a credible NGA solution.

This is principally (though not exclusively) due to:

- *Imagine's plan for each site to serve an average of XXX customers and our assessment that the proposed site configuration will not provide a 30 Mbit/s download to all users when they demand it*
- *the provision of insufficient detail of the coverage for the 6 Mbit/s upload service to all users who require it under normal conditions."*

and

"Imagine does not have a credible resource plan: Imagine's resource plan involving the use of a mix of staff and subcontractors to roll out the network is in line with industry practice. However the procurement of subcontractors and resources is currently suspended. Consequently, based on the information provided, we have substantial concern about the credibility of the resource plan and do not assess it as credible at this time."

Four years later and with 172 sites deployed, 259,411 'Amber' homes covered and over XX,000 satisfied high speed broadband customers with an up to 150Mbps service Imagine can, with confidence, provide the following information backed up with actual reports from the network on various aspects of the performance that address all such concerns raised in 2015.

2.7.3 RAN Configurations

Based on the same Huawei DBS5900 8T8R TD-LTE Advanced eNodeB platform, as described in section 2.1.1, Imagine deploys multiple different LTE Advanced architectures in its RAN network. Each particular architecture provides the most appropriate solution for the specific characteristics of the geographic and household distribution in the area to be covered.

These configurations used are:

S15/15 3 Sector: The primary architecture currently used on the majority of sites, this design utilises 3 x 70° beam width sector antennas that are soft split, left and right, to provide 2 virtual 35 degree sectors in the one physical sector. Each of these "virtual" sectors utilises 2 x 15 MHz carrier aggregated cells providing 30 MHz per left and right side. Each virtual sector is capable of up to 205 Mbps peak throughput, making the site capable of 1.230Gbps peak throughput.

S15/15 2 Sector: This design utilises 2 x 70° beam width sector antennas that are soft split, left and right, to provide 2 virtual 35 degree sectors in the one physical sector. Each of these "virtual" sectors utilises 2 x 15 MHz carrier aggregated cells providing 30 MHz per left and right side. Each virtual sector is capable of up to 205 Mbps peak throughput, making the site capable of 820 Mbps peak throughput.

S333: This design utilises 3 x 65° beam width sectors, each containing 3 carrier aggregated cells of 20 MHz. Each sector is capable of up to 430 Mbps peak throughput, making the site capable of 1.290 Gbps peak throughput.

S33: This design utilises 2 x 70° beam width sectors, each containing 2 carrier aggregated cells of 20 MHz. Each sector is capable of up to 430 Mbps peak throughput, making the site capable of 860 Mbps peak throughput.

ASFN: Adaptive Single Frequency Network, this design uses up to 3 x 70° beam width sector antennas that are combined to effectively provide a single combined "super" cell. The combined super cell uses 3 x 20 MHz carrier aggregated channels that provide up 550 Mbps peak throughput for the combined supercell, utilising space diversity between users to achieve this. The advantage of ASFN is a complete reduction of intra-site interference, increasing the coverage area of the site for areas with lower density of household premises.

Typically the Downlink capacity is the limiting factor and for a standard 3 sector site (using S15/15 soft split or S333 configuration) the maximum capacity is around XXX subscribers. The other 2 sector configurations are only used in areas where a 2 sector deployment is merited due to terrain or coastal features and have a correspondingly reduced coverage and proportionally lower capacity. ASFN is applied only where the density of households is very low.

Utilising the different configurations on a case by case basis when the sites are planned allows Imagine to carefully match not only the initial capacity to the expected take up but also allows the flexibility to rapidly expand capacity when and where it is required. Reconfiguration from one design to another requires only a remote change via the management system or at most a simple reconfiguration of the existing antennas on site.

The following sections deal in more detail with the throughput and capacity of the system and how this is actively managed by Imagine to maintain a quality service to all customers.

2.7.4 Throughput

Throughput figures are, amongst many factors a function of the number of resource blocks available for each configuration, and how efficiently the users are able to use these resource blocks depending on the quality of their signal.

The Total Peak Downlink Throughputs are shown in Figure 24 Peak Throughputs per Sector/Site below.

Figure 24 Peak Throughputs per Sector/Site

For a TDD network the effective spectrum is estimated to be the total spectrum divided in proportion to the TDD ratio – in the case of Imagine 3:1 for the Downlink. In a practical deployment the overall average throughput of the cell is determined by the capability of the individual users connections since the users CINR determines the channel quality indicator or CQI used by the UE and base station to determine the modulation coding scheme to be used and hence the efficiency at which the spectrum is used. An example of the mapping between CINR and MCS is given in the link budget tables in 2.13

Taking the average CINR across the users on a cell and mapping this to the MCS level gives a good estimate of the average throughput of the cell, this which can be verified by actual measurement in the deployed network.

Based on such measurement in the Imagine network users are capable of achieving 256QAM operation 77% of the time and 64QAM operation 98% of the time. Overall the average CINR of the CAT 12 devices deployed across the whole network is 23.8dB. Using the nearest lower figure in the table gives the following

Bearer	C/(I+N) Thresholds (dB)	Bearer	Label	Modulation	Channel Coding Rate	Bearer efficiency (bits /Hz)
58	26.98	58	DL 256QAM 0.89	256QAM	0.89	6.9
57	25.30	57	DL 256QAM 0.85	256QAM	0.85	5.8
56	24.37	56	DL 256QAM 0.736	256QAM	0.736	5.888
55	23.65	55	DL 256QAM 0.705	256QAM	0.705	5.64
54	23.05	54	DL 256QAM 0.683	256QAM	0.683	5.464
53	22.42	53	DL 256QAM 0.64	256QAM	0.64	5.12

For CAT 12 CPE this equates to an average achievable RLC user throughput of 63.5 Mbps per 15MHz carrier or 126 Mbps using 2CA carrier aggregation in the case of S15 Softsplit configuration and 84.6 and 254 respectively for S333/33 and ASFN configurations.

For the same configuration the equivalent figure for the Uplink with a CAT 12 CPE capable of 2CA and 64QAM modulation is XX Mbps per carrier or XXMbps in total using 2CA carrier aggregation for the Softsplit configuration and slightly higher at XXMbps and XX for S333/33 and ASFN using 3CA carrier aggregation.

XXXXXXXXX

This demonstrates an achieved average downlink spectral efficiency of 5.6bps/Hz and uplink spectral efficiency of 2.8bps/Hz which are well within 3GPP[12] targets of downlink peak spectrum efficiency of 30 bps/Hz and uplink peak spectrum efficiency of 15 bps/Hz for LTE Advanced Pro

In their 2015 assessment of Imagine's then proposed solution Analysis Mason[13] claimed that:

> *"since Imagine provides services through a fixed wireless access network, in order to assess Imagine's spectral efficiency, the "high-end" spectral efficiency of the Ofcom benchmark was considered. However, based on the above comparison, it can be seen that Imagine's assumed downlink spectral efficiency is greater than the "high-end" Ofcom benchmark. In our opinion, this is an aggressive/ overly optimistic assumption. This introduces some level of risk in the implementation of the design of failing to meet the target average download throughput"*

[12] 3GPP TR 36.913 version 14.0.0 Release 14

[13] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

In addition, further comments in this report[13] made specifically in relation to the uplink included:

> *"Imagine has assumed an uplink spectral efficiency of 3.6 bit/s/Hz. In our experience the uplink spectral efficiency tends to be approximately half that of the downlink. Imagine has assumed a downlink spectral efficiency of 5.6 bit/s/Hz. This is in excess of the "high - end" Ofcom benchmark. Therefore, in our opinion, an uplink spectral efficiency of 3.6 bit/s/Hz (which is greater than 64% of the down link spectral efficiency), is aggressive. The use of aggressive spectral efficiency assumptions introduces a substantial level of risk in the implementation of the design of not meeting the target average download throughput."*

Imagine's calculations of spectral efficiency are based on industry standard methods as applied specifically to a TD LTE Advanced Pro network and furthermore have now been verified by the performance measured in the live network. In our opinion Analysis Mason's views, based on a 2011 Real Wireless report for Ofcom, misinterpreted Ofcom's view as to the meaning of "High End" which led to an incorrect assessment of Imagine's figures as being an "aggressive/ overly optimistic assumption". Imagine's TD LTE-Advanced Pro network meets and far exceeds Ofcom's definition of a high-end network. Indeed, Imagine have, at the invite of Ofcom's CTO, presented to Ofcom's staff how this has been achieved

In 2016 correspondence[14] with Real Wireless Analysis Mason stated to Imagine that:-

> *"The spectral efficiency figures given in the report on the Ofcom website were based on typical system performance for a mobile platform with typical mobile network planning. Therefore they are not an appropriate comparison to Imagine's proposed Fixed Wireless TD-LTE Advanced network."*

Imagine's network, deployed in a Fixed Wireless Access configuration in a rural environment not only benefits from the most advanced (high end) performance enhancing features but in combination with higher terminal gain than mobile environments, careful network planning, and management of installation quality metrics the targeted spectral efficiency is not only achievable but is far from being aggressive or overly optimistic

Furthermore in the published report by Plum Consulting for ComReg[15] they estimate an average throughput of 79Mbps and resulting spectrum efficiency of approximately 4 bps per Hz across a fixed wireless network as follows:-

[13] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

[14] Email correspondence with Real Wireless, February 2016

[15] ComReg 15/140d, 22 December 2015, 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.

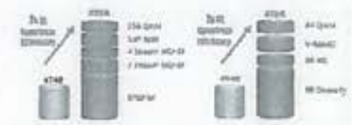
"For example, assuming that 80% of FWA connections can achieve a line of sight path and operate at the highest CQI level, whilst the remaining 20% have non line of sight paths and operate at the lowest viable CQI level to provide 30 Mbps yields the following overall spectrum efficiency:

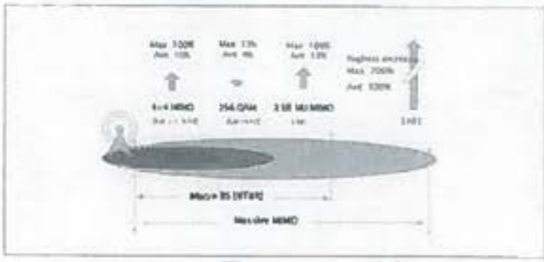
- *80% of connections achieve 89 Mbps / 20 MHz (based on highest CQI level 15) sic;*
- *20% of connections achieve at least 32.8 Mbps / 20 MHz (based on minimum CQI level of 7) sic;*
- *Overall throughput spectrum efficiency = (0.8x89 + 0.2x32.8) = 78 Mbps / 20 MHz, or 3.9 bps/Hz."*

It should be noted that Plum did not adjust this figure to account for the 3:1 TDD ratio as per ITU-T recommendations[19]. Nevertheless, the Plum figures are consistent with Imagine's unadjusted 2015 figure of 4.2bps/Hz given the technology deployed at the time.

Since 2015 progress has been rapid in the development of both RAN and CPE. LTE RAN software standards have advanced considerably with advanced Radio technologies that allow for higher power and more complex radio configurations to be deployed. For example, Multiuser beamforming and Adaptive SFN and Soft Split which can, among other things, allow for greater reuse of radio resources and spectrum thus increasing spectral efficiency.

[19] See ITU-R M.2134 regarding calculating the spectral efficiency for TDD systems





2.7.5 Capacity

Capacity takes the throughput of the system and based on speed and usage requirements determines how many customers can be connected to the system whilst meeting the need to deliver a "*minimum download speed of 30 Mbit/s* ***when they demand it***"

Using a standard capacity planning methodology developed by Huawei for FWA systems and based on standard probability calculations and inputs using kpi counters from the live network Imagine has determined the target capacity of a typical site for each site configuration based these average throughput figures.

XXXXX

Since the Downlink figures are lower these are used to set the expected capacity of the site.

The individual performance of sites varies and therefore whilst these figures are based on measured averages across the existing network the target capacity is used as a planning guideline only.

As sites are brought live and customers are connected Imagine closely monitors the performance of the site on a continuous basis as described in section 2.13.4.1 and when capacity or performance thresholds are reached additional capacity and/or coverage are planned into the network in sufficient time to prevent degradation of service. Due to the planned overlapping coverage from adjacent sites sales can be paused and grooming performed to offload customers immediately to existing adjacent sites or on a planned basis when new capacity infill sites are brought on line. Imagine can demonstrate from performance measurement of demand on the network that it meets the key criteria of delivering users a "*minimum download speed of 30 Mbit/s* *__when they demand it__*"

[redacted]

Figure 25 : Peak Time Max Uplink User Demand vs Resource Block utilisation

At peak time (busy period between 7pm and 11pm) for the 95thpercentile of cells the resource block utilisation is <80% - in other words the sites have free or unused capacity. At the same time the maximum user demand is on average XXMbps and the 95th percentile is above XXMbps

What this demonstrates is that even at peak time for the vast majority of sites there are unused resources even when users are achieving maximum DL throughputs well in excess of the minimum 30Mbps requirement.

2.7.6 Monthly Usage

In addition to looking at achievable speeds during peak times for a given number of subscribers it is also necessary to consider the capability of the network to support the total volume of data demanded by the subscribers.

At the current time, in the existing Imagine TD-LTE network the average monthly usage of each customer is on average of XXXGB as shown in as shown below in figure Figure 26 : Daily Network Usage

Figure 26 : Daily Network Usage

In Q2, the average daily usage was XX per user giving a Monthly usage for the Imagine network of XXXGB – this compares favourably with the rest of the Irish market – refer to Figure 27 : Monthly Traffic by BB Type (ComReg) and Figure 28 : Monthly Traffic by Platform below from latest ComReg Quarterly Market report[12]

Figure 3.4.2 illustrates average monthly data usage volumes by subscription type. In Q2 2019 an average fixed broadband subscriber used 185.6 GB of data per month. The majority of traffic is generated by residential subscribers with an average monthly data usage per residential subscriber reaching 194.3 GB in Q2 2019

This shows that at XXXGB per user in Q2 the Imagine users download a greater volume than the average fixed broadband user at 185.6GB and that the Imagine network carries more traffic than VDSL

[12] Quarterly Key Data Report for Q2 2019, ComReg 19/82 20/06/2019

and FTTP networks at 188.7GB and 193.7GB respectively and approximately the same as Cable at 251GB.

Figure 3.4.2 – Monthly Traffic per Fixed Broadband Subscription by Type

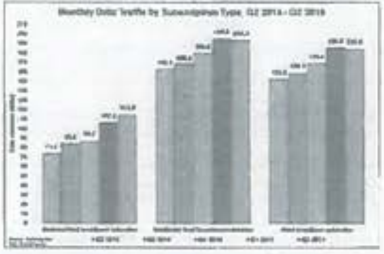


Figure 27 · Monthly Traffic by BB Type (ComReg)

Figure 28 · Monthly Traffic by Platform

It is estimated that, depending on the traffic profile, the Imagine network as currently configured could carry as much as XXX per user before additional capacity would be required to carry this volume of traffic.

2.7.7 Conclusion - Existing Network Capability

For the existing network we have shown based on network performance reports that by managing the signal levels from initial installation onwards we are able to achieve sufficiently high average CINR levels to ensure that users operate on the most efficient modulation levels (MCS) which has two important benefits in terms of performance namely high individual throughputs and high overall throughput for the cells and base stations thus allowing them to operate at a high capacity in terms of number of users connected whilst maintaining the required minimum throughputs at peak time.

The performance reports also show clearly that even at times of maximum demand there are sufficient resources remaining to allow all users to receive the throughput demanded in both downlink and uplink when they demand it.

Imagine users have the highest monthly usage in the industry, at XXXGB, the same level as fibre based Cable TV networks. The Imagine network has sufficient capacity in the current architecture to allow for this to increase significantly. This is equivalent to a sustained throughput of just less than 2Mbps per user during the busy hour.

Imagine closely monitors the performance of the sites on a continuous basis and when capacity or performance thresholds are reached additional capacity and/or coverage are planned into the network in sufficient time to prevent degradation of service.

In the 2015 published report by Plum Consulting for ComReg[18], using similar figures to Imagine for spectral efficiency, they state that;

> *"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."*

In section 3.2.7 of the same report they go on to estimate the base station capacity leading to the result that:

> *"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.*

Imagine's existing deployed network demonstrates better performance than was assumed by Plum at that time and thus is more than capable of providing and maintaining the NGA grade service described in the Plum report.

Imagine has shown not just theoretically but backed up with performance data from the live network, that the existing deployed network is capable of meeting and exceeding the throughput and capacity needs of customers and therefore of the NBP.

At the same time Imagine has the capability to extend the performance of the network not just through the immediate actions of adding more capacity sites but also through a range of currently available technologies that can be deployed as described in the following section.

2.7.8 Performance Roadmap

Even though the existing network has capability to satisfy current and planned demand Imagine is investing in a roadmap of solutions to build on the existing infrastructure and future proof its investment.

In the report for the NBP in 2018 Analysys Mason[19] put future requirements as

[18] 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.

[19] FTTP or 4G/5G for Ireland's NBP?

"In ten years' time we might expect around 20Mbit/s of bandwidth to be provisioned per user in Ireland (about ten times the figure today)"[3]

In its report on 5G Fixed Wireless[29] Analysys Mason make the following statements about projected future traffic

"In developed markets, extrapolating from historical trends, we forecast consumers to expect 1Gbps as standard by 2024, and to be consuming on average 1TB of data per month about 2 years after that."

It also notes that:

"1TB per month usage sounds a lot, but could be easier to manage than the access speed issue. Aggregate bandwidth per subscriber required to carry that data load is still under 8Mbps."

Thus To summarise these requirements the network will need to be capable of delivering the following:

- 1Gbps speeds by 2024
- 1TB of data per subscriber by 2026 – albeit that this could be delivered by a 8Mbps service
- 20Mbps provisioned bandwidth per user by 2028

2.7.9 Increasing Throughput and Capacity

There are several ways in which the existing LTE Advanced Pro network can be enhanced to increase throughput and capacity including the following.

- Building additional sites and base stations for capacity
- densification through deployment of small cells to increase capacity in hot spots
- M-MIMO and 5G
- Use of mmWave technology
- Additional Spectrum

The Imagine TD-LTE Advanced Pro network is built on a base station platform that uses software defined radios capable of being software upgraded to 5G or at most requiring the addition of a single card to the indoor equipment. Antennas, cables and outdoor radio heads remain the same.

In other cases, they require only the addition of new hardware at the existing site in a complimentary manner that integrates the new technology with the existing infrastructure. Furthermore because of the fixed nature of FWA, existing services and customer CPE can remain in situ while only new customers or those requiring an upgrade need to have new devices installed or upgraded.

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[29] 5G fixed-wireless access, the market opportunity for operators and vendors

2.7.9.1 Building additional sites and base stations for capacity

In line with standard practice for the deployment of large scale wireless networks the initial rollout is focussed primarily on coverage objectives in order to gain market share and secure a revenue stream. Once sufficient coverage is attained and sites begin to reach an agreed threshold this will trigger planning and implementation of additional capacity sites in an area to provide overlapping coverage and thus additional capacity.

2.7.9.2 Densification Through Small Cells

Imagine has fully tested and approved solutions from two vendors, AccelleRan and Airspan, for deployment of small cells in the LTE network. These can provide the equivalent capacity of a single sector of a macro cell in a small area, typically within a radius of 1-2km. These will be deployed to provide additional capacity and also coverage in areas containing small clusters of between 50 to 100 households.

2.7.9.3 M-MIMO & 5G

While the technology roadmaps for the evolution of LTE Advanced Pro to pre 5G and 5G NR are progressing rapidly. Massive MIMO base stations are widely available commercially with well over 100,000 base stations deployed globally. CPE are now rapidly moving towards dual mode LTE A and 5G CPE or pure 5G CPE devices which are commercially available in 3.6GHz from July 2019.

Imagine began its trials of 64T 64R Massive MIMO in Q3 2019 and expect commercial deployment of the first base stations to follow by Q1 2020.

The expected performance of M-MIMO and 5G is compared to the existing LTE Advanced and Advanced Pro in Figure 29 below.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	5GNR NSA	5GNR SA
Spectrum	[illegible]	[illegible]	60MHz	[illegible]	[illegible]
Practical User Peak Speed	[illegible]	[illegible]	[illegible]	[illegible]	600-1Gbps
Max Users per cell/site	70/420	70/420	50/630	60/540+	60/540++
Features	64QAM, TM8, 2CC	256QAM, TM9, 3CC	Multi user pairing, SRS Improvements	NSA to build deployment	Migrating to SA
Devices	CAT 6	CAT 6/12	CAT15	Dual band 5G NR/LTE	5G NR

Figure 29 : Imagine Forecast of expected performance of M-MIMO and 5G

The following slide also shows how with a combination of 60MHz spectrum used for 5GNR plus an additional 20MHz TD-LTE the target of >1Gbps single user throughput could be achieved with the evolution from ~400Mbps peak throughput with current LTE technology, to 700Mbps with Massive MMIMO to 960Mbps with 5G NR. It also suggests that with another 20MHz of spectrum the throughput would exceed 1Gbps

Theoretically 500MHz can almost meet the requirements of single user throughput target

2.7.9.4 mmWave

mmWave for 5G enhanced Mobile Broadband

Millimeter waves (mmWaves) refer to the range of the electromagnetic spectrum which includes wavelengths from 1 – 10 mm, corresponding to a frequency range of 30 - 300 GHz. However, in the context of 5G, the term mmWave often stretches to include slightly lower frequencies down to about 24 GHz.

One of the requirements defined by ITU for the fifth generation of mobile communications (5G) is enhanced Mobile Broadband (eMBB) systems that should not only meet the significant requirements for capacity increase, but also address the needs for higher user data rates (up to 10 Gbps). Due to the huge amount of available spectrum in the higher spectrum bands, the utilization of mmWave techniques is a promising way to achieve these rates.

There are several realistic deployment scenarios for mmWave technology as part of a 5G access network: FWA (Fixed-Wireless-Access), Indoor/Outdoor small cell access (hot spots, data shower, smart offices etc.), as well as backhaul for small cells.

The first phase of frequency allocation for 5G (aligned by ITU and 3GPP) defines a period of research for frequencies under 52.6 GHz, frequencies up to 100 GHz are assigned for phase two (3GPP Rel. 16) which should be completed December 2019. E-Band (66 – 76 GHz) is one of the frequencies between 24 GHz and 86 GHz considered after the most recent World Radio-communications Conference (WRC)

Figure 30 : Mobilising mmWave

According to Qualcomm we can expect the following performance from mmWave

- Peak throughput per sector is of the order of 5 Gbit/s,
- Single user peak throughput of the order of 2-3 Gbit/s
- Average throughput per sector is expected of the order of 1 Gbit/s
- These throughput require Carrier Aggregation of multiple channels
  - 8 x 100 MHz contiguous channels to get 5 Gbit/s
- Such channel bandwidths can be only be achieved in mmwave bands
- multiple MIMO layers in download
- High modulation schemes both in upload and download

The 60 GHz V-Band is one of the proposed bands FWA services. The 14 GHz of contiguous spectrum in this band offers more bandwidth than any other licensed or unlicensed mmWave band. Further, the 60 GHz band has chipsets and technology currently available on the commercial market.

The latest recommendations by The European Conference of Postal and Telecommunications Administrations Electronic Communications Committee (CEPT ECC), open up the 60GHz mmWave unlicensed band for Gigabit Fixed Wireless Access in Europe

2.7.9.5 Heterogeneous Networks, mmWave & Other RAN Technologies

In addition to planning the evolution to M-MIMO and 5G Imagine has initiated several projects to investigate how best to implement and integrate other new developments in RAN technology including mmWave, V-Band Point to Multi-Point, Mesh networks, and Open RAN

Future networks will also be heterogeneous and not just 5G as according to *Analysys Mason*[31] *"5G is not the only gigabit wireless show in town."* Imagine has a number of ongoing projects investigating the capabilities of different mmWave technologies

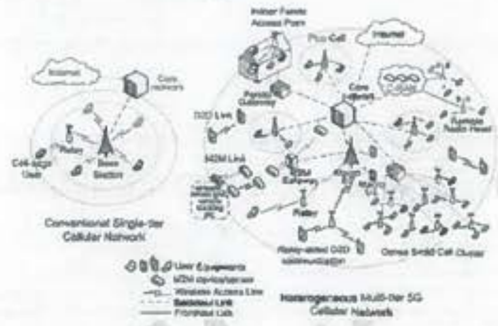


Figure 31 . Heterogeneous Network

Heterogeneous Networks will consist of massive number of different cell types (macro cells, femtocells and picocells) using different protocols, RF techniques and spectrum bands. To function as a multi-tier network in a transparent manner to the end user the network nodes must have functionality such as self-organisation, spectrum co-ordination, autonomous load balancing, power adaptation and interference minimization/mitigation

In addition the UE must have the ability to connect simultaneously with many base stations or access points by using the same or different radio access technologies (RATs)

Some of the technologies being investigated by Imagine are

Company	Equipment	Deployment Example Details
Pharr/C-Spire	*28GHz 5G millimeter wave fixed wireless*	*C spire has launched fixed wireless using millimeter wave spectrum in a housing development in Mississippi, using 28GHz 5G millimeter wave fixed wireless fromPharr.*

[31] Analysys Mason, 5G fixed wireless access, the market opportunity for operators and vendors, March 2019

		Residents connected to the service have been getting download speeds of up to 750 Mbps, upload speeds of up to 600 Mbps with latency as low as 8 milliseconds.
CCS	Metnet 60G unlicensed mmWave, self-organising mesh radios	In the rural Monmouthshire village of Llanddewi Rhydderch homes are benefiting from Gigabit broadband as part of an Innovative UK Government backed 5G Pilot Pilot, funded by the Department for Digital, Culture, Media & Sport (DCMS), using a 60GHz 'mesh' technology developed by Cambridge Communication Systems Ltd (CCS)
Nokia	WIPON 60GHz FWA	Multiple trials & Deployments - targeted at extending fibre via 1Gbps connections over very short distances- can be chained to give coverage along roads. See Figure 32 below
Siklu, Ignite, Mimosa	5G mmWave & Vband	Multiple FWA deployments

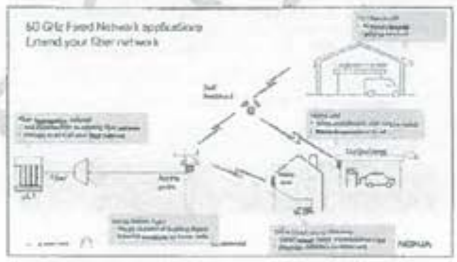
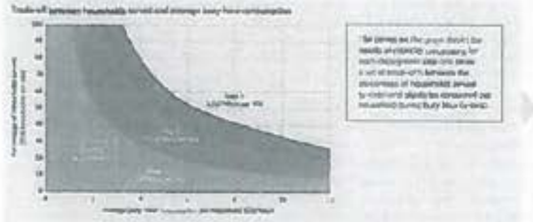


Figure 32 : Nokia WiPON

2.7.10 Path to 1Gbps

2.7.10.1 Ericsson Case study

As an example of how multiple technologies (TDD, FDD, mmWave and M-MIMO) can be brought together to provide the necessary capability to satisfy the medium-long term requirements for throughput and capacity Ericsson in their November 2018 Mobility report show how this could be achieved:



The case depicts an area with LTE mobile broadband coverage, along with an initial 5G build-out using mid-range spectrum. On average, the area has 1,000 households per km². FWA is deployed on the sites to provide fixed broadband.

The service provider must offer fiber like speeds of 100–1,000+Mbps with a minimum data rate of 30Mbps and capacity to serve busy-hour usage per household of 3GB/h. Assuming 10 percent of total traffic occurs during busy hour, which corresponds to average monthly traffic of 900GB per household.

On average, a base station covers 550 households. With a projected 30 percent service uptake the initial deployment is dimensioned to serve 165 households per site.

The graphs indicate the trade-off between the data consumed per user and the number (or percentage) of customers that can be connected for a given throughput per site.

At each stage in the evolution additional spectrum is brought into increase the throughput per site which can then allow either or both of the busy hour traffic per user and % of households served to increase.

Ericsson Mobility Report November 2018 - Making Fixed Wireless A Reality

	Spectrum Deployed	throughput capacity per site	average busy-hour traffic of per household	Busy hour Ave Throughput (BH - 10% of total)	percent of households served
Step 1	• 10MHz FDD in sub-3GHz bands for LTE • 40MHz 3.5GHz TDD LTE 8Tx/Rx MU-MIMO • 400MHz TDD NR (mmWave & M-MIMO) • outdoor CPE to maximize performance and indoor CPE as complement	1,315Mbps	3.6GB/h	9.2Mbps	[illegible]
Step 2	• 60MHz of TDD spectrum (100MHz total) • 200 MHz in the mmWave band (600MHz total)	2862Mbps	4GB/h	21.1Mbps	[illegible]
Step 3	• 40MHz of TDD spectrum (140MHz total) • 200 MHz in the mmWave band (800MHz total)	5667Mbps	10GB/h	26.7Mbps	31

What this case study shows is that it is possible to provide fiber-like speeds of 100-1,000+Mbps to a significant number of households with what is a reasonable amount of spectrum – comprising 140MHz of mid-band TDD spectrum and 800MHz in mmWave bands of which there are several tens of GHz to be made available - see section

2.8 Spectrum

In 2017 ComReg held a multiband auction for the allocation of 3.6GHz spectrum as a result of which Imagine secured an allocation of 60MHz contiguous spectrum in all rural regions in the range from 3560MHz to 3620MHz until 2032. The spectrum is technology neutral and highly suited for both LTE-A and 5G deployment.

Results of the 3.6 GHz Band Spectrum Award Information Notice Reference ComReg 17/38, 22May 2017

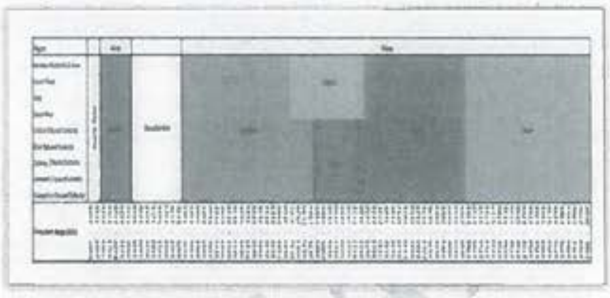


Figure 33 : Ireland Spectrum Holdings 3.6GHz

2.9 How Much Spectrum is Required to Support NGA

In their 2015 report Analysis of the potential spectrum requirements for NGA services[32] Plum Consulting state that:

> *"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."*

In conclusion Plum's analysis indicates that 100MHz of spectrum could serve *"50% of all subscribers in more rural areas"* and although Imagine only has 60MHz the Plum analysis did not envisage the use of soft split – which effectively doubles the frequency reuse - giving the equivalent of 120MHz spectrum – more than enough to deploy a network capable of delivering *"a high speed wireless broadband service compatible with the DAE 30 Mbps target"*

[32] 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

2.9.1 Future Spectrum- Proposed Multi Band Auction

As Imagine wish to deliver a service that not only exceeds the requirements of the NBP but provides a future proof solution ultimately capable of delivering multiple Gbps throughput by making use of new technologies as they become available Imagine will have a requirement for further spectrum assets

Ireland is set for a significant multi-band auction in 2020[33] (timing is subject to confirmation by ComReg) that will release 470 MHz of FDD and TDD spectrum in the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz Bands, with 350 MHz of additional spectrum that is currently not used for Wireless Broadband. This spectrum will all be capable of running 5G NR and all can be used in conjunction with Imagines current spectrum holding. Imagine will be active in the auction.

According to a 2018 preliminary consultation by ComReg[34] aside from the 350MHz of new spectrum in the Proposed Multi Band Spectrum Award there is potential for a further 1100MHz of spectrum to be released for 5G in bands above 6GHz including:

- *the 26 GHz Band is the pioneer band for 5G in Europe above 24 GHz;*
- *the frequency range 40.5-43.5 GHz (the "42 GHz Band") is a viable option for 5G in the longer term; and*
- *the frequency range 66-71 GHz could be an important band for 5G, where spectrum access facilitated under a general authorisation (rather than individual rights of use) is currently foreseen.*

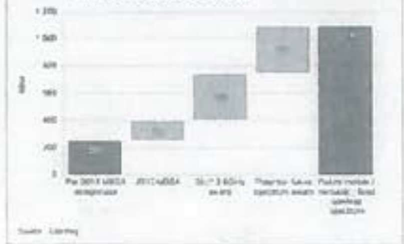
This is summarised in the graph below from Frontier Economics[35]

[33] ComReg ComReg 19/59R. Proposed Multi Band Spectrum Award, including the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz Bands

[34] ComReg Document 18/60 Proposed Multi Band Spectrum Award Preliminary consultation

[35] ComReg 18/103b Meeting Consumers' Connectivity Needs, a report from Frontier Economics

Figure 25 Total harmonised spectrum available for mobile, nomadic and fixed wireless broadband services



All such spectrum that, subject to competition, is open to Imagine to acquire is suitable for use in deployment of 5G FWA and will complement and integrate with the existing deployed infrastructure.

2.9.2 Future Spectrum:- mmWave bands

mmWave bands are still under study in many jurisdictions, in Ireland whilst some spectrum in this range is available for point to Point links to date it has not been made available for 5G or FWA applications.

In May 2019 the European Commission announced it is reserving a wide swath of spectrum from 24.25GHz to 27.5GHz for 5G devices — on a non-exclusive basis.

The EU is also requiring member states to harmonize their laws to permit 5G use of the 26GHz band by December 31, 2020. Initially, it expects the 26GHz spectrum to be used for fixed 5G broadband service, faster mobile 5G, and mixed reality applications, such as virtual and augmented reality content, as well as certain industrial applications.

To date 26GHz is used and licensed extensively for fixed point to point links. It is not clear if or when this or any other mmWave bands will be made available.

2.10 Coverage

The design philosophy for the network is to provide the optimum balance of coverage and capacity within the target coverage area.

In terms of cell edge probabilities for its commercial rollout Imagine has used 76% as a realistic figure to optimise investment and provide sufficient coverage probability to connect customers. There are many factors to support this as suitable figure for coverage planning.

- With the ability to optimise the positioning of the CPE device in multiple locations over a reasonably large footprint the actual probability of securing successful install is far higher than the 76% prediction and is closer to 90%
- With densification of sites and overlapping coverage CPE have the ability to connect to multiple sites thus increasing the actual probability of connection
- Newer CPE with a 17dB antenna gain have been introduced and are used where required to achieve better signal metrics at the cell edge and thus increasing the probability of a connection vs the planned coverage which is made using a 14dB CPE antenna gain
- Imagine has put in place a number of technical solutions that can be used to solve installation problems caused by LOS issues these are described below.

Although it has been claimed[18] that the number of sites required to deploy a FWA network to meet NBP requirements is a barrier to using FWA this is contradicted by a detailed report from Plum[19] in which they estimated for various scenarios the number of sites required to deliver an NBP service. For example in the figure below it shows that to deliver such a service to 50% of the households in Donegal would, with 60MHz of spectrum, require 95 sites, furthermore it goes on to state that *"ComReg's Siteviewer tool indicates a total of 224 mobile base stations in rural Donegal"* which rather than presenting a barrier give the potential operator plenty of pre-existing towers on which to deploy its network.

Figure 4-10 Spectrum and infrastructure [illegible] to deliver wireless broadband to 50% of households in rural Donegal [illegible] ratio of [illegible]

In the case of Imagine's network deployment we are able to deploy different site configurations to optimise the balance between cost effective coverage and the ability to increase capacity when needed as demand grows. This allows capital to be directed effectively to where it is most needed.

[18] Analysys Mason FTTP or 4G/5G for Ireland's NBP?

[19] ComReg 15/140d, 22 December 2015, 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.

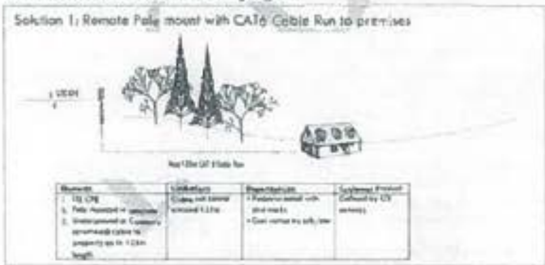
In order to address the issues around the Cell Edge probability and the requirement for 6Mbps uplink Imagine has provided multiple coverage maps for consideration and to compare the benefits of each as follows.

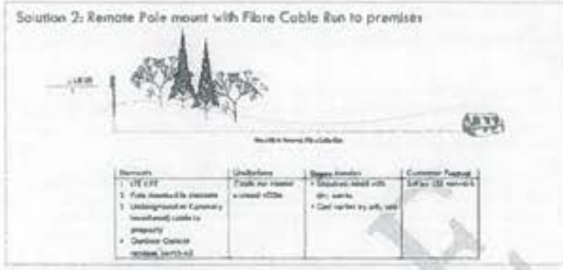
	Imagine Deployment	[illegible]	[illegible]
	- 150Mbps DL 6Mbps UL - 76/90% Cell Edge/Area probability	- 30-6Mbps DL-UL - 95/99% Cell Edge/Area probability	- 30-2Mbps² DL UL - 76/90% Cell Edge/Area probability
Current "172" sites	✓	✓	✓
Planned "XXX" sites	✓	✓	✓

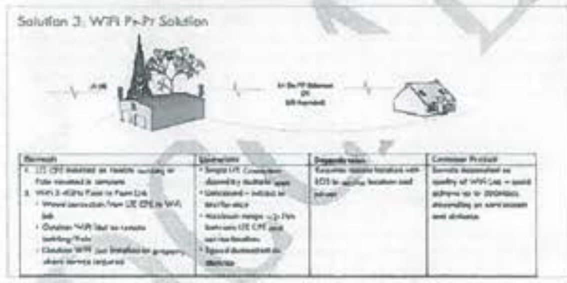
2 Uplink to be order of magnitude better than DSL technology – should be between 1-2 Mbps and endure that uplink does not constrain coverage.

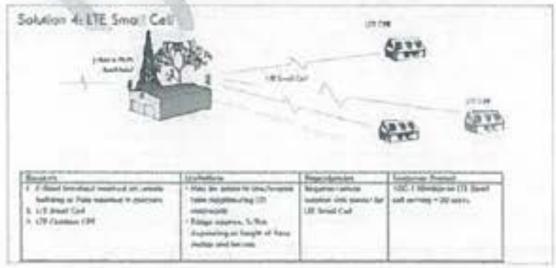
2.10.1 Extended Coverage Solutions

These solutions are shown in the following diagrams









2.11 Barriers to Deployment

In the report for the NBP in 2018 Analysys Mason[30] makes reference to potential barriers to 5G deployment:

> *Had the bidders chosen a 4G or 5G solution they would have faced numerous other practical deployment issues including identifying thousands of suitable new sites to build new towers and masts, and the associated uncertainty of how such a site portfolio might need to grow in future due to increasing end user demand.*
>
> *Recent policy work in the UK relating to 5G deployment (focussing [SIC] on small cells)[5] has highlighted 13 specific barriers to planning and deploying such infrastructure, spanning regulation; practical implementation challenges; and communications issues between private- and public-sector stakeholders. Most, if not all, of these barriers are likely to apply in Ireland*

With regard to barriers to planning and deploying, the report referenced in this statement is in fact another report by Analysys Mason[31] for the UK BSG looking at barriers to the UK becoming a leader in 5G as opposed to a national rollout of broadband. Of the 13 barriers identified 5 relate to UK or ECC government or policies and have no relevance to the Irish NBP, 2 relate to deployment in urban areas, leaving approximately only 5 issues of relevance to Ireland most of which can be overcome and indeed at least 2 are being addressed in some form in the Irish market by the Mobile Phone and Broadband Taskforce (MPBT) for example by[32]:

- Reducing the cost and streamlining planning processes for the deployment of telecommunications infrastructure (Actions 7 – 11 MBT).
- Install ducting on new national primary/secondary roads (Action 6 MBT)
- Develop and publish a policy for all local authorities around access to and use of state infrastructure (Action 18 MBT)

It is Imagine's opinion therefore that the potential barriers to deployment of a 5G FWA in support of the NBP have been greatly overstated and though not trivial could be readily overcome.

[30] FTTP or 4G/5G for Ireland's NBP?

[31] Lowering Barriers to 5G Deployment, Report for the Broadband Stakeholder Group, July 2018

[32] Comreg 18/103b Meeting Consumers' Connectivity Needs, a report from Frontier Economics

2.12 Review of Previous Submissions

Having laid out the performance of the existing network it may be helpful to address the key criticisms of our previous submission in response to the DECNR 2015 Supplementary Information Request[33] and the multiple subsequent follow up clarifications and consultations. In various responses from the department and its consultants many conclusions were drawn which ultimately proved to be incorrect. This includes:

> *"the solution proposed will not be implemented in the timeframe proposed in May 2015"*

and

> *"Imagine is not proposing a credible NGA solution*
>
> *Although the technology proposed by Imagine is capable of providing NGA services, the site configuration and the network solution Imagine is proposing, incorporating that technology is not a credible NGA solution.*
>
> *This is principally (though not exclusively) due to:*
>
> - *Imagine's plan for each site to serve an average of XXX customers and our assessment that the proposed site configuration will not provide a 30 Mbit/s download to all users when they demand it*
> - *the provision of insufficient detail of the coverage for the 6 Mbit/s upload service to all users who require it under normal conditions."*

and

> *"Imagine does not have a credible resource plan. Imagine's resource plan involving the use of a mix of staff and subcontractors to roll out the network is in line with industry practice. However, the procurement of subcontractors and resources is currently suspended. Consequently, based on the information provided, we have substantial concern about the credibility of the resource plan and do not assess it as credible at this time."*

Four years later and with 172 sites deployed, 259,411 "Amber" homes covered and over XX,000 satisfied high speed broadband customers with an up to 150Mbps service Imagine can, with confidence state that all of the proposed performance characteristics of the 2015 planned network have been met and in most cases exceeded.

In their 2015 assessment of Imagine's then proposed solution Analysis Mason[34] claimed that

[33] National Broadband Plan High Speed Broadband Map Supplementary Information Request, 27th March 2015

[34] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

"since Imagine provides services through a fixed wireless access network, in order to assess Imagine's spectral efficiency, the "high-end" spectral efficiency of the Ofcom benchmark was considered. However, based on the above comparison, it can be seen that Imagine's assumed downlink spectral efficiency is greater than the "high-end" Ofcom benchmark. In our opinion, this is an aggressive/ overly optimistic assumption. This introduces some level of risk in the implementation of the design of failing to meet the target average download throughput"

In addition, further comments in this report[79] made specifically in relation to the uplink included

"Imagine has assumed an uplink spectral efficiency of 3.6 bit/s/Hz. In our experience the uplink spectral efficiency tends to be approximately half that of the downlink. Imagine has assumed a downlink spectral efficiency of 5.6 bit/s/Hz. This is in excess of the "high - end" Ofcom benchmark. Therefore, in our opinion, an uplink spectral efficiency of 3.6 bit/s/Hz (which is greater than 64% of the down link spectral efficiency), is aggressive. The use of aggressive spectral efficiency assumptions introduces a substantial level of risk in the implementation of the design of not meeting the target average download throughput."

Imagine's calculations of spectral efficiency are based on industry standard methods as applied specifically to a TD LTE Advanced Pro network and furthermore have now been verified by the performance measured in the live network. In our opinion Analysys Mason's views, based on a 2011 Real Wireless report for Ofcom, misinterpreted Ofcom's view as to the meaning of "High End" which led to an incorrect assessment of Imagine's figures as being an *"aggressive/ overly optimistic assumption"*. Imagine's TD LTE Advanced Pro network meets and far exceeds Ofcom's definition of a high-end network. Indeed, Imagine have, at the invite of Ofcom's CTO, presented to Ofcom's staff how this has been achieved.

In 2016 correspondence[80] Real Wireless stated that:-

"The spectral efficiency figures given in the report on the Ofcom website were based on typical system performance for a mobile platform with typical mobile network planning. Therefore they are not an appropriate comparison to Imagine's proposed Fixed Wireless TD-LTE Advanced network."

Imagine's network, deployed in a Fixed Wireless Access configuration in a rural environment not only benefits from the most advanced (high end) performance enhancing features but in combination with higher terminal gain than mobile environments, careful network planning, and management of installation quality metrics the targeted spectral efficiency is not only achievable but is far from being aggressive or overly optimistic.

[79] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

[80] Email correspondence with Real Wireless, February 2016

Furthermore in the published report by Plum Consulting for ComReg[81] they estimate an average throughput of 78Mbps and resulting spectrum efficiency of approximately 4 bps per Hz across a fixed wireless network as follows:-

"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."*

It should be noted that Plum did not adjust this figure to account for the 3:1 TDD ratio as per ITU-T recommendations[82]. Nevertheless, the Plum figures were consistent with Imagine's unadjusted 2015 figure of 4.2bps/Hz given the technology deployed at the time.

Since 2015 progress has been rapid in the development of both RAN and CPE, LTE RAN software standards have advanced considerably with advanced Radio technologies that allow for higher power and more complex radio configurations to be deployed. For example, Multiuser beamforming and Adaptive SFN and Soft Split which can, among other things, allow for greater reuse of radio resources and spectrum thus increasing spectral efficiency.

Figure 34 . 8T8R to 4T4R spectral efficiency improvements in UL and DL

In 2015 Imagine were running a 2T2R configuration on hardware ready 4T4R equipment. Since then Imagine has now rolled out 8T8R. In terms of CPE, in 2019 Cat 12 is now the industry standard with Cat 18 also commercially available. These CPE come with 4 x Downlink CA and 2 x Uplink CA as well as 256QAM and 4x4 MIMO support. A summary of the impact of such features is shown in Figure 35 below

[81] ComReg 15/140d, 22 December 2015, 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.

[82] See ITU-R M.2134 regarding calculating the spectral efficiency for TDD systems

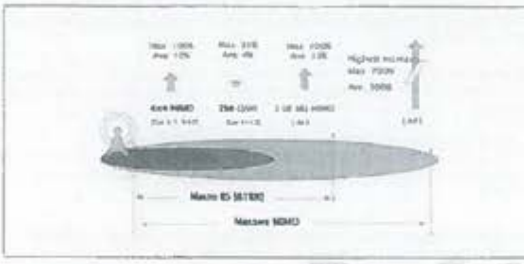


Figure 35 : Uplift of various LTE technologies since 2015 (source ZTE)

It should be noted that the above throughput performance is achieved and maintained through the rigorous application of installation quality thresholds as detailed to ensure that each customer connection is operating to the highest efficiency levels possible to maintain the overall efficiency of the base station. Imagine, in retrospect, was overly conservative in the spectral efficiencies we proposed.

With regard to capacity in it's 2015 assessment of Imagine's then proposed solution Analysis Mason[39] stated the following:

"In their business plan, Imagine assumes that, on average, XXX subscribers can be served per site (for years 2016, 2017 and 2018). The objective of this section is to assess whether or not each site has enough capacity to serve XXX subscribers and to provide a minimum download speed of 30 Mbit/s for all users when they demand it. ..

And go on to state that:

... Although, Imagine methodology highlights that their design would be able to support the transmission of a total volume of data per month (i.e. XX GB per month per subscriber). It fails to demonstrate that for each of these subscribers, the network could provide a minimum download speed of 30 Mbit/s when they demand it. This is because the above methodology only involves monthly data volumes calculation and not instantaneous or sustained bandwidth per user."

[39] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

Imagine has shown, with data from the live network to back up its assumptions and results, that not only can it support the number of customers per site but that it can also deliver a *"minimum download speed of 30 Mbit/s when they demand it"* and furthermore provides a service far in excess of the minimum speed for a significant number of users and time. It has been shown that at peak times users demands are being fully met with spare resources available in the base station.

With respect to data volumes Analysys Mason had the following to say[40]

"Notwithstanding the inadequacies of the methodology, the input assumption that subscribers to NGA networks use on average of XX GB per month is out of line with recent market based data published by OpenReach[6] and Ofcom[7] which state that NGA subscribers use XXX GB and between 80-150 GB respectively.

Assuming a data consumption of XXX GB per user per month, it would decrease the number of subscribers supported per site to XXX

Therefore, based on the evidence provided to date by Imagine, we believe that there is a high risk that Imagine's design will not be able to sustain XXX subscribers per site, where each subscriber will be able to get a 30 Mbit/s broadband download speed when they demand it."

Data from the Imagine network shows that its customers are currently consuming on average XXXGB per month, far in excess of the 2015 benchmark figures from Openreach and Ofcom and indeed higher or equal to current figures in any other network in the Irish market.

In terms of concurrency and the ability to provide a *"minimum download speed of 30 Mbit/s when they demand it"* Analysys Mason had the following to say[41]

"The requirements specified in the NGA assessment criteria include the requirement to deliver a minimum download speed of 30 Mbit/s to all users when they demand it. In this context, the user concurrency ratio for the downlink is critical.

For the purpose of this analysis we have considered concurrency ratio. Concurrency ratio is usually used by LTE equipment vendors to dimension the network in terms of capacity. From experience, LTE equipment vendors use a concurrency ratio between 10% and 30% for the dimensioning of the downlink in FWA networks. This means that between 10% and 30% subscribers are assumed to be using the service at the same time. For absolute clarity, if for example a concurrency ration [SIC] of 10% was used, this would mean that not more than 10% of the subscriber base in the coverage design footprint will be able access the service during the busy hour and be delivered a minimum download speed of 30 Mbit/s when they demand it."

[40] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

[41] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

In the first instance the above analysis is overly simplistic in its view of concurrency – it appears to assume that in the case of x% of concurrent users that each of these would be the same x% that consume data constantly and continuously throughout the busy hour. In practice, not only do users not consume data continuously but, depending on different applications used including streaming of video, the actual rate of data required per second varies significantly over the period of time that the service is used.

Imagine's more accurate estimation, backed up by actual data from the network as provided above, shows that not only does it provide 30Mbps download when demanded but that for the vast majority of the time there are significant surplus network resources remaining available in the cells.

With respect to uplink Analysys Mason had the following to say[42]

"As highlighted above, we believe that the spectral efficiency for the uplink assumed by Imagine is aggressive by comparison with standard industry assumptions and introduces a high risk to the design being realised in practice. It is Analysys Mason's view that this is an unrealistic design assumption.

Consequently, Analysys Mason is not able to conclude that the network which Imagine proposes to deploy will have the capacity in the uplink, to be able to deliver the 6 Mbit/s minimum upload speed to the number of users set out in their business plan simultaneously in terms of total site capacity."

As with the assessment and reality of the downlink capability Imagine has shown that the actual uplink performance of the existing network at an achievable peak time maximum of XXMbps per user is above the 2015 expectation and exceeds not only what was proposed but also the 6Mbps requirement of the NBP.

In its 2015 assessment of Imagine's coverage Analysys Mason made the following three points regarding Imagine's then proposed coverage: [43]

"The link budget provided by Imagine (in a file called "Section 2.1.2 (X) Link Budget") includes a cell edge coverage probability of [illegible]% for the design and planning of its fixed wireless access network. In our view this seems low.

Based on these comparable [illegible] broadband schemes, among others we recommend that operators use a cell edge probability of between [illegible]% and [illegible]% when designing their networks."

And

Imagine has also indicated an assumption that CPE antenna height would be X metres above the ground. In our view this seems high and we typically assume a height of 5 metres for fixed wireless access. In principle, the higher the CPE antenna, the larger the coverage achieved by the base station.

Use of an antenna height of X metres for a rollout of the scale proposed by Imagine is a cause of some concern and introduces risk into the coverage assumptions.

And

"Imagine has clarified that the thresholds calculated in the link budget are not used in its coverage maps.

Consequently, Analysys Mason has not been able to establish which homes can receive a download service of at least 30 Mbit/s from each site."

Taking the last point first, this is a misinterpretation of Imagine's statement which were summarised as *"Atoll directly incorporates the same parameters contained in the link budget spreadsheet as part of the inputs to its algorithm"*. In other words the link budget thresholds are used by the planning tool to produce the maps.

With regard to the height of user installations at X meters, the X meter figure is very clearly used to determine the cell edge and does not imply by any means that all installations require this height to be successful. Imagine made this very clear through the following statement the time:

"It should also be noted that the Xm height is used in the link budget to determine the maximum range of the service and therefore it is not the case that every CPE device in coverage must be at a height of Xm in order to obtain the required signal strength and quality to meet the service metrics."[44]

In other words the entire rollout is not dependent on every connection requiring a height of Xm. In 2019 Imagine now have in excess of XXX customers deployed and this has shown that in fact with the densification of the network lower height installs are required to use natural shielding of interference (from CPE and overlapping cells) and optimise the reflections to get high modulations including 256QAM and make use of MIMO. As such the average heights are closer to 5m.

[42] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

[43] Report for DCENR, Technical and deployment assessment of Imagine's SIR response, 10th December 2015

[44] Imagine Response - Analysys Mason NBP Queries 06-11-15 final

2.13 Wireless Platform Specific Information

A1.2	*Platform Specific Information*
2b	*Wireless Platform.*

2.13.1 Per Sector Information

A1.2b.1. Please provide the following data in a spreadsheet on a per sector basis:

a. sector ID
b. site ID
c. site coordinates and projection system
d. sector azimuth
e. access technology (including relevant standards)
f. carrier frequency
g. number of carriers
h. bandwidth per carrier (e.g. 20MHz)
i. structure status (greenfield or existing)
j. tower or structure height (above ground level)
k. transmit antenna height (reference base of antenna)
l. transmit power
m. antenna gain
n. antenna radiation pattern for vertical and horizontal radiation pattern (patterns should be provided in Excel or another computer readable file, loss in dB per degree)
o. MIMO scheme
p. number of transmit antennas
q. number of receive antennas
r. antenna tilt - electrical (reference positive degrees for down-tilt, negative number for up tilt)
s. antenna tilt - mechanical (reference positive degrees for down- tilt, negative number for up-tilt)
t. spectrum licence conditions including ComReg licence

Please see attached files

- **Section 2.13.1 Qu1 Per Sector Information**
- **Section 2.13.1 Qu1 Pt n Antenna Radiation Pattern**
- **Section 2.13.1 Qu1 Pt. T ComReg Licence**

2.13.2 Carrier Aggregation

A1.2b.2. Please describe any planned use of carrier aggregation (CA)

Carrier Aggregation is a key technology in LTE Advanced and 5G to enable higher capacities on fixed and mobile networks in the down link as well as the uplink. Carrier aggregation in LTE offers successively higher peak data rates as well as better broadband experience across the coverage area.

The date rates scale with the amount of spectrum allowing LTE networks from 3GPP Rel 10 onwards to support up to 5 carriers with up to 100 MHz of spectrum. Imagines current architectures can support up to 3 carriers with peak data rates up to 450 Mbps (Cat 12).

The increased peak data rates of carrier aggregation allow for shorter duration times for a user being active can be provide higher capacity for bursty applications , such as web browsing, streaming, social media apps and others.

Imagine deploys carrier aggregation as follows:

- 3x 20 MHz downlink CA for the ASFN, S333 and S33 architectures,
- 2 x 15 MHz CA for the S15/15 soft split architecture
- In the uplink, 2CA is currently supported providing up to 28 mbps with CAT 12

In addition to carrier aggregation the current network deployment also supports both DL 4x2 MIMO and Beamforming TM 7/8 whereby the base station transmits 4 streams and the UE receives them on two receiver elements. This provides better performance in advance of the availability of full 4x4 MIMO. The additional base station capacity results in a higher number of users per sector.

2.13.3 Per Site Information

A1.2b.3. Please provide the following data in a spreadsheet on a per site basis:

a. number of sectors on installation

b. any planned evolution of the number of sectors over time

c. backhaul technology

d. backhaul capacity

e. site acquisition assumptions including information regarding site ownership and statement of probability of inclusion of site in rollout

Please see attached spreadsheet Section 2.13.3 Qu3 Per Site Information for the above information

2.13.4 Mode of Reception

A1.2b.4 ***Please provide the following data for each proposed mode of reception (e.g. indoor CPE, window-mounted CPE, external CPE) at the end user's premises:***

a	*mode of reception*
b	*service assurance*
c i.	*antenna height*
c ii.	*transmit power*
c iii.	*MIMO scheme*
c iv.	*number of transmit antennas*
c v.	*number of receive antennas*
c vi.	*antenna gain*

a	*mode of reception*

a. mode of reception	Gemtek Cat 12 (WLTG-123) CPE is mounted on a chimney or wall outdoors to give the optimum reception	ZinTel Cat 12 (ZR612V) CPE is mounted on a chimney or wall outdoors to give the optimum reception
b. service assurance	See following paragraphs	See following paragraphs
c i. antenna height	Xm	Xm
c ii. transmit power	23dBm ± 2dB	23dBm ±2dB
c iii. MIMO scheme	2T4R, DL 2x2 (4CA) MIMO/DL 4x4 (2CA) MIMO UL 2x2 MIMO TM2, 3, 4, 7, 8, 9: DL 4x4 MIMO @ TM3/4/9	2T4R, DL (4CA) 2x2 MIMO; DL (2CA) 4x4 MIMO UL 2x2 MIMO TM2, 3, 4, 7, 8, 9: DL 4x4 MIMO @ TM3/4/9
c iv. number of transmit antennas	2	2
c v. number of receive antennas	4	4
c vi. antenna gain	13 dBi	17dBi

Table - UE Specifications

2.13.4.1 b. Service Assurance

Service Assurance is based on well proven installation practices based on greater than 10 years of experience of planning, connecting and managing outdoor installations in fixed wireless deployments. All CPE installations are carried out by Imagine staff or sub-contractors who are trained and experienced. Imagine do not permit self installation by users or via dealers. Install guide for our installers are described in Appendix D Install Manual Full v5.2.pdf The sales and provisioning process include the use of automated workflow tools that are described in Appendix D Imagine Sales and Provisioning Process.pdf

All installations are subject to passing an installation Acceptance Check as per the automated process described above. If an installation fails, the acceptance check the customer will be offered alternative products whose metrics can be met or will be offered an alternative product either wireless or fixed line.

Proactive management of quality metrics is carried out post installation to ensure the signal quality metrics are maintained both for the individual customer and on a network wide basis. Data is collected via the NMS and processed to flag any reduction in metrics post install, and these are then actioned by the call centre to contact the customer.

Deploying the TD-LTE network as a fixed wireless solution provides predictability and control over the RF metrics of customers with only those with acceptable metrics being accepted onto the network in order to maximise the capacity of the system to connected users. By only using outdoor antennas maximises coverage and ensures highest possible metrics are achieved. Strict management and control of the process by which customers get access to the network and the number of users per sector ensures the highest modulation, capacity and network performance and ensures the quality of service provided customers are prequalified by location against the coverage prediction maps and the specific metrics are tested and evaluated during the activation process. Terms and conditions of use, ongoing monitoring and customer service processes ensure that these metrics are maintained

The technical and operational approach to achieve the predicted RF metrics is well established in our current operations and existing wireless networks. With this approach we are satisfied and have demonstrated that the RF metrics will deliver an aggregate throughput of upto 300Mbps where 3CA is enabled.

2.13.4.1.1 Managing the online experience

Fair Resource Allocation Policy or FRAP is in line network facility that enforces policy [redacted]

Imagines tries to give the best service to the vast majority of its customers at all times. It sees about 90% of its customers usage as acceptable and around 10% as heavy and requires management. As is normal in networks of this type around 10% of the customers can generate 90% of the traffic. So on a daily basis if a user exceeds a generous daily allowance it is deemed to be heavy and categorised immediately as such.

[redacted] This is particularly noticeable at busy network times where light users (90%) see upto 20% improvement on their throughputs without FRAP being deployed. FRAP counters are reset at the end of each day.

In addition to daily ongoing heavy user management FRAP is an important tool in a Fair Usage Policy (FUP) that Imagine employ to manage the heaviest of users.
FUP (Fair Usage Policy)

The FUP is designed to manage more persistent heavy users on the network. At a customer level these are processes that manage a customers journey as they consume network resources and limit the negative affect particularly heavy users can have on other users on the network.

[redacted] Contacting the customer initially by email and eventually by phone most customers are unaware their usage is abnormal. After going through a diagnosis process with the customer the root of the problem is invariably found, and the customer modifies their behaviour. This not only improves the performance for the customer it also improves the resources available to all other customers on that sector.

[redacted]

2.13.4.1.2 Busiest Sectors

Every week Imagine have an acute focus on pinch points in the network from a customer point of view. It categorises each sector on the network relative to the busyness of the sector defined by customer experience peaks during the day. It ranks these in order.

Every week a cross departmental meeting takes place looking at the busiest sectors and deep diving on why they are peaking and putting individual project plans in place to improve performance on these sectors where possible. This meeting is chaired by the CTO.

This process has been the focus of much learnings across the business and a great way of seeing where issues arise quickly. Additionally, this has proven a great process where the business is continually aware of issues as they arise on the network and quickly improves performance for those that need it most generally before customers even know there is a problem.

A1.2b5	*Please describe the following inputs to the coverage map:*
a.	*propagation model and selected parameters*
b.	*planning tool and associated configuration*
c.	*digital terrain map (including resolution)*
d.	*clutter map (including resolution)*

2.13.5 Description of Coverage Maps

5a Propagation Model

Imagine uses the Standard Propagation Model (SPM) with the Forsk Atoll 64 bit V3.5.0 1641 (https://www.forsk.com/) Radio Planning Software to model its coverage service areas. The Digital Terrain Map (DTM) utilised is the SRTM 50m model for rural areas with an SRTM 10m model for built up areas. The clutter map used is the latest Lux Carta (https://luxcarta.com/) 10m clutter data for Ireland.

a. *Propagation model and selected parameters:*

The SPM uses empirical mathematical formulas to calculate the probability of a service in a certain area. The SPM model is tuneable and requires calibration. The Imagine tuned SPM has been formulated over 15 years from experience in the fixed wireless broadband industry. Our current tuned model provides very accurate results, as is required for the commercial roll out.

This model uses the terrain profile, diffraction mechanisms, clutter classes, and effective antenna heights in order to calculate the effective path loss and coverage areas for a given service.

The clutter class is deterministic (i.e., the clutter is sharply defined with an average altitude per clutter class). The diffraction model used in this case is "*Deygout with Correction (ITU R P 526-5)*"[11] and has provided the most accurate results for Imagine.

K-Factor tuning has happened over the last 15 years and is closely monitored and finely tuned on an ongoing basis to provide the most accurate results, as seen from live and test data.

The figures below are extracted from our current tuned version of the SPM formula in Atoll:

[11] [illegible]

Table 3 : Current Imagine SPM Parameters

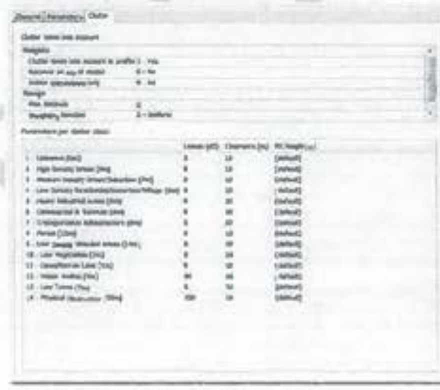


Table 4 : Current Imagine SPM Clutter Parameters

b. *Planning tool and associated configuration*

Imagine uses the Forsk Atoll 64 bit V3.5.0.1641 (https://www.forsk.com/) Radio Planning Software tool for planning service coverage. The project configuration utilised is LTE. This model includes the LTE-Advanced feature set and many other highly developed features, some of which are not applicable to fixed wireless networks.

The configuration of the way Imagine has Atoll setup is multifaceted to suit the architectures that it deploys. The configuration of Atoll can be analysed in the files of the attached appendices XXXXXXXX.

c. *Digital terrain map (including resolution)*

Imagine uses the SRTM[44] digital terrain model. For rural Ireland the map uses the 50m model and a 10m model for built up areas.

Increasing the resolution for rural areas has shown no real benefit on prediction accuracy over long distances. In urban and built up areas, the distances covered are shorter and the 10m model does provide more accuracy.

d. *Clutter map (including resolution)*

The clutter map used is the latest Lux Carta (https://luxcarta.com/) 10m clutter data for Ireland. The statistical average levels of clutter height have been adjusted to suit the Imagine model. The clutter map is updated weekly from field acceptance test results and live network data.

Imagine uses a large clutter loss for water bodies and physical obstructions. This is done so as not to exaggerate the total coverage areas of a site, where we provide our fixed services.

All other clutter uses the clutter heights table below. This is used in Atoll with the associated deygout diffraction model to calculate the clutter path loss. All UE are classed as being 8m above ground level in the model.

Code	Name	Height (m)
	Default Values	
1	Unknown	[illegible]
2	High Density Urban	[illegible]
3	Medium Density Urban/Suburban	[illegible]
4	Low Density Residential/Suburban/Town/Village	[illegible]
5	Heavy Industrial Areas	[illegible]
6	Commercial & Tarmac	[illegible]
7	Transportation Infrastructure	[illegible]
8	Forest	[illegible]
9	Low Density Wooded Areas	14
10	Low Vegetation	[illegible]
11	Open/Native Land	[illegible]
12	Water Bodies	[illegible]
13	Low Trees	[illegible]
14	Physical Obstruction	[illegible]

[44] [illegible]

2.13.6 Link Budget

A1.2b6 Please provide a full Excel-based link budget for the downlink and uplink including all intermediary step calculations i.e. include all formula used to calculate all line items (e.g. line A + line B + line C = line D). The link budget should include at a minimum the following line items and their associated units:

a.	*EIRP*
b.	*system bandwidth*
c.	*required signal-to-interference-plus-noise ratio (SINR)*
d.	*receiver sensitivity*
e.	*maximum allowable path loss*
f.	*indoor penetration loss as applicable per clutter type or geographic type*
g.	*cell edge probability*
h.	*cell area probability*
i.	*mean and standard deviation used to calculate slow fade margin*
j.	*slow fade margin*
k.	*mean propagation loss*
l.	*formula showing conversion of link budget into design threshold on which coverage map is based*

Please see attached spreadsheet **Section 2.13.6 Q6 Link Budget** for the above information

2.13.7 Interference Management

> *A1.2b7 Please describe the planned approach to interference management in the access network making reference to carriers and frequency reuse plans.*

2.13.7.1 Overall Approach

To minimise interference and optimise performance of the TD-LTE network Imagine consider four main areas where interference can be addressed as follows -

- Radio Planning
- Radio Optimisation
- Site Design
- CPE Installation methods
- LTE Interference Management Capabilities
- Network Management

2.13.7.2 Radio Planning

Imagine utilise a radio planning process that is able to accurately predict the TD-LTE coverage from proposed and planned base station sites taking account of the services proposed and the site specific conditions for each site. Furthermore, the process incorporates the ability to measure and verify such predictions once sites are built and use the results to improve future predictions.

Managing interference is an inherent part of the radio planning process, since the radio planning tool is able to model and predict interference and plots produced can be used to show where interference occurs and through resulting frequency planning and site planning processes produce an overall radio plan that minimises interference to within Imagine's specified levels to ensure service quality.

Imagine follow a radio planning process that is familiar to mobile operators across the industry and is supported by commonly available radio planning tools. The tools and techniques are similar to those used to plan mobile networks however due to the nature of a fixed wireless deployment there are differences in the priority given to the level of detail and accuracy of predictions.

The radio planning process is used by Imagine to -

- Plan site locations, site design and frequency plans for the overall network to maximise coverage and minimise interference
- compare relative coverage from candidate sites to assist with site selection process
- evaluate number of households in coverage to validate business case assumptions
- validate site performance including coverage in the site acceptance process
- perform coverage checks on web and in-bound sales enquires using address lookup to determine whether the address is in coverage and what service is available at that address.
- target marketing campaigns for door-to-door sales and/or mailing campaigns

The following diagrams illustrates how drive test results are used to verify and tune the planning model and also shows the standard radio planning process used in Imagine.

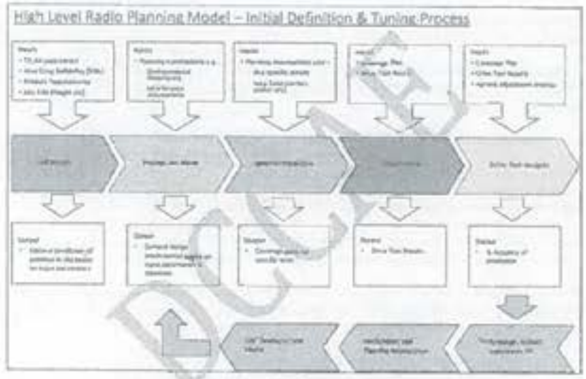


Figure 26. Imagine Radio Planning Model Tuning

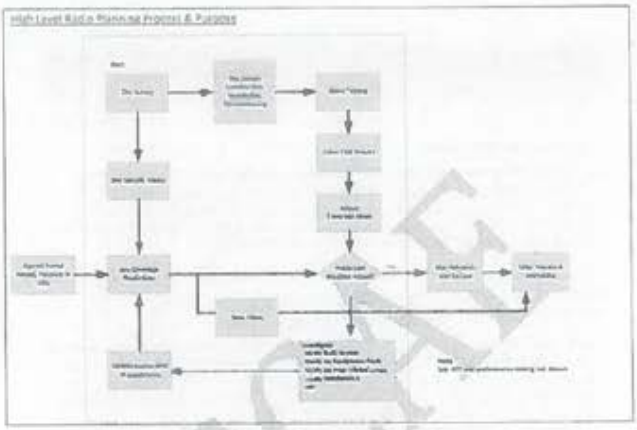


Figure 27. Imagine High Level Radio Planning Process

2.13.7.3 Radio Planning: Carriers and Frequency Reuse

Imagine deploys its TD-LTE Advanced network using multiple channels or carriers on each site in order to minimise inter-cell and inter site interference.

Following site surveys and site design reviews, the radio planning will be further revised using site specific azimuths

RF optimisation occurs after sites are built and drive test measurements taken on every sector of each site. Aside from identifying any design or operational problems the resulting measurements are compared to the predicted plots to verify the accuracy of the predictions and to identify any unexpected interference, which will be dealt with by altering the site design or applying other mitigation techniques

2.13.7.4 Radio Network Optimisation

On an ongoing basis there is a continuous process of network optimisation to take account of the dynamic nature of the network as new sites are introduced into the live network of existing sites.

Optimisation takes account of operational measurements from the live network to dynamically review the radio plans and identify and execute any required actions to address issues and/or improve overall performance.

Optimisation requires inputs from the network management systems as well as drive test measurements and other field measurements such as spectrum analysis. Changes that may result from network optimisation may include changes to the frequency plan, changes to site design, changes to future planned sites etc. Once actions are carried out further measurements are made to verify the results and make further changes iteratively if required until the network is fully optimised.

2.13.7.5 Site Design

Site design takes place during and subsequent to site survey. Site design can play a significant part in reducing interference. For example:-

- antenna locations can be chosen to shield the antenna from transmissions from adjacent sites
- antenna tilts and azimuths can be chosen to minimise interference to adjacent sites

2.13.7.6 LTE Interference Management Capabilities

LTE Advanced standards (releases 10 and 11) incorporate several network and UE based interference management techniques to help to manage interference. Examples of such techniques are:

- **Within the RAN**.- Inter-cell interference coordination (ICIC), eICIC (enhanced inter-cell interference coordination) and CoMP (coordinated multipoint transmission and reception). In particular eICIC and CoMP improve performance at the cell edge. Single user and multi user beamforming also reduce interference and improve performance at the cell edge.
- **Coordinating between RAN and UE**: multiple-input multiple-output (MIMO) enhancements, including multiuser MIMO (MU-MIMO) and single user MIMO (SU-MIMO).
- **Within the UE**: maximal ratio combining (MRC), interference rejection combining (IRC), and interference cancellation (IC) with receiver beamforming (BF) that take into account network conditions

The above features are deployed in Imagines TD-LTE Advanced to manage interference

2.13.7.7 Network Management

A vital part of managing interference on an ongoing basis is the ability to monitor the network to detect interference, having the necessary tools to investigate the source and the operational processes to implement any changes necessary to eliminate or reduce interference.

2.13.7.8 Monitoring the Network

Primary monitoring of the network will be carried out using the Huawei U2000 Unified Network Management System which is designed to efficiently and uniformly manage transport, access, and IP equipment at both the network element (NE) layer and the network layer.

The U2000 provides unified management and visual O&M through collection, correlation, display, and analysis of key performance indicators (KPIs) in quasi-real time.

While there are many hundreds of KPI metrics that can be measured and reported, specifically in relation to the management of interference some of the key metrics available are:

- Average RSSI
- Average SINR
- UL CSI (Channel State Information)
- CQI
- RSRP (Reference Signal Received Quality)
- RSRQ (Reference Signal Received Quality

Through the constant monitoring and analysis of fault alarms and RF metrics as above problems can quickly be identified and troubleshooting performed. Once basic faults are eliminated more in depth analysis of the RF conditions is performed and may be combined with field testing and spectrum analysis and an agreed course of action agreed with Radio Planning Engineers to resolve any interference issues identified.

2.13.7.9 Network Analytics

The Huawei U2000 Network Management System is used to configure and manage the IP core and eRAN equipment. It is also used to collect signalling traces to monitor end-to-end performance for all network elements. System reports are generated by the Huawei PRS (Performance Reporting System), which provides monitoring and visualization of key performance indicators and network faults.

In addition to the U2000 and PRS, network performance data is also extracted and loaded into an internally developed custom-designed analytics platform. Data is stored in a MySQL database and analysed using R, which is arguably the most commonly used analytics and data visualisation language. The Rstudio Shiny package is used to deliver interactive web applications for automated network reports, performance management, GIS, KPI analysis and customer support. This system provides a responsive and flexible platform for developing applications and reports for managing the service as the technology and internal business processes evolve.

Separately the UEs are monitored using data from an ACS (Access Control System) and the CDR (Call Data Records) to obtain a detailed history of radio performance and data throughputs. In conjunction with the U2000 and PRS, a comprehensive end-to-end view of the services from UE to EPC - as experienced by the customer - is used to proactively identify radio interference, capacity or throughput issues and to manage network outages and network optimization activities.

A1.2b8 Any other relevant information that could assist the Department in assessing the concrete nature of the technical plan

2.13.8 Additional Information

The technical plan is based on proven TD-LTE Advanced technology that has been extensively tested and proven not only in Imagine's own trials but by hundreds of operators worldwide - according to GSA (www.gsa.com) 644 operators are investing in LTE across 181 countries. This comprises 607 firm network deployment commitments in 176 countries (of which 393 networks have launched), and 39 pre-commitments trials in a further 5 countries.

Not only does this provide the benefits and economies of scale for the technology itself but also ensures the widespread availability of the necessary eco system of tools, methodologies and systems to support the planning, deployment and operation of the system.

Imagine's technical plan is based on models and parameters that have been developed and tuned to the specific fixed wireless deployment proposed by Imagine after extensive engagement with radio Engineers and planners from Huawei's research and product teams. Furthermore the link budget and coverage predictions have been verified through the use of drive tests and field measurements to ensure the validity and accuracy of the predictions.

TD-LTE solution proposed by Imagine will provide the capability to deliver high speed broadband services 30Mbps downlink and up to 150Mbps over a coverage range of 6.5km using outdoor CPE.

The performance of the solution proposed by Huawei has been demonstrated and comprehensively tested in Imagine's network.

Drive testing has validated the results predicted by the detailed RF studies performed which addressed the expected propagation characteristics associated with use of 3.6GHz spectrum for both indoor and outdoor CPE.

These tests have shown that the solution meets the specific performance assumptions and coverage objectives expected of 3.6GHz TD-LTE network in a fixed wireless broadband configuration.

Imagine have demonstrated that based on the geographic rollout of sites and the spectrum available to Imagine it will be possible to support a deployment of 3 sector sites with 2x20MHz per sector with minimal reuse of channels and therefore maximize the radio performance of the sites.

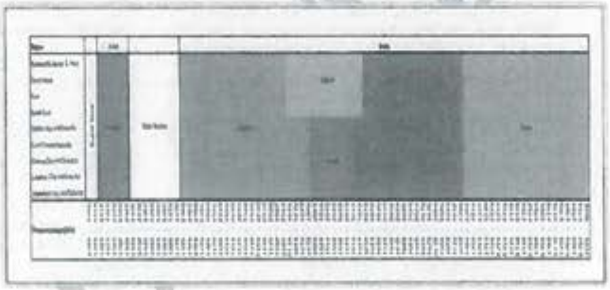
All elements of the end to end solution adhere to the relevant industry standards widely deployed by operators around the world. As a carrier grade solution the Imagine network will therefore have the levels of availability and reliability associated with solutions implemented by Tier1 carriers globally.

The backhaul solution proposed by Imagine based on microwave links and a fibre connection will provide a resilient, uncontended carrier grade backhaul network with the ability to increase capacity as required.

In June 2018 to further validate Imagine's technical plan Imagine engaged Wireless 20/20 an independent market research and consulting company focused solely on the emerging broadband wireless market to carry out a comprehensive review of Imagine's technical plan underpinning the assumptions used in the business plan. Wireless 20/20 gave a positive endorsement of Imagine's technical plan. A full copy of their final report is attached as Appendix 5 Imagine Technical Review Summary Report Final Wireless 2020.pdf

2.13.8.1 Spectrum

In 2017 ComReg held a multiband auction for the allocation of 3.6GHz spectrum[47] as a result of which Imagine secured an allocation of 60MHz contiguous spectrum in all rural regions in the range from 3560MHz to 3620MHz until 2031. The spectrum is technology neutral and highly suited for both LTE-A and 5G deployment.



The 3.6GHz band has been identified as the pioneer sub 6GHz band for 5G and already has a strong Eco system for dual mode LTE-A plus 5G NR deployments in Non Standalone mode and according to 3GPP, FWA is the first use case for 5G that will be commercially implemented.

[47] Results of the 3.6 GHz Band Spectrum Award Information Notice Reference:ComReg 17/38, 22May 2017

The RAN hardware that Imagine has deployed in the TD-LTE Advanced Pro network (Huawei 5900 eNodeB's) is 5G ready and can run 3GPP Release 15 compliant 5G NR with a simple software upgrade. The core that Imagine runs is also 5G ready and can operate as a 3GPP Release 15 compliant 5G NSA core.

The Eco system for CPE is also advancing fast and Imagine will be trialling 5G NR single mode and dual mode (with LTE-A) by the end of 2019. Product specs for dual mode CPE are included in the appendices

2.13.8.2 Proposed Multi Band Auction

Ireland is set for a significant multi-band auction in 2020[48] (timing is subject to confirmation by ComReg) that will release a lot of FDD and TDD spectrum nationally including the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz Bands. This spectrum will all be capable of running 5G NR and all can be used in conjunction with Imagines current spectrum holding. Imagine will be active in the auction.

XXXXXX

The current status of this auction is that it is at the final consultation stage with more details expected in the October timeframe. At this stage it is too commercially sensitive to give any more information on Imagines plans due to the nature of the auction.

2.13.8.3 Imagine as a case study

Imagine is seen by LTA-A and 5GR vendors and other operators (Mobile and FWA) alike as a reference model for FWA implementation and is referenced as a case study by vendors globally. Huawei often refer to the FWA implementation of Imagine's network at international conferences.

Many regulators have also consulted with Imagine on its FWA implementation and Imagine have been pleased to host both the Malaysian and UK regulators for workshops at its offices in Sandyford. Most recently and subsequent to a local workshop Ofcom invited Imagine to do its monthly lunchtime briefing to a wider OFCOM audience at its offices in London in July 2019.

Imagine have also been pleased to host operators from Italy, Canada, Norway, Paraguay, Brazil and Belgium who have all visited Ireland for a deep dive on the Imagine FWA deployment. Other operators from Turkey, Estonia and Austria have also been in frequent contact to glean inslides into how Imagine deploy FWA.

Imagine are represented frequently at international conferences globally (Asia, US, and Europe) and are regular key note speakers at the World Broadband forum in both North America and Europe and the LTE World Summit and have currently been shortlisted for "innovator of the year"

[48] ComReg 19/59R, Proposed Multi Band Spectrum Award, Including the 700 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz Bands

by the World Broadband forum with the result known in October 2019 at their flag ship conference in Amsterdam.

Imagine are one of the first members of the GTI TDD global initiative, spearheaded by Vodafone, Softbank, China Mobile and Reliance. At this global forum Imagine is active in influencing standards and de facto features and form factors of equipment. It also has early access to specifications and industry prototypes. Imagine also attends key workshops run by the EEC that set and influence standards deployed in Ireland through EU directives.

2.13.8.4 Vendor trials.

Imagine has chosen Huawei as its main vendor for core and Ran and enjoys a global strategic partnership with them. Imagine gets direct access tio Huaei R&D and early access to software and hardare SKU's. In addition Imagine is also trialling LTE-A and 5G with other vendors like Nokia and Ericsson as a vendor diferesification excercise. Imagine is also in advanced stages of negotiation with other non-Chinese vendors on a new 5G NR Standalone core based on COTS hardware as well as a replacement for the existing LTE-A core should it need it.

2.13.8.5 Other wireless and wired solutions

Imagine see LTE-A Macro RAN as being only part of the solution to reach customers. Though it reaches the vast majority of customers Imagine have at its disposal a selection of other solutions based on licensed and no licenced spectrum. It has for example done extensive trials with Dnesair and Acceleram small cell solutions and is looking to implement innovative Cambium based solutions for those hard to reach customers that traditionally have been ignored by Macro based RAN solutions.

For many years Imagine have been fully connected to Open Eir and resell its copper and fibre narrow and broadband products up to and including FTTP. As a full ISP Imagine has all the capabilities to leverage the Open Eir network and other wholesale suppliers such as Siro and national broadband Ireland should it have an offering.

2.13.8.6 Imagine Capability and Resourcing

2.13.8.6.1 General Capability

As an established operator with over 12 years of experience in rollout and operation of fixed wireless networks, Imagine has the full capability to build operate and maintain the network and service our customer's needs.

Currently, we have 254 permanent staff in the organisation and we are a fully self-contained communications company with resources spanning the complete range of activities from Network Design, Build, Operate, Manage and Maintain to complete customer service and care and the full complement of support services needed to run the company. Our internal resources, while growing steadily, are complemented by external partners who provide us with additional temporary resources during periods of intense activity as well as fully outsourced services for selected activities.

The company project manages the entirety of the roll-out and contracts to venders or to third party suppliers' certain activities such as site planning, drive-testing of sites, site testing and acceptance and ongoing optimisation of the network.

All Imagine Engineering and Field staff as well as any sub-contractor staff are fully trained and vendor certified in the planning and deployment of LTE/5G and associated IP and backhaul equipment.

This is overseen by a number of highly experienced senior Engineering and project management staff with experience in multiple mobile and broadband network deployments in Ireland and internationally to oversee the evolution of the network.

Further information outlining in more detail some of the organisational capabilities, partnerships management approaches and risk management issues are laid out in this document.

2.13.8.6.2 Overall Deployment Strategy

Imagines current plan is to continue to expand our existing network coverage evolving toward a coverage footprint indicated in our nominal XXX sites plan.

We will continue to assess further areas where the business case is met and where we might roll out additional sites beyond this current nominal plan. This process will be further assisted and influenced by current discussions with other retail and wholesale operators. Discussions, including extending and "in-filling" coverage in areas where other NGA networks are being deployed will also inform our planned infrastructure deployment. The outcome of these discussions could lead to a faster and more extensive rollout of the Imagine infrastructure and underpin further investment.

As this process evolves, we will identify those areas where we intend to deploy infrastructure and will inform the department regularly of new areas which are now in coverage so they can be taken into account in the ongoing management of the mapping process. This process will be further assisted and influenced by current discussions with other retail and wholesale operators. Discussions including extending and "in filling" coverage in areas where other NGA networks are being deployed will also inform our actual infrastructure deployment. The outcome of these discussions could lead to a faster and more extensive rollout of the Imagine infrastructure and underpin further investment.

2.13.8.6.3 Further Network Rollout

Imagine recommenced rolling further base stations in the network out at a rate of c. 15 sites per month from early 2019 and a total of 172 are now live.

The rate of rollout will be determined inter alia by demand and the rate of service uptake. While our current plan forecasts new network build at a rate of XX new sites per month it can be expected that this may under certain circumstances increase to a rate of c. XX sites per month.

2.13.8.7 Network Roll-Out Programme Management

2.13.8.7.1 PMI Framework

The LTE roll-out project is managed by Imagine and delivered by internal Imagine staff complemented by the use of carefully selected partners, vendors and service providers. Imagine is following the Project Management Framework from the Project Management Institute (PMI) to ensure ongoing management of the project, on time, within budget and conforming to high standards of performance and quality.

2.13.8.7.2 Project Workflow Tool

Imagine has established a Project Management Office (PMO) specifically to manage network build. The project manager and key staff within the PMO are Imagine staff, they are qualified under PMI and highly experienced in the roll out of national networks. We have developed a bespoke project management / workflow tool (High Site Manager) to ensure the various work elements are co-ordinated and all issues impacting the smooth flow of the project are highlighted for the PMO to take necessary action. All vendors and service providers have a qualified PM as part of the team who will report to the Imagine PM and provide all of the necessary ongoing tracking and control elements defined under the PMI framework. The vendors and service providers have a direct interface to the Imagine workflow system to ensure all tasks are traced and any issues escalated

2.13.8.7.3 Network Roll Out Service Provider Selection

Imagine have conducted and extensive RFP process aimed at selecting service provider partners. The RFP covered the following:

- Site Acquisition services
- Site Design
- RF & TXN Design
- Site Construction & Rigging
- Equipment Installation & Commissioning
- Testing & Optimisation
- Logistics support

This process resulted in the selection of preferred partners to streamline processes and ensure uniformity of project management and communications.

There are a number of external partners currently providing services to us across a range of areas.

1. Site Design
    - Imagine have contracted the services of a leading site design company to provide surveys, MSV's, DD's, Drawings and structural analysis. This design resource will also act as our PSDP
2. RF Design
    - Imagine have onboarded two partners to complement our in-house radio planning resources.

3. TX Design
    - Under the management of our internal transmission manager, we have engaged transmission planning services which also includes management of activities including equipment staging and configuration
4. Site Build
    - Three main site-roll-out contractors have been appointed. Each of these provide site build services including construction, installation and commissioning.

The Roll Out contractors provide logistics for steelwork, cables and construction consumables. Imagine's logistics partner supports the distribution of other equipment including CPE.

2.13.8.7.4 Site Provider Selection

For the purpose of site selection, roll-out planning and risk management in our site selection we tend to choose the best site from a technical point of view which has least risk associated with it. In general, we favour deployment of our network on sites operated by the various MSA operators in the market all of whom we have agreements and long-standing relationships with. This ensures we have ready, predictable access to thousands of existing sites all across the country

2.11.8.8 LTE Project Risk Management

The table below illustrates the various roll out risks, the probability of occurrence, their potential impact and a summary of the mitigation actions normally taken. The details are elaborated in notes (i) to (x) in the next pages that follow.

[illegible]	[illegible]	[illegible]	[illegible]
i. node or site identification and selection. Risk of non-availability of selected site. Risk of site not being technically feasible or viable.	Low for the majority of sites Moderate for unproven sites (See note i)	Manageable	Early & accurate site selection. Select predictable sites where possible ie existing & MSA sites. Risk profile for each site category. Scheduling to allow time for problem sites Identification of alternative sites in each area
ii. node or site acquisition. Risk of site being reserved by other operators. Risk of site owner terms and conditions being unworkable. Risk of site provider ownership, title or lands change issues (ie [illegible] of single site owners).	Low for the majority of sites covered by MSA Moderate for sites requiring new agreement (see note ii)	Manageable	Leverage existing MSAs and site framework agreements. Maximise selection of unproblematic site network

[illegible]	[illegible]	[illegible]	[illegible]
iii. planning permission for site or node. Risk of planning permission refusal. Risk of §21 exemption not being available.	Low for Majority Moderate for sites requiring pp	Low	Maximise selection of existing sites or exempt sites. Schedule sites with Planning Permission to allow time for full process including appeal. Ensure planning applications are of high quality. Use development partners. Adhere to planning guidelines. Have alternative site.
iv. backhaul. Risk of fibre service provider failing to deliver. Risk of fibre delay. Risk of [illegible] in urban [illegible] areas [illegible]. Risk of microwave line of sight failure. Risk of non availability of microwave channel licence.	Low	Manageable	Leverage framework agreements with backhaul service providers. Minimum of 3 framework agreements available nationally. Minimum of 2 fibre service providers available to any one site group. Choose preferred fibre service provider with best available redundant service for each site group and identify alternative node with another service provider in same group. Plan alternative microwave path for each site. Plan microwave links for less congested bands (consult ComReg)
v. local protest. Risk of local objections impacting planning applications. Risk of local protest impeding access to sites.	Medium	Moderate	Minimise number of Greenfield developments. Advertise positives of broadband service availability. XXX relationship. XXX

[illegible]	[illegible]	[illegible]	[illegible]
vi. [illegible] Risk of reduced [illegible] of equipment [illegible] fibre [illegible]	Low	Low	Select vendor where fibre already available Use [illegible] in cases where fibre digs required Use of boring techniques where digs not possible
vii. vendor supply and lead times Delay in vendor equipment shipping Delay in availability of specialist services	Low	Medium	Lead times specified in supply contract requires a number of months supply of equipment stored in country in advance of order Use of detailed design phase to allow design issues requiring specialised services Plan and forecast equipment requirements Make use of equipment "float" Avoid custom site equipment solutions Second source for high volume equipment, CPE etc.
viii. [illegible] of stores (logistics) Risk of failure of logistics chain	Low	Moderate	[illegible] specialised logistics services
ix. power supply and connection to the electricity network	Low	Moderate	Select existing sites & HSAs. For greenfield sites select site where power is generally available and Schedule Greenfield sites to allow for power lead time

[illegible]	[illegible]	[illegible]	[illegible]
x. [illegible] customer [illegible]	Low	Low	Use Imagine customer contact centre to [illegible] communication with existing customers in case of migration. Simplify install process

2.13.8.9 Risk Analysis and Mitigation

These notes refer to i to x in the risk management table above.

2.13.8.9.1 i. node or site identification and selection

The Imagine team have extensive experience of network roll-out in Ireland and in other countries. We are fully aware of risk management and mitigation measures are built into the roll-out process.

An important element of our mitigation strategy is the early identification of proposed sites. This allows us to identify sites where the lead time is likely to be long and to schedule these later in the roll-out.

We have identified XXX sites as part of our nominal coverage plan. For every site included in our roll-out plan we have identified at least one alternative existing site or other available option.

2.13.8.9.2 ii Node or Site Acquisition

The risks listed above for site identification can also apply to the node or site acquisition stage. In addition new risks associated with site owner interaction may also arise, e.g. tower space being reserved for another operator, lack of sufficient title, lack of bank consent (where the bank have a charge over the property), owners with unreasonable rental expectations, owners / lawyers who want to impose unreasonable terms for liability, access restrictions etc.

The mitigation measures for these risks are similar to those for site identification. It is important to ensure that the majority of sites progress in a predictable manner. There will always be problem sites where problems have to be solved individually but these can be kept to a manageable level through the selection of existing sites or MSA sites where available. To date 70% of all sites selected are either sites where Imagine have an existing licence or sites covered by an agreement Imagine has in place with an MSA operator. Imagine has MSAs in place with ESBT, Vodafone, Three/O2, Meteor/Eircom, Towercom, RTE, CIE, Shared Access, ISM, Cignal, Hibernian Towers, WIG (Kielpa).

2.13.8.9.3 iii Planning Permission for Site or Node

As stated above the requirement for planning permission is minimised through the selection, where possible, of existing towers or structures where a section 31 exemption applies. Planning permission may occasionally be required in cases where the preferred candidate fails at site acquisition stage or where an exemption does not apply. In most of these cases we will work with either our preferred partners in this area (ESB or Shared Access) to ensure a high success rate in any planning applications required.

XXXX

In the case of the XXXX

Imagine have kept the number of planned greenfield developments to an absolute minimum. In these cases, we have selected sites which are in keeping with local planning guidelines and which minimise the visual impact. Imagine's site acquisition teamwork with the site acquisition contractor to ensure that any planning applications are to a high standard. These sites are scheduled later in the roll-out to

allow for requests for further information from the planners to be dealt with, for appeals to be processed where required and for further alternative sites to be identified if necessary

2.13.8.9.4 iv. backhaul

Imagine have considered the risk of a fibre service provider failing to deliver the required service, delivering late or failing to provide adequate quality of service or reliability. We have conducted an extensive RFP process which we issued to each of the wholesale service providers with a list of potential node sites and sought proposals to provide reliable backhaul service on each of these.

There is no one fibre provider who can provide a complete solution for all of our planned sites. Our approach therefore has been to put in place framework agreements with all of the main service providers (i.e.: eNet, ESBT, eir, Virgin and BT). This allows us to choose the best solution available for each of our fibre nodes and to have an alternative solution available for each fibre node in case of individual service provider issues.

This approach has worked well for the sites deployed to date. We have fibre PoPs currently operational all across our network and we have used all of the main fibre providers on multiple occasions. We have commercial terms, service delivery processes, performance KPIs and operational SLAs in place with all of these service providers and we are satisfied with overall performance and the quality of the service provided. We have network topology information from each service provider to allow us to identify optimal backhaul router with maximum redundancy. At our core network, we have multiple independent points of connection with each fibre service provider.

Regrettably, fibre connection is not always available particularly in the more remote areas of Regional Ireland. In this case we must complement our backhaul network with modern microwave links to the nearest fibre PoP to provide full fibre-like uncontended backhaul to the site. The link from individual sites to the fibre node is planned using the Pathloss tool which models the specific link path using terrain and clutter data. This gives a high degree of confidence regarding link availability and performance. Imagine have extensive experience in microwave link roll-out and we are aware of the risk that local LoS obstacles may be discovered at survey stage. Therefore, we always plan an alternative route permitting us to re-plan links within the available site lead time.

2.13.8.9.5 v. local protest

Protest has not been a significant issue with wireless broadband roll-out but we are aware of the need to manage this risk. Our team have engaged successfully in local consultation both on other projects and on Imagine's own programmes.

2.13.8.9.6 vi. wayleaves

The issue of wayleave refusal is a risk where the plan requires fibre digs. Imagine's plan is to use mainly existing fibre nodes for the backhaul network. There will be a small number of cases where short digs are required to connect our node site to the nearest fibre route. In these cases, if wayleave becomes a problem we have agreements with our service providers to make use of underground boring solutions

2.13.8.9.7 vii. vendor supply and lead times

Imagine have been working closely with our main equipment vendors (including Huawei) and other vendors and service providers to ensure that lead times and responsibilities are fully defined and agreed. These are contractually binding and significant stock is normally held in-country to permit roll out requirements to be met.

2.13.8.9.8 viii. location of stores (logistics)

Imagine do not use retail stores, this heading refers to risks associate with equipment stores and logistics. The main risk in this case is the failure of the logistics chain. The main mitigation measure is to use proven logistics partners with their facilities located locally in Ireland to avoid delays due to weather etc.

Our main equipment vendor, Huawei, has its main stores in Dublin. Imagine use XXX for warehousing and site equipment is pre-configured, tested and shipped from here to each site in time for I&C by the roll-out contractor.

Roll-out contractors manage the logistics for consumables, steelwork, cables etc. These have stores located in several locations across Ireland.

2.13.8.9.9 ix. power supply and connection to the electricity network

In the vast majority of cases Imagine use either existing Imagine sites with existing Imagine power installation or co-locate sites where power connections can be quickly provided by ESB via the mini pillar "Reg Farrell box". On non-MSA sites, power can be delivered to an Imagine meter point and our own power installation team connect this to our equipment.

The sites where power connection risks are highest are Greenfield sites. In the case of the XXX solution the power connection is part of the agreed development. These sites will be scheduled to allow sufficient time for this to be completed. In the case of the Greenfield developments at individual sites, we have chosen the sites so that they are close to an existing power distribution point.

2.13.8.9.10 x. managing customer communication

Imagine use our own customer contact centre to maintain contact with existing customers during installation

2.13.8.10 Network Roll-Out Resourcing

A diagram showing the organisational structure and principle members of the team that manage and implement the roll-out project is shown below.

XXXXXXXXXXXXXXXX

2.13.8.11 Partnerships and External Resources

Imagine have concluded technical and commercial discussions with each of its vendors and service provider partners and have already demonstrated a strong capability to execute a timely network deployment.

Construction contractor agreements are in place and operating nationally with

- Secto Services
- CRA
- Spectrum.

Our primary design partner and PSDP is 4Site.

A.I.E.P provide transmission services, equipment staging and ATP services to us across our network.

Equiendo and Aspire are our primary Radio Planning partners.

2.13.8.12 Equipment Vendors

Our primary equipment vendor is Huawei for all RAN, Core and our IP network equipment.

Our RAN antenna are provided by Alpha and Huawei and we use Aviat and Ceragon for microwave backhaul.

The LTE Core Network (EPC plus PCRF) as well as underlying IP Layer 2/3 infrastructure is already in place. As the rollout progresses and demand grows this will have capacity upgrades installed as the number of sites and customers increases.

All remaining equipment such as LTE eNodeB, microwave backhaul, LTE UE are ordered as required to support the rollout schedule. Equipment requirements are forecast and ordered on a rolling basis and a number of months stock of equipment is held in our warehousing facilities to ensure network deployment and operation proceeds smoothly.

As an established and experienced operator with over 12 years of experience in rollout and operation of fixed wireless networks Imagine has the full capability to build operate and maintain the proposed network. The company will project manage the implementation and will contract to either the main vendor or directly to third party suppliers elements of the rollout implementation and supplement internal capability to support site acquisition through to planning, drive testing of built sites, acceptance onto the live network and ongoing optimisation of the network during rollout.

All Imagine Engineering and Field staff as well as any sub-contractor staff are or will be fully trained and vendor certified in the planning and deployment of LTE and associated IP and backhaul equipment.

This is backed up by a number of highly experienced senior Engineering and project management staff with experience in multiple mobile and broadband network deployments in Ireland and internationally to oversee the network deployment.

3 List of Appendices and Attachments

Appendices

Appendix A1 Huawei 5613 RRU Hardware Description.pdf
Appendix A2 A2 Huawei 5614 RRU Hardware Description.pdf
Appendix B1 Aviat CTR 8540 Data Sheet.pdf
Appendix B2 Aviat WTM4000 Product Presentation.pdf
Appendix B3 Ceragon FibeAir IP-20C Brochure.pdf
Appendix B4 WTM 3300 Product Detailed Presentation.pdf
Appendix B5 Huawei 5G MW-Imagine.pdf
Appendix C1 GemTek Wireless CPE Roadmap.pdf
Appendix C2 GemTek Cat 12 Product Spec.pdf
Appendix C3 Nokia 5G indoor CPE.pdf
Appendix C4 ZmTel LTE Cat 12 Product Spec.pdf
Appendix C5 Zyxel Dual Mode LTE-A 5GKR.pdf
Appendix D1 Imagine Technical Review Summary Report Wireless 2020.pdf
Appendix E1 Imagine Sales and Provisioning Process.pdf
Appendix E2 Outdoor CPE Install Manual.pdf

Map Files

Q6 Coverage Data DL Outdoor UE Prediction ESRI Shapefiles and eircodefiles - Live
Q6 Coverage Data DL Outdoor UE Prediction ESRI Shapefiles Planned

Files

Qu1 Per Sector Information & Pt n Antenna RPE.xlsx
Qu1 Pt. T ComReg Licence.pdf
Qu1 Per Site Information.xlsx
Qu6 Link Budgets.xls
Qu6 Atoll_3.4.0_Technical_Reference_Guide_Radio

4 Imagine's Response for Planned NGA Networks

E.2 Submissions with respect to planned NGA networks

Appendix A1 A description of the overall planned network architecture

A1.1.1. xxx

A1.1.2. *A description of the planned access network technology and the specification of the access equipment (including the relevant telecoms standards with which the equipment complies):*

A1.1.3. *A description of the planned backhaul network technology (national and metro) and the specification of the backhaul equipment (including the relevant telecoms standards with which the equipment complies).*

A1.1.4 A design for the planned national backhaul network including any traffic and capacity assumptions.

A1.1.5. The specification of all types of customer premises equipment which the operator plans to use in the planned network

A1.1.6. Coverage data, in the form of a Polygonised (vector) dataset with 'DOWNLOAD SPEED' attribute attached to the polygon for the planned network

A1.1.7. Any other relevant information that could assist the DCENR in assessing the concrete nature of submission on the planned network.

A1.2 Platform Specific Information

2b Planned Wireless Platform.

4.1.1 Planned Network Per Sector Information

A1.26.1. Please provide the following data in a spreadsheet on a per sector basis: in the Planned Network

a. sector ID

b. site ID

c. site coordinates and projection system

d. sector azimuth

e. access technology (including relevant standards)

f. carrier frequency

g. number of carriers

h. bandwidth per carrier (e.g. 20MHz)

i. structure status (greenfield or existing)

j. tower or structure height (above ground level)

k. transmit antenna height (reference base of antenna)

l. transmit power

m. antenna gain

n. antenna radiation pattern for vertical and horizontal radiation pattern (patterns should be provided in Excel or another computer readable file, loss in dB per degree)

o. MIMO scheme

p. number of transmit antennas

q. number of receive antennas

r. antenna tilt - electrical (reference positive degrees for down-tilt, negative number for up-tilt)

s. antenna tilt - mechanical (reference positive degrees for down-tilt, negative number for up-tilt) *c. Spectrum licence conditions including ComReg licence*

A1.2b 2. Please describe any planned use of carrier aggregation (CA) in the Planned Network

4.1.2 Planned Network Per Site Information

A1.2b.3. Please provide the following data in a spreadsheet on a per site basis for the planned network

f. number of sectors on installation

g. any planned evolution of the number of sectors over time

h. backhaul technology

i. backhaul capacity

j. site acquisition assumptions including information regarding site ownership and statement of probability of inclusion of site in rollout

A1.2b.4 Please provide the following data for each proposed mode of reception (e.g. indoor CPE, window-mounted CPE, external CPE) at the end user's premises for the planned network

a. mode of reception

b. service assurance

c.i. antenna height

c.ii. transmit power

c.iii. MIMO scheme

c.iv. number of transmit antennas

c.v. number of receive antennas

c.vi. antenna gain

A1.2b5 Please describe the following inputs to the coverage map for the planned network

a. propagation model and selected parameters

b. planning tool and associated configuration

c. digital terrain map (including resolution)

d. planning tool and associated configuration

e. clutter map (including resolution)

A1.2b6 Please provide a full Excel-based link budget for the downlink and uplink including all intermediary step calculations i.e. include all formula used to calculate all line items (e.g. line A + line B + line C = line D). The link budget should include at a minimum the following line items and their associated units for the planned network.

a. EIRP

b. system bandwidth

c. required signal-to-interference-plus-noise ratio (SINR)

d. receiver sensitivity

e. maximum allowable path loss

f. indoor penetration loss as applicable per clutter type or geographic type

g. cell edge probability

h. cell area probability

i. mean and standard deviation used to calculate slow fade margin

j. slow fade margin

k. mean propagation loss

l. formula showing conversion of link budget into design threshold on which coverage map is based

Section Qu6 Link Budget.xls

A1.2b7	*Please describe the planned approach to interference management in the access network making reference to carriers and frequency reuse plans for the planned network*

A1.2b8	*Any other relevant information that could assist the Department in assessing the concrete nature of the technical plan for the planned network*

E. Information Required if a submission is made

E.2 Submissions with respect to planned NGA networks

Appendix A2 Deployment Information

A2 T.1. xxx

NBP Mapping Response Document

Submission In Respect To Existing NGA Network

The following document outlines Ivertec Ltd.'s existing NGA Network. The document has been produced to ensure that under European State aid rules, the DCCAE fully maps all commercial NGA services.

ivertec

Company Information

ivertec

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W: www.ivertec.ie

Confidentiality

All information and data embodied in this tender document are strictly confidential and commercially sensitive, all information is supplied on the understanding that it will be held confidentially and not disclosed to third parties without the prior written consent of Ivertec Ltd.

Document

This document has been prepared by James Sugrue, Ivertec Ltd. The company commits to documenting it's NGA services as required by the DCCAE as published in DCCAE's documents, -

i. "NBP Conclusion of the Mapping Exercise for the Intervention Area Pre Deployment" dated 29th July 2019
ii. "Mapping Future High Speed Broadband Networks, Criteria for assessment of investment plans" dated October 2015

Date of Issue: 27/09/2019

Contents

1. COMPANY INFORMATION

Ivertec Broadband Key Statistics	Value
Number of years providing broadband services	13
Number of Employees	16
Number of Internet Service Subscribers	[redacted]
Number of NGA subscribers	[redacted]
Premises passed/covered with NGA service	23,247 (At a 7.5km Radius)
NGA Download Speeds	30 Mbps to 100 Mbps
NGA Upload Speeds	> 6 Mbps
Coverage Area	Kerry, Cork, Limerick, Clare
Number of Fiber enabled Hubs	[redacted]
Number of Tower Sites	[redacted]
Number of NGA enabled Tower Sites	[redacted]
NGA CAPEX investment 2018 to 2019	[redacted]

2. INTRODUCTION

Ivertec operates an NGA network utilising the latest Fixed Wireless Access technology from Cambium Technologies. Ivertec has selected Cambium Technology's 450medusa product range which include features such as smart beam forming, antenna arrays, Multi User MIMO, interference mitigation and throughput of over 900 Mbps per 90 degree sector in a 20 Mhz channel.

The network is underpinned with Next Generation Network (NGN) fibre hubs procured from OpenEir.

From the regional fibre hubs, licensed and unlicensed wireless links serve tower sites with data links ranging from 300Mb to 2Gb.

Ivertec offers NGA speed products including 30Mb, 50Mb and 100Mb.

Ivertec also offers a low-cost VoIP telephone service to both residential and business users. Customers can avail of unlimited calls to Irish landlines, Irish mobiles and most international landlines. This ensures customers can move away from older technologies such as copper DSL lines without fear of losing their landline telephone number or associated services e.g. Alarm systems.

The Ivertec network is managed and monitored to ensure high availability and low latency. Redundancy and failover are designed and built into the network infrastructure.

Customers avail of converged all-IP services including VoIP, teleconferencing, IPTV and streaming services such as RTE player and Netflix.

3. NETWORK

3.1 NETWORK ARCHITECTURE

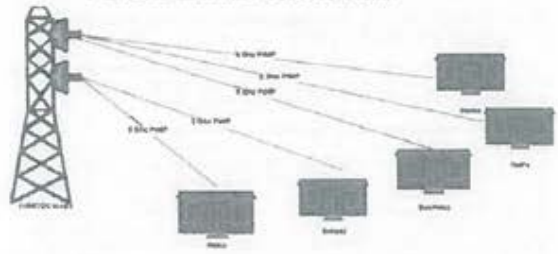
3.2 ACCESS NETWORK TECHNOLOGY

3.2.1 Access Network Overview

Our NGA service uses Fixed Wireless Access (FWA) technology using the ISM 5GHz & License Exempt 5.8GHz bands

Access Points/Base Stations are mounted on towers spread throughout the target market area. Customers are connected to a tower site using a CPE (Customer Premises Equipment) which consists of a radio unit with integrated antenna. The CPE is mounted on the exterior of the home/business and pointed towards the nearest tower site. The antenna is aligned at installation time to maximize the signal quality. The CPE is powered via Power Over Ethernet (POE) using Cat6 ethernet cable which is routed from the external CPE into the customers premises. An ethernet/LAN port is available on the POE unit for customers to connect their internal network or Wi-Fi Router

IVERTEC BROADAND - ACCESS NETWORK



3.2.2 Access Network Base Station Specification

Ivertec operates Cambium Networks 450medusa Access Points (Base Stations) on its towers to provide NGA compliant broadband speeds.

PMP 450m is an outdoor point-to-multipoint (PMP) AP incorporating cnMedusa technology. It has a seven-element adaptive dual-polarity array smart antenna and massive MU-MIMO capabilities. The antenna array is composed of fourteen chains, connected to seven vertical and seven horizontal antennas covering 90 degrees in the azimuth.

Through the combination of MIMO, spatial multiplexing through beamforming and highly efficient channel sounding, a massive MU-MIMO system is created.

Each PMP 450 customers premises equipment (CPE) operates in 2x2 MIMO mode. In the 5 GHz band the PMP 450m AP is capable of communicating with up to 7 CPEs simultaneously, supporting a total of up to 14 streams, making PMP 450m a 14x14 massive MU-MIMO system.

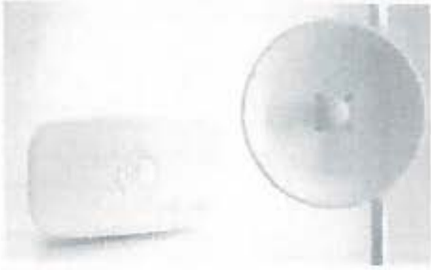
The primary advantage of PMP 450m versus traditional 2x2 MIMO based APs is that it multiplies the sector throughout. Using the channel state information each CPE reports through the sounding mechanism, PMP 450m creates groups of up to seven CPEs. CPEs are selected for one of these groups based on their azimuth spacing and amount of traffic, and their channel information is used to create up to seven spatially separated beams. Each beam points to one CPE in the group, and its nulls are aligned with the directions of the other CPEs in the group, limiting interference between CPEs. Groups are created every TDD cycle (frame) based on current traffic and the latest RF conditions. CPES within a group communicate with the PMP 450m AP simultaneously, then (in the next symbol or in the next frame) the PMP 450m creates a new group and performs simultaneous communication with those CPEs. In ideal conditions, PMP 450m is able to communicate with seven subscribers simultaneously. With cnMedusa, subscribers are unaware of the groups to which they belong. Consequently, there is no over the air overhead or latency associated with group management. Groups in the downlink and uplink directions are independently created. CPEs are selected to be part of a group in one direction only based on the traffic in that direction. A completely new group is then formed in the other direction. Communicating with multiple subscribers in the same channel at the same time provides a much higher sector capacity without requiring more wireless spectrum, resulting in a dramatic increase in spectral efficiency. For Ivertec, this means that a larger number of subscribers can be supported in the sector in the same spectrum, or that existing subscribers in the sector can experience higher average throughput.

The PMP 450m AP supports a sector capacity of more than 900 Mbps in a 20 MHz channel and more than 1.3 Gbps in a 40 MHz channel.

- Manufacturers Specification is listed in Appendix 1.

3.2.3 Access Network Customer Premises Equipment (CPE) Specification

Ivertec deploys Cambium Technologies 450b CPEs. The 450b are available in 2 platform sizes, a mid gain with 17db- 25 cm antenna and high gain with 24db 45cm dish antenna.



The Cambium 450b CPE has the following features; -

- Capable of up to 300 Mbps aggregate in a 40 MHz channel
- Gigabit Ethernet interface provides the maximum transfer rates to the device
- Channel Width 5 MHz, 10 MHz, 15 MHz, 20 MHz, 30 MHz, or 40 MHz
- Physical Layer 2x2 MIMO OFDM
- RX Modulation 256-QAM
- Ethernet Interface 100/1000BaseT, full duplex, rate auto negotiated, 802.3 compliant
- Protocols Used IPv4, IPv6, UDP, TCP/IP, ICMP, Telnet, SNMP, HTTP, FTP
- Ultimate Sensitivity -94 dBm
- ARQ
- GPS synchronisation with Base Station

- Manufacturers specification is listed in Appendix 2.

3.2.4 Access Network – Mast Site Routers

Depending on mast site configuration and throughput, a series of MikroTik routers are used to forward customers internet traffic over a Layer 2 / 3 redundant network. Ivertec's router model of choice is Mikrotik Cloud Core CCR1016-12G

The Cloud Core Router CCR1016-12G has the following features. -

- 16 core networking CPU
- 2 GB Ram
- 10/100/1000 Ethernet ports
- Redundant power supply
- Ports directly connected to CPU
- Up to 12 Gbps throughput with RouterOS queue/firewall configuration

- Manufacturers Specification is listed in Appendix 3

3.3 BACKHAUL NETWORK

3.3.1 National Backhaul

Ivertec's national backhaul is sourced from OpenEir. The national backhaul has 2 elements. -

1) A Wholesale Ethernet Interconnect Link (WEIL) product
2) Multiple Wholesale Symmetrical Ethernet Access (WESA) products

The Wholesale Ethernet Interconnect Link (WEIL) enables Ivertec to aggregate individual fibre connections (WESAs) at regional towns into a single point of handover at Ivertec's data center presence at InterXion, Dublin. Ivertec has procured a 10Gb capacity WEIL from OpenEir

3.3.2 Metro Backhaul

Ivertec employs a range of wireless point to point (PtP) technologies to connect it's fibre points of presence to its access towers.

For links requiring 1Gb or greater capacity we use licensed Ceragon links using 11Ghz, 13 Ghz, 18Ghz and 80 Ghz frequencies

- Manufacturers specification listed in Appendix 4

For short links requiring up to 1GB capacity we use licensed and unlicensed Racom equipment using 10Ghz, 17Ghz and 24Ghz frequencies

- Manufacturers specification listed in Appendix 5

All PtP wireless links are implemented with a fade margin to ensure 99.99% availability

All towers are served by diverse links from alternate fibre points of presence to guarantee high availability levels. See figure below showing a subset of Ivertec's network with multipath links to each tower.

All Metro backhaul links are monitored 24/7 by our Network Management System (NMS) for capacity and latency performance. Links that consistently breach 60% capacity invoke a procurement process to upgrade the link to ensure future bandwidth demands are met

3.3.3 Edge Network

We have an external edge capacity of 10Gb

3.4 NATIONAL BACKHAUL DESIGN

Openfw is responsible for the provision, repair and maintenance of the Wholesale Ethernet Interconnect Link (WEIL) and each of the Wholesale Ethernet Symmetrical Access (WESA) links under a Service Level Agreement.

Ivertec monitors the WEIL and WESA links usage patterns and provides forecasts to Openfw to ensure sufficient bandwidth capacity is planned and delivered.

Ivertec implements diverse links to its access towers so that failure of a link from one regional fibre point of presence will automatically fail over to an alternative link from another regional town. See Metro Backhaul Multipath above.

3.5 CUSTOMERS PREMISES EQUIPMENT

Ivertec deploys Cambium Technologies 450b CPES. Details are outlined in the Access Network in section 3.2.3 above.

- Manufacturers specification listed in Appendix 2.

3.6 OTHER INFORMATION

3.6.1 Quality Management System

Ivertec operates a quality management system based on the Information Technology Infrastructure Library (ITIL) framework. ITIL is a set of detailed practices for IT service management (ITSM) that focuses on aligning IT services with the needs of business.

4. DETAILED SECTOR INFORMATION

Please refer to the attached document "NGA Sector Technical Data" for detailed information on each Access Point in operation at our NGA capable base-stations. Please refer to the attached file "cnMedusa.pdf" for the radiation pattern of the 450m Access Points.

5. CARRIER AGGREGATION

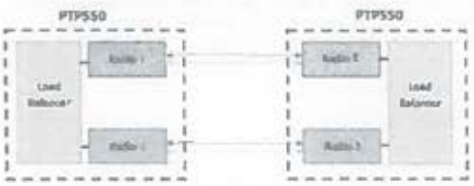
For smaller NGA capable base stations, Vortec employ a 5 Ghz Unlicensed PTP (Point to Point) radio link provided by Cambium Networks. The PTP550 utilizes Carrier aggregation to increase bandwidth, improve reliability and minimize the amount of spectrum required to operate in an unlicensed band. The PTP550 uses the same GPS Sync source as our 450m Access Points to prevent any interference on NGA capable sites.

5.1 LOAD BALANCING USING CHANNEL (CARRIER) AGGREGATION

PTP 550 provides up to 1.4 Gbps throughput with ARQ and asymmetric non-contiguous channel aggregation across the 5 GHz band.

PTP 550 utilizes two integrated radio interfaces which are "bonded" together to achieve 1.4 Gbps throughput (with two 80 MHz channels).

The load balancing mechanism works as follows.



With Channel Bonding enabled, the PTP 550 applies a load balancing algorithm to balance the traffic on a per traffic flow basis.

Initially, the load balancing algorithm identifies the following information within each traffic flow.

- Transport layer protocol – TCP or UDP
- Source IP address and source TCP / UDP port
- Destination IP address and destination TCP / UDP port

The algorithm then considers the configured channel bandwidth of each radio and the number of flows passing through each radio.

PTP 550 Channel Bandwidth Configuration		Load Balancing Ratio
Radio 1	Radio 2	Radio 1 Flows: Radio 2 Flows
20 MHz	20 MHz	1:1
20 MHz	40 MHz	1:2
20 MHz	80 MHz	1:4
40 MHz	20 MHz	2:1
40 MHz	40 MHz	1:1
40 MHz	80 MHz	1:2
80 MHz	20 MHz	4:1
80 MHz	40 MHz	2:1
80 MHz	80 MHz	1:1

If both radios are configured with the same channel bandwidth then the load balancing algorithm ensures that the number of flows on each radio interface is equal. If the radio interfaces are configured with different channel bandwidths, then the number of flows on each radio will be based on the ratio of the channel bandwidths in use by the radios.

6. SITE BACK-HAUL INFORMATION

Please refer to the attached document "NGA Site Back-Haul Capacity" for a detailed list of the hardware and maximum available capacity for each NGA capable Base Station.

7. CLIENT PREMISE EQUIPMENT IN DEPLOYMENT

Cambium Networks 450 platform increases performance with the addition of the 450b Subscriber Module

Key Features:

- Ultra wide band radios support the entire band, from 4.9 to 5.925 GHz
- Gigabit Ethernet interface provides the maximum transfer rates to the device
- New System on a Chip (SoC) enhances Packet Processing Power more than 4x that of the 450 SM. 50000 packets per second
- Capable of up to 300 Mbps aggregate in a 40 MHz channel

Two models currently deployed

- 450b Mid-Gain
  - Antenna Height: +4 Meters
  - IP55 Rated
  - Transmit Power: 17dbi
  - 2x2 MIMO OFDM
  - Antenna Gain: 27dbm
- 450b High-Gain
  - Antenna Height: +4 Meters
  - IP67 Rated
  - Transmit Power: 24dbi
  - 2x2 MIMO OFDM
  - Antenna Gain: 27dbm

- The manufacturers specification is attached in Appendix 2

8. COVERAGE MAP

8.1 IVERTEC'S COVERAGE AREA

Ivertec can provide speeds exceeding 30mbps to the following premises in both Kerry & Cork from our current NGA enabled base-stations. The images below highlight every property that is currently able to receive our existing NGA service with speeds of up to 100Mb.

he image above depicts our NGA coverage at a range of 7.5km from our nearest NGA enabled base-stations. For the purpose of this submission we have limited our coverage area to only 7.5km but can offer the same bandwidth requirements at distances greater than 15km. Please refer to the attached document "PMP 450 Capacity Planner R16.0.1" for an accurate calculation tool to compare the differences between subscribers connected to our NGA enabled base stations at varying distances. Please refer to Appendix 7 for detailed instructions on how to use the PMP 450 Capacity Planner.

Please refer to the attached document "Ivertec NGA Eircodes" for a full list of all properties covered by our NGA base-stations. These Eircode's and above maps are based upon a coverage map of 7.5km radius taking both the terrain and trees into account using the latest LIDAR data provided by wirelesscoverage.com. The image above was taken from one of our coverage maps. These coverage maps have been attached in several usable formats, including:

- IverTec-NGA-Coverage.cpg
- IverTec-NGA-Coverage.dbf
- IverTec-NGA-Coverage.kml
- IverTec-NGA-Coverage.prj
- IverTec-NGA-Coverage.qpj
- IverTec-NGA-Coverage.shp
- IverTec-NGA-Coverage.shx

8.2 LIDAR LOS TESTING AND METHODOLOGY

We have engaged WirelessCoverage.com to build a Digital surface model based on high quality LIDAR / DSM data. We have supplied Wirelesscoverage.com a list of Sites and height of sectors to produce a list of premises that would be covered with clear line of sight.

8.3 APPROACH ACCORDING TO WIRELESSCOVERAGE.COM

The approach used for this project was designed to be as comprehensive and detailed as possible, using the best quality data and modelling tools available.

Detailed data was prepared to perform this analysis comprising of: -

- The latest EIRCODE dataset, purchased in August 2019
- A Digital Surface Model (DSM) for the whole country from Bluesky International, who have the most contemporary dataset currently available. They hold data at 1m resolution, which was scaled to 2.5m resolution using a bilinear interpolation method. Where any gaps in their coverage were identified SRTM data was used and interpolated to avoid any hard edges in the height data. More information on the data is available in Appendix A
- Mast Site Data from our ISP
- WISDM Wireless Modelling system, which performs detailed line of sight tests between all properties and all tower sites. Further details on the WISDM Line of Sight Engine are included in Appendix C

8.4 METHOD ACCORDING TO WIRELESSCOVERAGE.COM

Data from our ISP was collected in September 2019 and imported into WISDM. Sites were classified as Standard or NGA and we also gathered details on future planned sites. The distinction between Standard and NGA sites is based upon the quality and style of equipment currently installed at these sites, along with the backhaul feeds. Those classified as NGA are capable of connecting premises at NGA speeds of 30Mbps download.

Using WISDM, wirelesscoverage ran several coverage passes to all EIRCODE centroids: -

1. All Sites from our ISP at NGA
2. All Sites from our ISP at non NGA

Within each pass, WISDM takes each Site within the test and performs a Wireless Line of Sight test to each property within a given radius. It is important to note that a Wireless Line of Sight Test differs from an optical test, as it takes into account the Fresnel 1 Zone around the direct (optical) path. This is a more robust means of determining line of sight. In this exercise, we

discounted all properties that had more than 15% Fresnel 1 incursion, and therefore does not include properties with Near Line of Sight, which in many cases could successfully be connected. Where a property does have Wireless Line of Sight, it is excluded from further tests within that pass, in order to avoid double-counting properties.

We then performed analysis of the coverage list from each operator with NGA coverage to identify those properties that could receive NGA service from more than one operator.

8.5 NGA ASSUMPTIONS

Due the variety of equipment mounted at each site for different operators, we have taken a cautious approach to whether a site is capable of delivering NGA speeds. As such, we have taken a worst-case assumption of the type of equipment used for access points or base stations.

We considered the signal level that would be required to get the full modulation rates on the most basic of commonly installed fixed wireless equipment, as well as a significant fade margin. Assuming a nominal operating frequency of 5.7 GHz with regulatory compliant power output (EIRP) from a base station of 33 dBm (2 Watts) and a client receiver with 30cm diameter antenna providing 22 dB gain, the receive signal level (RSL) with clear line of sight would be -70.1 dBm at 7.5 km. Using a basic radio system, such as the Ubiquiti Rocket M5 access points and associated M5 customer receiver such as Nanobeam M5 system on a 20 MHz channel, and an assumed noise floor of 90 dBm, a client would connect at MCS13, providing a physical interface rate of 104 Mbps and a typical throughput rate of approximately 54 Mbps, which is safely above the NGA threshold and leaves a considerable fade margin assuming the access point is not over-subscribed.

8.6 ASSUMPTIONS AND CONSTRAINTS

As with all modelling approaches to wireless coverage, there are factors which could over-state or under-state coverage. Here is a summary of the key factors as they relate to this project: -

8.6.1 Over-statement factors

- A small percentage of the national map data used was derived from low-resolution (10 to 30m) data, which could mean that obstructions to the wireless signal path calculations were missed. We estimate an error rate of <2% over-statement.
- Since the high-resolution data was produced between 2015 and 2017, it is likely that additional tree growth and new building works will have occurred in the intervening period which means

that some wireless paths are now blocked. We estimate a resultant over-statement of <1% from this.

- Whilst it may be possible to receive a high-quality signal at a given property, it is possible that there is no suitable location on the property to mount a receiver due to the construction or location of the property. For example, waterside properties or those with unusual construction such as all-glass exterior can be very challenging.

8.6.2 Under-statement factors:

- In this exercise, we performed single-point line of sight tests to each EIRCODE property. In reality, it is possible that the Wireless Line-of-Sight to that one point may be obscured and therefore reported as no coverage, but if a receiver was mounted at a different point on the property, a connection could be established. We estimate an under-statement of 3-4% from this factor.
- We used a watershed method for wireless line of sight calculation which allows for little or no Near Line of Sight connections. Many modern radio systems using the diversity associated with MIMO transmission allows for high quality connections to be established in Near Line of Sight operation and these have not been incorporated in the model. This is estimated to have an effect of <10%, but it is highly dependent on the technology used by the operator.
- We have assumed that 30cm dishes are used at the customer property to achieve an appropriate signal level. It is common practice to install 40cm dishes or larger, which have higher gain and therefore can receive a good signal at a longer range. Using larger dishes could increase the coverage from each access point substantially.

8.6.3 Multi Dwelling Units (MDUs):

- WISDM currently has a design constraint which means that the premises counted in coverage checks shows the same EIRCODE for all properties that have the same physical location (i.e. Multi-dwelling units). This means that the coverage lists appear to have duplications. It was not possible to resolve this issue in the time available to complete the project.

8.7 LIDAR DSM DATA SOURCE COVERAGE ACCORDING TO WIRELESSCOVERAGE.COM

Figure 1: Map of 1m DSM Data from Bluesky International, collected between 2015 and 2017

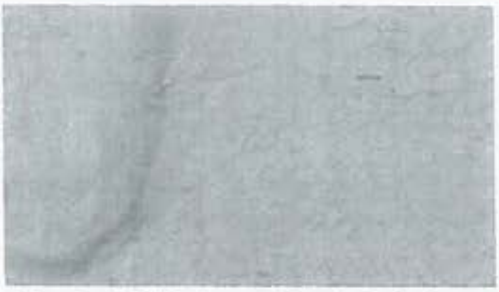


Figure 2. Example render of DSM Data showing trees, buildings and other surface features

8.8 WISDM OVERVIEW

WISDM comprises of several components and processes to complete the overall solution. As the heart of the system is a very high-performance wireless Line of Sight (LoS) calculation engine. The LoS engine can calculate over 150 million wireless line of sight tests per second and can use a wide variety of terrain and surface obstruction data sets at any resolution.

8.9 HIGHLIGHTS

Wireless coverage WISDM comprises of a family of ultra high performance wireless planning systems developed by Soundless Networks Ltd.

WISDM WISP Edition is an interactive planning and design system built to facilitate the creation of scalable, robust and performant fixed wireless networks for Wireless IPSs. It enables the rapid creation of 'ideal' wireless networks over very large areas of thousands of square kilometers. It is well suited to rural expanses as well as mixed and urban environments too. Once an ideal network has been designed, the network can be fine tuned to consider build constraints and resiliency in real time.

WISDM 5G Edition (not covered here) provides a range of capabilities that are optimized for the planning and design of high performance wide area 5G networks. As WISDM is built to operate with high precision for frequencies up to over 100GHz, it is extremely well suited to Millimeter Wave deployments and high-density network design.

WISDM can also be used to analyses the coverage of an existing wireless network and perform 'what-if' tests to plan ad-hoc extensions to a network to verify potential coverage and backhaul.

Using WISDM, a predictable coverage model can be prepared in hours and detailed coverage of individual properties can be predicted with an extremely high level of accuracy. Site planning and acquisition is accelerated by use of the interactive planning tools, allowing rapid decisions about mast location to be made with instant coverage impact reporting.

8.10 LOS ENGINE

The WISDM LoS Engine is a custom-built high-performance wireless propagation calculator developed in Native C and CUDA. It is a multi-threaded application, currently running on a server farm at Wireless Coverage and is accessed via a C API. This currently operates with 5,000 GPU cores to achieve around 500 million line of sight transactions per second when creating viewsheds but can be scaled further as required.

The LoS Engine has forward and reverse lookup features that are optimized to illustrate coverage from a single point, or supply from multiple points. These features are so fast that they can be operated in real time and take into consideration precision line of sight calculations as well as frequency, loss (according to ITU recommendations) and 3d antenna patterns for both transmitter and receiver.

8.11 LINE OF SIGHT ENGINE TECHNICAL OVERVIEW

Specific variants of the Line of Sight Engine exist for Forward (Viewshed) and Reverse (Best AP) coverage over large areas at any sample resolution. Below is an example of point to point request, but this is replicated over larger areas for the Forward and Reverse viewshed methods, where a map grid is also specified. The application uses the following parameters as input to each request via an API:-

- Site A Lat/Lon
- Site A transmitter height above ground in meters
- Site A transmitter power dBm
- Site A transmitter antenna gain in dBi
- Transmit frequency in MHz
- Scanning resolution in meters
- Site B Lat/Lon
- Site B receiver height above ground in meters
- Site B receiver antenna gain in dBi
- Percentage of first Fresnel required for partial line of sight in %
- Percentage of first Fresnel required for no line of sight in %
- Antenna Model (used for beam pattern)

The response for each request includes the following:

- Link distance in meters
- Pass Status (Full Line of Sight, Partial Line of Sight or No Line of Sight)
- Predicted Receive Signal Strength (RSL) in dBm, assuming full Line of Sight
- Azimuth from Site A in degrees from true North
- Azimuth from Site B in degrees from true North
- Elevation from Site A in degrees
- Elevation from Site B in degrees
- Antenna Model (used for beam pattern)
- Optional link ground profile .PNG image file, illustrating the link profile and first Fresnel shape

Figure 2 Sample LoS Engine Input and Output

Figure 3 Sample LoS Ground Profile Image

8.12 MATHEMATICAL AND TECHNICAL LOS MODEL

A DSM elevation raster (of chosen resolution) of the target area is loaded into memory (~1105 GeoTIFF file equates to around 6,500 sq. miles. Imported with GDAL C library) into a flat array of 32 bit floats in a geodetic WGS84 latitude / longitude grid. This stays loaded in memory for every call of the function. A function exists to return the height in meters above sea level for any given latitude + longitude using bilinear interpolation in the grid. This allows for very fast indexed surface elevation lookups for any point in target area with high resolution.

64-bit integers are used for indexing coordinates and x87 80-bit floating-point numbers are used in coordinate calculations.

2 functions exist, geodetic_to_ecef and ecef_to_geodetic for converting between ellipsoidal WGS84 coordinates and cartesian ECEF coordinates.

geodetic_to_ecef is an implementation of Section 10.2.1 from B. Hofmann Wellenhof, H. Lichtenegger, J. Collins' GPS - theory and practice as follows:

$$N(\varphi) = \frac{a^2}{\sqrt{a^2\cos^2\varphi + b^2\sin^2\varphi}}$$
$$X = (N(\varphi) + h)\cos\varphi\cos\lambda$$
$$Y = (N(\varphi) + h)\cos\varphi\sin\lambda$$
$$Z = \left(\frac{b^2}{a^2}N(\varphi) + h\right)\sin\varphi$$

where h is height in meters, φ is latitude, λ is longitude, a is the Earth's equatorial radius in meters, b is the Earth's polar radius in meters, (X,Y,Z) is the cartesian ECEF coordinate.

ecef_to_geodetic is an implementation of J. Zhu's "Exact conversion of earth-centered, earth-fixed coordinates to geodetic coordinates" formula as follows:

$$[illegible]$$

where (X,Y,Z) is the cartesian ECEF coordinate, h is height in meters, φ is latitude; λ is longitude; a is the Earth's equatorial radius in meters; b is the Earth's polar radius in meters; e is the Earth's first orbital eccentricity; e' is the Earth's second orbital eccentricity.

The 3D cartesian coordinates of each radio is found by sampling the ground elevation of the two points and adding on the mast heights, and then using geodetic_to_ecef. The accurate straight line distance between the two radios can be found by using

The straight line between each (x,y,z) position is divided into linear interval points at the desired scan resolution. These points are then converted back into (latitude, longitude, height) WGS84 coordinates using ecef_to_geodetic.

The surface elevation at each of these WGS84 points is sampled and the resulting coordinates + height are converted back into ECEF coordinates.

The resulting 3D ECEF coordinates should mostly be in a flat plane and represent the elevation profile of the terrain under the line between the two radios, including the curvature of the Earth. These coordinates are transformed into flat 2D coordinates by rotating them through 3 axes using transformation matrices. Once they are rotated to a flat plane against the axes, the resulting Z coordinate will be approximately zero and is discarded to produce 2D coordinates.

A 2D straight line is plotted between the two radio coordinates and perpendicular to this line, points are calculated and plotted for the first Fresnel zone and given threshold percentages within the Fresnel zone. The radius r in meters of the first Fresnel zone is calculated using:

$$[illegible]$$

where c is the speed of light in ms−1, d is the distance along the line in meters; t is the total distance between the two radios; f is the frequency in megahertz.

Intersection with the surface profile polygon and the plotted Fresnel threshold points is tested using binary search + linear interpolation.

The basic RSL s in decibels is calculated using:

$$[illegible]$$

where l is the free-space path loss in decibels, d is the distance in meters, f is the frequency in megahertz; p is the power of the transmitter, g1 and g2 are the antenna gains of each antenna; t is the transmission line loss, assumed to be 1 decibel. Further ITU-R attenuation models are applied for appropriate bands, but not described in this document.

- WISDM whitepaper attached in Appendix 6

9. APPROACH TO INTERFERENCE MANAGEMENT

9.1 PMP 450M OVERVIEW

PMP 450m is an outdoor point-to-multipoint (PMP) AP incorporating cnMedusa technology. In the 5 GHz band, it has a seven-element adaptive dual-polarity array smart antenna and massive MU-MIMO capabilities. The antenna array is composed of fourteen chains, connected to seven vertical and seven horizontal antennas, covering 90 degrees in the azimuth.

- Each PMP 450 SM operates in 2x2 MIMO mode. In the 5 GHz band, the PMP 450m AP is capable of communicating with up to 7 subscribers simultaneously, supporting a total of up to 14 streams, making PMP 450m a 14x14 massive MU-MIMO system.
- The PMP 450m platform offers great flexibility sustaining opportunities for future enhancements. It has quad core processors, powerful FPGA with 20 Gbps interface to

processors, 14 flexible RF transceivers, and 2x5 Gbps fiber external interface direct to the FPGA

- Resources are allocated by the access point to different subscribers by electrically tuning the antenna elements to different phases. This technique is known as beamforming, as the antennas used to communicate to a particular subscriber are tuned such that their radio beam is targeted (or "formed") to overlap a specific subscriber.
- The goal of beamforming is to allow spatial multiplexing. This is the name given to making concurrent transmissions possible in the same wireless spectrum by using physically separated radio beams.
- By targeting a beam to a specific subscriber, the beam to each subscriber is much narrower than the beam from an AP (in a conventional system, sectors are typically 90 or 120 degrees), multiple beams can then be used at once without them overlapping to the extent that would cause significant interference.

Beamforming can be applied in both the uplink and downlink directions and has significant benefit to overall network interference mitigation as well. This functionality does not require changes to the subscribers; only at the AP. PMP 450 subscribers already use directional (i.e. narrow) antennas to communicate to the AP.

Figure 1
[illegible]

Figure 2
Beamforming to a single user

Figure 3
Beamforming to seven users simultaneously

9.2 ADVANTAGES OF PMP 450M POWERED BY CNMEDUSA

- The primary advantage of PMP 450m versus traditional 2x2-MIMO based APs, like the PMP 450 AP and the PMP 450i AP, is the support of MU-MIMO mode, which multiplies the sector throughput.
- Using the channel state information each subscriber reports through the sounding mechanism, PMP 450m creates groups of up to seven subscribers. Subscribers are selected for one of these groups based on their azimuth spacing and amount of traffic, and their channel information is used to create up to seven spatially separated beams.

Each beam points to one SM in the group, and its nulls are aligned with the directions of the other subscribers in the group, limiting interference between subscribers.

- Groups are created every TDD cycle (frame) based on current traffic and the latest RF conditions. Subscribers within a group communicate with the PMP 450m AP simultaneously, then (in the next symbol or in the next frame) the PMP 450m creates a new group and performs simultaneous communication with those subscribers. In ideal conditions, PMP 450m is able to communicate with seven subscribers simultaneously.
- Communicating with multiple subscribers in the same channel at the same time provides a much higher sector capacity without requiring more wireless spectrum, resulting in a dramatic increase in spectral efficiency. For an operator, this means that a larger number of subscribers can be supported in the sector in the same spectrum, or that existing subscribers in the sector can experience higher average throughput.
- The cnMedusa technology has been optimized for simultaneously streaming data to and from many users such as video. With the same frequency reuse benefits as other PMP 450 series APs, spectral efficiency is the highest in any commercially available system. The spectral efficiency of the PMP 450m AP is up to 45 b/s/Hz in a sector and up to 90 b/s/Hz in a four-sector deployment with back-to-back frequency reuse.
- Given that in many deployments' spectrum is scarce, being able to increase capacity without having to increase the channel bandwidth is a significant advantage for the network operator. That these gains are achieved by only changing the AP hardware is another significant benefit.

9.3 EXAMPLES OF MU-MIMO PATTERNS

MU-MIMO patterns are generated frame by frame according to the SMs the PMP 450m AP needs to communicate with.

Figure 3 shows some examples of MU-MIMO composite patterns. The composite pattern is the overlap of the individual beamforming patterns, each with a peak in the direction of one of the SMs in the group, and nulls in the direction of the other SMs. Having nulls in the direction of the other SMs in the group keeps the interference between concurrent transmissions at a minimum.

In the examples in Figure 4, we see the AP with the SM's (orange triangles) oriented towards it, with four shades of blue per beam in the coverage area various modulation levels. From the darker shade of blue to the lighter, the modulations are 256-QAM, 64-QAM, 16-QAM and QPSK.

[illegible]

[illegible]

9.4 BEAMFORMING ARRAY GAIN

If the MU-MIMO feature is not enabled, PMP 450m communicates to each individual SM in beamforming mode. Using the channel state information provided by the subscriber through the sounding mechanism, PMP 450m forms a narrow beam in the direction of the intended subscriber, therefore limiting interference to nearby sectors.

- Reduced interference: The narrow beams created in the downlink and uplink beamforming mode, as well as MU-MIMO mode, not only increase link budget, and therefore coverage and throughput, but they also reduce the system's interference.
- In the downlink, when transmitting in beamforming mode, interference is only created in the direction of the intended subscribers. Any other device operating on the same frequency in the same area will not suffer from interference due to this transmission unless it is located in the same direction. Compared to an AP that transmits in all directions in the sector, as in a conventional system, the interference created by PMP 450m is greatly reduced.
- In the uplink direction, when receiving in beamforming mode, PMP 450m is only receiving (or "listening") in a narrow beam directed toward the intended subscriber. Any transmissions outside this beam are not received and cannot interfere with the desired signal. Keeping the interference level low using these techniques means that on average the subscribers can achieve higher modulation levels, which increases the uplink sector capacity and overall system efficiency.

Figure 5 shows an example of increased uplink throughput and reduced uplink interference using beamforming mode.

Figure 5. Example of uplink throughput and interference rejection improvement

The figure to the left shows a typical sector deployment.
The AP receives transmissions from one SM at a time. The modulation each SM uses for transmission depends on the SM's distance to the AP. The blue shades show the areas where the SMs operate at progressively reduced modulation: 256QAM, 64-QAM, 16-QAM and QPSK. The SMs in the light blue region operate at the lowest modulation (QPSK).
The figure to the right shows the same deployment, but with the AP operating in uplink beamforming mode.
The beam is now directed only in the direction of the intended subscriber.
As the array gain of the antenna increases the link budget, the areas covered by higher modulation operation are extended. The SM at the edge of the coverage area, that was originally operating at QPSK modulation can now operate at 16-QAM modulation, doubling its throughput. The overall sector capacity is also improved when one SM's link improves, as SMs are served faster, and resources can be allocated to other SMs.
In addition to the benefit of link budget improvement, and therefore increased throughput, the interference rejection capability of the AP also improves with uplink beamforming.
As the AP is typically installed in a high location, with visibility of a large area and possibly a large number of interfering devices, it is more susceptible to interference.
In the figure to the left, an interfering signal in the coverage area (red device) may corrupt the received signal coming from any of the SMs in the coverage area. This results in the SM having to operate at a lower modulation, therefore achieving a lower throughput.
In the figure to the right, only the signal coming from the direction of the transmitting SM is received at the AP. Any interfering signal outside the narrow beam is rejected, and therefore does not affect reception of the signal. In this case the modulation the SM operates at is not degraded, the SM's throughput is higher, and the overall sector capacity is also higher.

10. APPENDIX 1 PMP 450M SPECIFICATION

Equipment specifications

[illegible]

Specifications for 5 GHz PMP 450m Series - AP

[illegible]

Table [illegible] 5 GHz PMP 450m Series - AP specifications

Category		Specifications
Model Number		PMP 450m AP
Spectrum		
Channel Spacing		Configurable on 2.5 MHz increments
Frequency Range		[illegible] MHz
Channel Bandwidth		5, 10, 15, 20, [illegible] MHz
Interface		
MAC (Media Access Control) Layer		Cambium Proprietary
Physical Layer		[illegible] Multi User MIMO OFDM
Ethernet Interface		100/1000BaseT, half/full duplex, rate auto negotiated (802.3 compliant)
Protocols Used		IPv4, UDP, TCP, IP, ICMP, Telnet, SNMP, HTTP, FTP
Network Management		HTTP, HTTPS, Telnet, FTP, SNMP v3
VLAN		[illegible]
Sensitivity		
Nominal Receive Sensitivity (w/ FEC) @ 5 MHz Channel	5.1 GHz	[illegible]
	5.2 GHz	[illegible]
	5.4 GHz	[illegible]
	[illegible]	[illegible]
Nominal Receive Sensitivity (w/ FEC) @ 10 MHz Channel	5.1 GHz	[illegible]
	5.2 GHz	[illegible]
	5.4 GHz	[illegible]
	5.8 GHz	[illegible]
Nominal Receive Sensitivity (w/ FEC) @ 15 MHz Channel	5.1 GHz	[illegible]
	5.2 GHz	[illegible]
	5.4 GHz	[illegible]
	5.8 GHz	[illegible]
Nominal Receive Sensitivity (w/ FEC) @ 20 MHz Channel	5.1 GHz	[illegible]
	5.2 GHz	[illegible]
	5.4 GHz	[illegible]
	5.8 GHz	[illegible]
Nominal Receive Sensitivity (w/ FEC) @ 30 MHz Channel	5.1 GHz	[illegible]
	5.2 GHz	[illegible]
	5.4 GHz	[illegible]
	5.8 GHz	[illegible]

Minimum Receive Sensitivity [illegible] MHz Channel	5.1 GHz	[illegible]
	5.4 GHz	[illegible]
	5.4 GHz	[illegible]
	5.6 GHz	[illegible]
Performance		
Subscribers per Sector		Up to 238
ARQ		Yes
Cyclic Prefix		1/16
Frame Period		2.5 ms, 5 ms
Modulation Levels (Adaptive)		Modulation Levels / MCS / SNR (in dB)
		2x / QPSK / 10
		4x / 16QAM / 17
		6x / 64QAM / 24
		8x / 256QAM / [illegible]
Latency		[illegible] MU-MIMO [illegible]
Maximum Deployment Range		Up to 40 miles (64 km)
GPS Synchronization		Yes, via Autosync [illegible]
Quality of Service		Diffserv QoS
Link Budget		
Antenna Beam Width	5 GHz	90° integrated sector (Dual polarity, H+V)
Antenna Gain		+14 dBi
Maximum EIRP		+48 dBm
Physical		
Data Interface and [illegible]	Port 1	• 10/100/1000BASE-T Ethernet Data • [illegible]

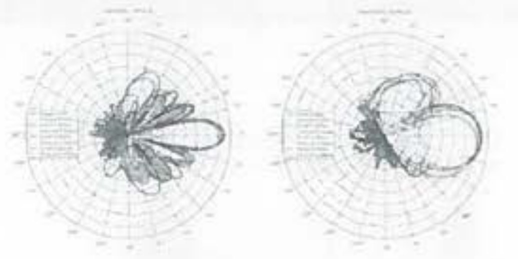
Antenna Connection		Integrated Sector Array
Surge Suppression (with LPU)		EN61000-4-5: 1.2 us/50 us, 500 V voltage waveform Recommended external surge suppressor Cambium Networks Model: [illegible]
Mean Time Between Failure		> 40 years
Environmental		IP66, IP67
Temperature / Humidity		-40°C to +60°C (-40°F to +140°F) 0-95% non-condensing
Weight	Integrated	Approx 14.2 kg (31 lbs)
Wind Loading - Front Facing		[illegible] / [illegible]
Dimensions (HxWxD)	Integrated	[illegible]
Power Consumption		70 W typical, 80 W peak (up to 120 W max with AUX port PoE enabled)
Input Voltage		58 V, 1.7 A
Mounting		Pole mount with included brackets
Security		
Encryption		128-bit AES and 256-bit AES

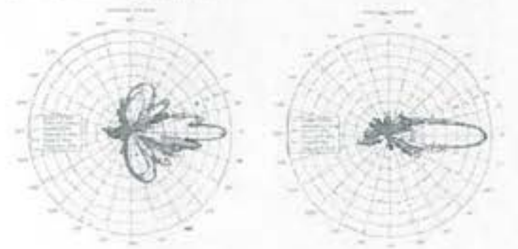
Note: AES-256 requires a license key

11. APPENDIX 2 450B SPECIFICATION

[illegible]

[illegible]





12. APPENDIX 3 CCR1016-12G SPECIFICATION

CCR1016 12G

Specifications

Product code	[illegible]
CPU	[illegible]
Size of RAM	[illegible]
Storage	[illegible]
10/100/1000 Ethernet ports	[illegible]
Supported input voltage	[illegible]
Redundant supply	[illegible]
USB port	[illegible]
Serial port	[illegible]
Dimensions	[illegible]
Operating temperature	[illegible]
[illegible]	[illegible]
Max power consumption	[illegible]

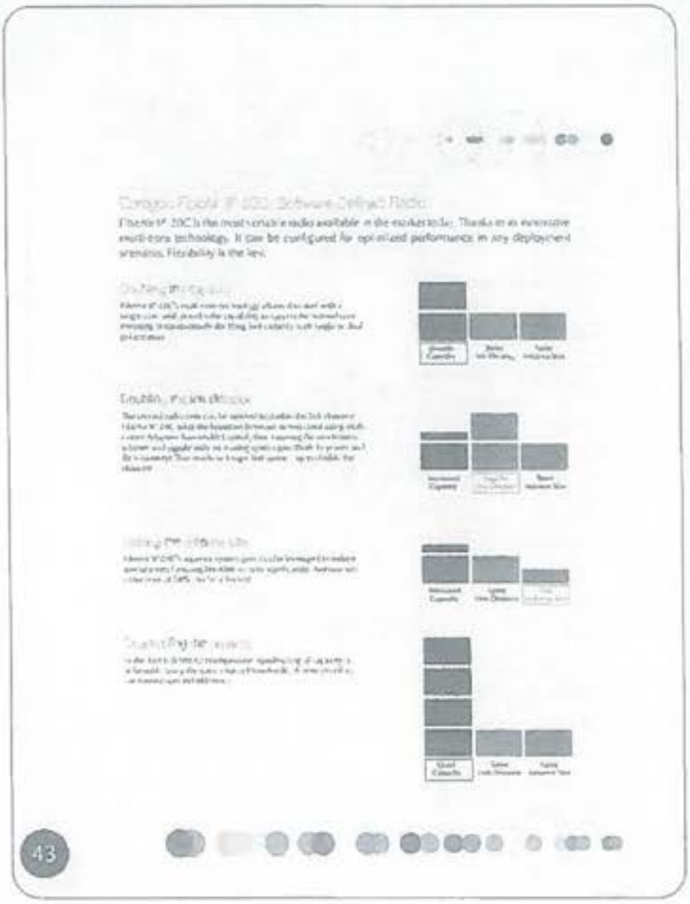
Included parts

13. APPENDIX 4 CERAGON IP20C


Sheet

FibeAir® IP-20C

CERAGON


FibeAir IP-20C is the most versatile radio available in the market today. Thanks to its innovative multi-core technology, it can be configured for optimized performance in any deployment scenario. Flexibility is the key.

Radio

Synchronization

Technical Specifications

Ethernet

Standards

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

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14. APPENDIX 5 RACOM PTP

RAy – Microwave link

RAy

RAy3

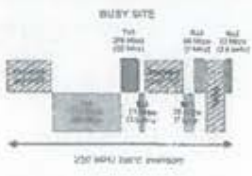
[illegible]

RAy2

[illegible]

RACOM

General overview



RAy Tools Mobile App

Reliability

Security & Integrity

Long range & Data speed

Easy to install and maintain

Configuration & Diagnostics

RAy3 technical parameters

15. APPENDIX 6 WISDM WHITEPAPER

wisdm
by Wireless Coverage Ltd

WISDM v1.4
WISP Edition

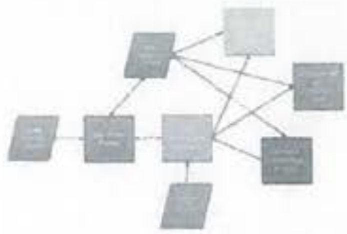
Wireless Internet Service Design and Modelling

COMMERCIAL IN CONFIDENCE

Executive Summary

Highlights

Overview



LoS Engine

[illegible]

[illegible]

Line of Sight Engine Technical Overview

[illegible]

- Site A Lat/Lon
- Site A transmitter height above ground in metres
- Site A transmitter power dBm
- Site A transmitter antenna gain in dBi
- Transmit frequency in MHz
- Scanning resolution in metres
- Site B Lat/Lon
- Site B receiver height above ground in metres
- Site B receiver antenna gain in dBi
- Percentage of first Fresnel required for partial line of sight in %
- Percentage of first Fresnel required for full line of sight in %
- Antenna Model (used for beam pattern)

The response for each request includes the following:

- Link distance in metres
- Path Status (Full Line of Sight, Partial Line of Sight or no Line of Sight)
- Predicted Receive Signal Strength (RSSL) in dBm, assuming full Line of Sight
- Azimuth from Site A in degrees from true north
- Azimuth from Site B in degrees from true north
- Elevation from Site A in degrees
- Elevation from Site B in degrees
- Antenna Model (used for beam pattern)
- [illegible] ground profile PNG image file illustrating the link profile and first Fresnel zone

[illegible]

[illegible]

Mathematical and Technical LoS Model

[illegible]

[illegible]

[illegible]

[illegible]

Site Finder Process

Introduction

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Operational Attributes

[illegible]

[illegible]

Output Data

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Site Coverage and Modelling Tool

Introduction

[illegible]

[illegible]

[illegible]

[illegible]

Input Data

[illegible]

[illegible]

[illegible]

Site Status

Sites can be suggested by [illegible] as well as added by the planner. Each site can also be assigned a Status to reflect whether it is purely speculative, or has been confirmed and agreed as a part of the network. The following [illegible] Status can be applied:

- Speculative (placed on the map for evaluation)
- Agreed (established as a favourable Site, but further work required)

- Confirmed (further work has been [illegible], such as a physical survey and landlord agreement reached)
- Rejected (will not be [illegible])

Rejected Sites are not included in the Total Coverage calculations and are displayed as greyed-out on the map.

Backhaul Modelling Process

Introduction

Configuration Parameters

Presentation

Confirming and Describing Links

Wide Area Network Visualizer

Introduction

Network and Build Phase Planning

Introduction

[illegible]

Network Locations (Site Groups)

[illegible]

Figure [illegible] - Example of multiple networks

[illegible]

[illegible]

[illegible]

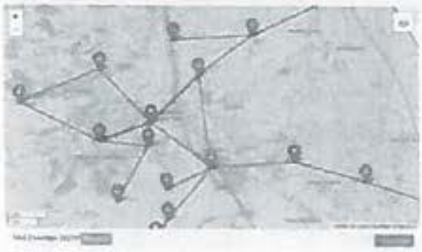
[illegible]

[illegible]

Backhaul Network Capacity Planning

Introduction

Capacity Testing



Output Reports

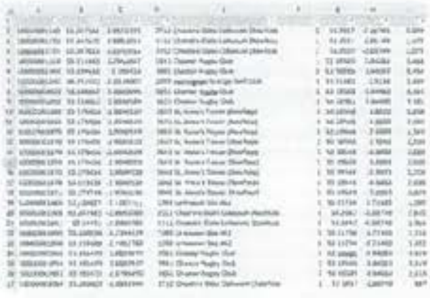
Sites + Existing Sites .SPIVY 33k Updated

[illegible]

[illegible]

[illegible]

[illegible]



[illegible]

16. APPENDIX 7 PMP450 CAPACITY PLANNER GUIDE R16.0.1

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PMP 450/450i/450b/450m Capacity Planner Guide

Release 16.0.1

PMP 450/450i/450b/450m Series Introduction

The purpose of this document is to provide a quick description on how to use the PMP 450/450i/450b/450m Capacity Planner.

[illegible]

[illegible]

OFDM (Orthogonal Frequency Division multiplexing) is a multi-carrier radio signal modulation [illegible]

The following are the subcarriers modulation schemes which can be used by the PMP 450 Series:
- QPSK
- 16-QAM
- 64-QAM
- 256-QAM

The OFDM channel bandwidth can be configured with one of these possible values: 5 MHz, 7 MHz, 10 MHz, 15 MHz, 20 MHz, 30 MHz and 40 MHz. [illegible]

[illegible]

MIMO (Multiple Input Multiple Output) [illegible]

MU-MIMO (Multi User Multiple Input Multiple Output) [illegible]

[illegible]

Antenna options

Cambium Networks offers two sector antennas to be used with the AP module [illegible]
- 60° sector antenna for sites with up to 6 AP modules
- 90° sector antenna for sites with up to 4 AP modules

[illegible]

The PMP 450 SM module antenna system gain may be increased by using a passive device:
- [illegible]
- Reflector dish that adds 11-14 dB to the antenna gain (depending on the frequency band)

[illegible]

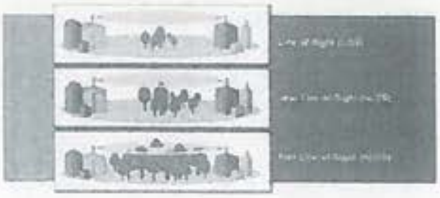
Types of connections

The PMP 450 Series can provide LOS (Line-Of-Sight), nLOS (near Line-Of-Sight) connectivity and NLOS (Non Line-Of-Sight) connectivity. [illegible]

- LOS: the optical line between the AP and the SM and the first Fresnel zone are clear.

- nLOS: the optical line between the AP and the SM is clear, but a portion of the first Fresnel zone is blocked.

- NLOS: [illegible]



Link budget calculation

The link budget is the list of all the gains and losses that contribute to the propagation of the radio frequency signal that travels from the transmitter to the receiver.

The parameters that are taken into account for the calculation of the link budget are detailed below.

Transmitter output power: the median power level of the transmitter in the transmission channel expressed in dBm (decibels to milliwatt). This level can be configured for the AP transmitter within the regulatory limits and is automatically adjusted in the SM transmitter through ATPC (Automatic Transmit Power Control) functionality in order to get the maximum value.

Cable loss: the loss expressed in dB associated with the coaxial cable used to connect the transmitter with the antenna. The loss typically depends on the length of the cable and its quality.

Transmitter antenna gain: assuming that the transmitter antenna main axis is oriented in the direction of the receiver antenna, the maximum gain given in dB declared by the manufacturer is used.

EIRP (Effective Isotropic Radiated Power): is the sum of the transmitter output power and transmitter antenna gain minus the cable loss, expressed in dBm.

Receiver antenna gain: assuming that the receiver antenna main axis is oriented in the direction of the transmitter antenna, the maximum gain given in dB declared by the manufacturer is used.

Fade margin: the amount of power given in dB that represents the difference between the median signal level at the receiver input and the receiver sensitivity. When the link fades exceeding the fade margin an outage occurs. Fade margin must be selected by the user according to the link availability target that must be met.

Receiver sensitivity: the minimum median signal level needed at the input of the receiver to achieve a receiver output quality specific to a particular modulation scheme. Higher order modulation schemes require higher quality receiver output and higher received power signal levels.

System Gain: the difference, expressed in dB, between the EIRP and the lowest order modulation receiver sensitivity and cable loss. It conventionally refers to the minimum of the uplink and downlink system gain and represents the maximum FSPL achievable with a particular system configuration.

FSPL (Free Space Path Loss): it represents the radio frequency propagation calculation used in the tool and is the attenuation between the transmitter antenna and the receiver antenna in free space given by the Friis formula:

- FSPL (dB) = 32.44 + 20logf + 20logd

Where *f* is expressed in MHz and *d* is expressed in kilometers.

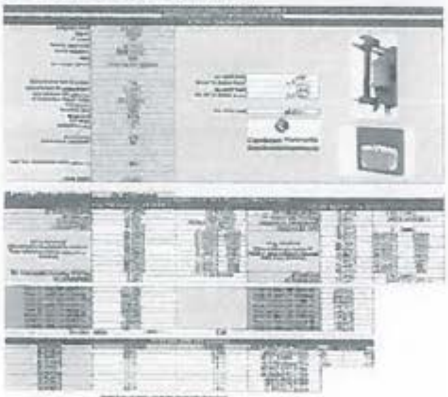
- FSPL (dB) = 36.6 + 20logf + 20logd

Where *f* is expressed in MHz and *d* is expressed in miles.

This link budget calculation can be considered a valid approximation for LOS propagation in flat fading conditions where the operating bandwidth is less than the coherence bandwidth of the radio channel, that is when the same degree of fading affects all frequencies of the signal bandwidth. In case the radio channel is experiencing frequency-selective fading affect the LOS range results may not be valid.

LINK BUDGET

The User Interface of the LINK BUDGET tab is divided in three main parts: System Configuration, Downlink and Uplink Budgets and Coverage and Throughput.



SYSTEM CONFIGURATION

In the SYSTEM CONFIGURATION menu, the fields in green represent the parameters that can be set by the user according to the system configuration that is applied to the PMP 450/450i/450b/450m systems. The fields in white are output values to be used as references for the input parameters setting.

The reference values are the following:

AP EIRP limit: limit of the combined power emitted by the AP antenna system, as defined by the regulatory region selected

Max AP Tx Power: upper limit of the combined power that can be applied to the AP antenna system, in order to be compliant to the EIRP limit

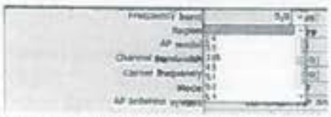
SM EIRP limit: limit of the combined power emitted by the SM antenna system, as defined by the regulatory region selected

Max SM Tx Power: upper limit of the combined power that can be applied to the SM antenna system, in order to be compliant to the EIRP limit. It is defined in conjunction with the SM product selected

Max range limit: Distance (in miles or km) between the AP and the farthest SM that can be supported with the selected configuration

The input parameters are the following:

Frequency band: selection of the frequency band (900 MHz, 2.4 GHz, 3.5 GHz, 3.65 GHz, 4.9 GHz, 5.4 GHz or 5.8 GHz)



Region: selection of the regulatory set of rules to be applied according to the country of operation.

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AP model: selection of Access Point Radio. Options are 430, 450i or 450m.
Note that not all options are available in all bands.

Channel Bandwidth: selection of the width of the operating channel (5MHz, 7 MHz, 10MHz, 15 MHz, 20MHz, 30 MHz or 40 MHz).
Not all bandwidths are available in all bands. The list of available channel bandwidths depends on the selected Frequency band.

Carrier Frequency: selection of the center carrier frequency of the operating channel within the frequencies allowed by the regulatory applied. When the Frequency band is selected, this value is automatically updated with a frequency at the center of the band.

Mode: selection of point-to-multipoint (PMP) or point-to-point (PTP) mode.

Note that when PTP mode is selected, the two additional tabs, "Network Planning" and "Sector Throughput Calculator" are not visible anymore, as they are not applicable in PTP mode.

AP antenna system: selection of the antenna used for the AP module.
The list of options depends on the selections made for "Mode" (PMP or PTP), "AP model" (450, 450i, or 450m) and "Frequency band".

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3rd party Antenna gain: definition of the gain of the 3rd party antenna, valid only in case the AP antenna system parameter is set to "3rd party antenna".

3rd party Antenna cable loss: definition of the cable loss of the 3rd party antenna, valid only in case the AP antenna system parameter is set to "3rd party antenna".

Connectorized SMs in sector?: Select "Yes" if any SMs in the sector uses a connectorized antenna. Otherwise select "No".

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Connectorized SM antenna gain: setting of the gain of the SM antenna, valid only in case there are Connectorized SMs in the sector.

Connectorized SM cable loss: setting of the cable loss of the SM antenna, valid only in case there are Connectorized SMs in the sector.

AP Transmitter Output Power: setting of the combined power transmitted by the AP module to its antenna system. The value MUST be lower than the specified Max AP Tx Power resulting from the EIRP limit and AP antenna gain.
Note: if the AP EIRP limit or the SM EIRP limit are indicated as "-", then the selected regulatory does not impose any limit on the corresponding EIRP.

AP EIRP limit	36 [dBm]
Max AP Tx Power	19.0 [dBm]

A configuration error message appears in case the value is set outside the allowed range or is invalid (for example, if it is not an integer number).

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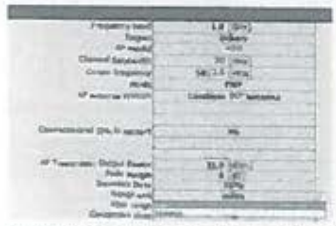
In addition, the EIRP of the AP module is shown in red if it is exceeding the limit defined by the regulatory setting.

Fade Margin: setting of the margin on signal fading that the user wants to introduce in order to obtain the desired link availability.
The following table summarizes the estimated fade margin for a certain link availability.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7 dB	47 dB	5 dB	47 dB
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5 dB	9 dB	34 dB	57 dB

Downlink Data: Percentage of frame time dedicated to downlink (AP to SM) transmission. Valid inputs are any value between 15% and 85% with a 1% granularity.

Range unit: Unit of distance (miles or kilometers) to be used in the calculations.



Max range: distance (in miles or km, depending on the selection in Range unit) between the AP and the location of the farthest SM the user wants to serve with the AP. With a smaller cell size, a larger percentage of users can communicate with higher order modulation, and the sector capacity is higher. On the other hand, with smaller cells network planning becomes very important, in order to limit interference between sectors using the same frequency.
In PTP mode, this is the distance between the Master and the Slave.
If the value input in this field is larger than the maximum distance calculated using the other parameters selected in the green cells (shown in the Max range limit field), the value appears in red.

Contention slots: Number of uplink symbols reserved for random access (network entry and bandwidth requests). Valid inputs are integer numbers from 1 to 15.
A larger number of contention slots reduces the probability of collision when two or more SMs attempt to send a request, but it also reduces the number of symbols dedicated to data transmission, and therefore reduces the maximum throughput.
The number of contention slots has to be selected according to the specific deployment parameters in each sector. If the number of contention slots is too small, then latency increases in high traffic periods. If the number of contention slots is too high, then the maximum capacity is unnecessarily reduced. The two main contributing factors to the selection of the number of contention slots are the number of VCs in a sector, and the type of traffic in the sector.

- If the number of VCs in a sector is large, it is recommended to increase the number of contention slots, in order to reduce the probability of two or more requests colliding. The suggested contention slot settings as a function of the number of active VCs in the sector are shown in the Following Table

Number of VCs	Suggested number of contention slots
[illegible]	[illegible]
[illegible]	4
[illegible]	[illegible]
[illegible]	[illegible]

Note that each SM uses one or two VCs. All SMs have a Low Priority Channel that uses one VC. If the High Priority Channel is also enabled for the SM, then the SM uses a second VC. Therefore the number of active VCs in a sector is greater than or equal to the number of SMs registered to the AP in the sector. For example, a network including 30 SMs with High Priority Channel disabled and 20 SMs with High Priority Channel enabled has 60 active VCs and may be configured with 4 contention slots.

Besides the number of VCs, the other main factor in contention slots selection is the type of traffic. If the sector experiences a lot of uplink traffic composed of small packets, for example in a sector that serves several VoIP streams, the average number of bandwidth requests transmitted by each SM is high. Another scenario with constant uplink traffic is video surveillance, which also generate a large number of uplink bandwidth requests.
In these cases the probability of two or more SMs transmitting a request in the same symbol is high. When this happens, the latency of the system increases, and it is recommended to increase the number of contention slots from the number in the previous Table. If an AP is experiencing latency or SM-reentering issues, increasing the number of contention slots may increase system performance, depending on traffic mix over time.

Recommendation on Contention Slots number selection

1- Calculate the number of active VCs in the sector (one VC per SM for SMs with Low Priority VC enabled only, two VCs per SM for SMs with High Priority VC enabled)
2- Evaluate the traffic mix that is expected in the sector, more specifically the expected percentage of real-time traffic (as. VoIP, gaming, video conferencing, and video surveillance)
3- If the expected amount of real-time traffic is small, select the number of contention slots according to the previous Table
4- If the expected amount of real-time traffic is large, select a number of contention slots larger than the number in the previous Table
5- Mitigate latency in your system. If the percentage of real-time traffic (or any uplink traffic) increases and the sector experiences increasing latency and SM reentering issues, increase the number of contention slots from the current setting.
This is the reason why the maximum number of contention slots is 15, even if the previous Table shows 8 contention slots for more than 150 VCs. If the number of VCs is more than 150 and a significant portion of the traffic is real-time, the frequency with which bandwidth request messages are transmitted requires a higher number of contention slots, potentially as high as 15. A sector with a high number of video surveillance cameras would also require a larger number of contention slots to reduce the probability of collision between requests.

Adjacent Frequency Support: This configuration parameter is available in the 3.5 and 3.65 GHz bands, and in the 4.9 to 5.8 GHz bands if the SM is selected as PMP 450i. In all other cases, adjacent frequencies can be used in adjacent sectors without guard bands and without limiting the transmit power.
In the 3 GHz bands, selecting "Yes" limits the SM Tx power to 23 dBm (2 dB lower than the 25 dBm maximum the radio can support).
In the 5 GHz bands with PMP 450b SMs, selecting "Yes" limits the SM Tx power to 25 dBm (2 dB lower than the 27 dBm maximum the radio can support).
This feature allows operating with adjacent channels in adjacent sectors. If "No" is selected, the SM Tx power is set at the maximum value, but adjacent channels need to have a guard band if used in adjacent sectors.

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Environment: type of propagation environment. The options for this field are LOS, near LOS, NLOS (suburban) or NLOS (urban).
The following table summarizes the excess path loss used in the range calculation formula for each selection of the Environment parameter.

Environment	Excess path loss
[illegible]	[illegible]
[illegible]	5 dB
NLOS (suburban)	[illegible]
NLOS (urban)	25 dB

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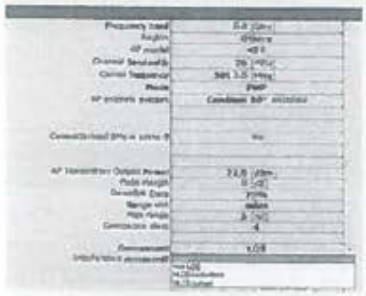
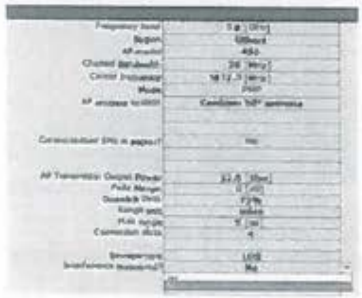


Interference measured?: Select "Yes" if the system experiences interference. Otherwise select "No".



SM antenna for measuring loss?: Antenna type used at the SM while performing interference measurement. The list of antennas depends on the frequency band selected (for example, the CLIP is available in the 5.4 GHz and 5.8 GHz bands only) and the presence of Connectorized SMs in the system

Connectorized SMs in sector?	Yes
Connectorized SM antenna gain	11 [dBi]
Connectorized SM cable loss	0 [dB]
AP Transmitter Output Power	[illegible] [dBm]
Fade Margin	[illegible] [dB]
Downlink Data	75%
Range unit	miles
Max range	5 [mi]
Contention slots	4
Adjacent Frequency Support	Yes
Environment	LOS
Interference measured?	Yes
SM antenna for measuring interf	[illegible]
Downlink interference level	[illegible]
Uplink interference level	[illegible]
% of SMs with uneven paths (MIMO-A)	[illegible]
Frame length	[illegible]

Downlink interference level: Value (in dBm) of the downlink interference measured at the channel currently used (co-channel).

Uplink interference level: Value (in dBm) of the uplink interference measured in the channel currently used (co-channel).

Frequency band	5.8 [GHz]
Region	Others
AP model	450
Channel Bandwidth	20 [MHz]
Carrier frequency	[illegible] [MHz]
Mode	PMP
AP antenna system	Cambium 90° antenna
Connectorized SMs in sector?	No
AP Transmitter Output Power	22.0 [dBm]
Fade Margin	0 [dB]
Downlink Data	75%
Range unit	miles
Max range	5 [mi]
Contention slots	4
Environment	LOS
Interference measured?	Yes
SM antenna for measuring interf	PMP 450 Integrated
Downlink interference level	-94 [dBm]
Uplink interference level	-94 [dBm]

% of SMs with uneven paths (MIMO-A): Percentage of SMs that are in a location experiencing a different RSSI on the two Rx branches (for example, in NLOS conditions). For these SMs the rate adapt algorithm will select a MIMO-A modulation mode if the throughput of the MIMO-A mode is higher than the MIMO-B throughput that can be sustained in the same channel condition.
This field is valid only if Mode is selected as "PMP".

Frequency band	5.8 [GHz]
Region	Others
AP model	450
Channel Bandwidth	20 [MHz]
Center frequency	[illegible] [MHz]
Mode	PMP
AP antenna system	Cambium 90° antenna
Connectorized SMs in sector?	No
AP Transmitter Output Power	22.0 [dBm]
Fade Margin	0 [dB]
Downlink Data	75%
Range unit	miles
Max range	5 [mi]
Contention slots	4
Environment	LOS
Interference measured?	No
% of SMs with uneven paths (MIMO-A)	50%?

SMs Tx Output Power: Combined output power of the Slaves. This field is valid only if Mode is selected as "PTP". Note that in PMP mode there is no corresponding input because the transmit power of the SM is controlled by the AP through the power control algorithm.

PTP MIMO mode: Transmission mode used in the PTP link. Options are "MIMO-A" or "MIMO-B".

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Frequency band	5.8 [GHz]
Region	Others
[illegible] model	450
Channel Bandwidth	20 [MHz]
Carrier Frequency	5812.5 [MHz]
Mode	PTP
BHM antenna options	3rd party antenna
3rd party antenna gain	20 [dBi]
3rd party antenna cable loss	1 [dB]
Connectorized SMs in sector?	No
AP Transmitter Output Power	22.0 [dBm]
Fade Margin	0 [dB]
Downlink Data	75%
Range unit	miles
Max range	5 [mi]
Environment	LOS
Interference measured?	No
BHS Tx Output Power	22 [dBm]
PTP MIMO Mode	MIMO-B
Frame length	MIMO-A

Frame length: Length of the TDD frame. Options are 2.5 ms and 5 ms.

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Frequency band	5.8 [GHz]
Region	Others
AP model	450
Channel bandwidth	20 [MHz]
Carrier frequency	5812.5 [MHz]
Mode	PMP
AP antenna type	Cambium 90° antenna
Connectorized SMs in sector?	No
AP Transmitter Output Power	22.0 [dBm]
Fade Margin	0 [dB]
Downlink Data	75%
Range unit	miles
Max range	8 [mi]
Contention slots	4
Environment	LOS
Interference measured?	No
% of SMs with [illegible] (MIMO-A)	0%
Frame length	2.5 [ms]
SM antenna option for displaying data	[illegible]

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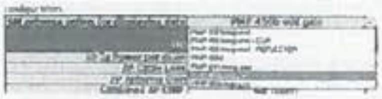
LINK BUDGET

In the LINK BUDGET part of the user interface results are shown for the selected SM antenna configuration.



The settings of all the parameters included in the link budget calculation are listed in two columns, one for the downlink direction (from AP to SM) and one for the uplink direction (from SM to AP).

Note that the calculations are performed with sensitivity values with one decimal point precision, but both the sensitivity values and the gain values are shown as integer numbers.

COVERAGE AND THROUGHPUT

In the COVERAGE AND THROUGHPUT section the results of the link budget calculation are shown again for the selected SM antenna configuration.

DL Range and UL range: represent for each modulation mode the maximum distance at which the radio link can operate with the selected configuration and fade margin. Values of range in red indicate that the potential range is larger than the maximum range set in the Max range field in the SYSTEM CONFIGURATION section. Also, the range is limited to 40 miles, because that is the configuration limit supported by the radio.

Max DL/UL/Total Throughput: the Downlink/Uplink/Total capacity of the sector assuming all the registered SMs are operating at that modulation.

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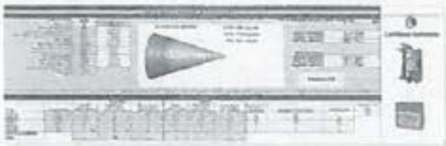
DL/UL/Total Capacity: Downlink/Uplink/Total capacity of the sector, taking into account the percentage of users using each modulation, under the assumption that the users are evenly distributed in the covered area and that they all generate the same amount of traffic. The capacity of the sector is calculated as a proportion of the peak capacity taking into account the AP antenna pattern and the fact that the users are evenly distributed in the covered area.
If the Mode is selected as "PTP", this is simply the DL/UL/Total throughput at the modulation that the link can support at the given distance.
The covered area is limited by the Max range field set in the SYSTEM CONFIGURATION section.
Appendix A shows an example of capacity calculations.
Note that, in PMP mode, the DL/UL/Total Capacity values will be displayed in red as a warning if the Max range field in the SYSTEM CONFIGURATION section is larger than the coverage that can be achieved with the most robust modulation and coding rate (QPSK MIMO-A). In this case, the capacity calculation is carried out within the covered area only. Numbers in red mean that the calculation does not cover all the area indicated by the Max range field.
In PTP mode, if the Max range field in the SYSTEM CONFIGURATION section, which in this case indicates the distance between the BHM and the BHS, is larger than the coverage that can be achieved with the most robust modulation and coding rate (QPSK MIMO-A), the DL/UL/Total Capacity values show an "Out of range" message.
If 450m is selected, the DL/UL/Total capacity assumes non MU-MIMO operation. With MU-MIMO operation enabled, the DL capacity increases by a factor that depends, among other factors, on the average group size.

The plot in the COVERAGE AND THROUGHPUT section shows the range of communication that can be achieved in the downlink with each MIMO-B modulation level, up to the maximum range set in the Max range field in the SYSTEM CONFIGURATION section. MIMO-A modulation mode is also used because this mode is used not only when the RSSI in the two branches is different, but also for extending the range when the RSSI in the two branches is comparable but too low (and a 3 dB combining gain is necessary to maintain the link).
If some modulation levels cover an area outside the Max range field, these modulation levels are not used. The legend in the plot indicates which modulation levels are not used, together with the peak DL/UL/Total throughput for each used modulation level.
The plot is visible only if Mode is selected as "PMP".

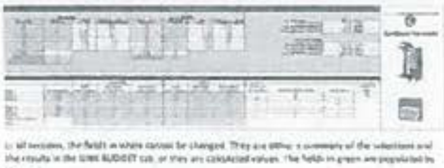
NETWORK PLANNING

The NETWORK PLANNING tab calculates the total number of customers that can be supported in a sector, given a selected distribution of stats.
This tab is visible only if Mode in the LINK BUDGET tab is selected as "PMP".

This tab consists of two sections.
The top section, "Network Configuration", takes as input the distribution of the SMs' antenna types in the sector.



The bottom section, "Input SMs directly", takes as input the distribution of the DL and UL modulation for each SM. This section is useful for an existing sector, where the modulation distribution is available.



In all sections, the fields in white cannot be changed. They are either a summary of the selections and the results in the LINK BUDGET tab, or they are calculated values. The fields in green are populated by the user.
After changing the fields in green, click the CALCULATE button to run the calculations and update the results.

Downlink Data: percentage of frame time allocated to the downlink (AP to SM). This field corresponds to the Downlink Data field in the SYSTEM CONFIGURATION section of the LINK BUDGET tab.

Max range: distance between the AP and the location of the farthest SM the user wants to serve with the AP. This field corresponds to the Max range field in the SYSTEM CONFIGURATION section of the LINK BUDGET tab.

PMP 450 Integrated, PMP 450 Integrated + CLIP, PMP 450 Integrated + REFLECTOR, PMP 450d, PMP 450i Integrated, PMP 450 Connectorized, PMP 450i Connectorized, PMP 450 Rugged, PMP 450b mid gain, PMP 450b high gain: percentages of SMs using each of the possible SM antenna systems.

These fields cannot exceed the corresponding Max% value fields that are calculated using the parameters selected in the LINK BUDGET tab.
If the sum of all percentages is not equal to 100%, the values are shown in red, an error message appears, and the figure and results are not shown.

% of time for BC/MC traffic: percentage of the downlink time used on average to transmit broadcast and multicast traffic.

MU gain: This field is visible only if PMP 450m is selected as AP model in the LINK BUDGET tab. The multiplexing gain (or MU gain) is a multiplicative factor applied to the DL throughput that takes into account MU-MIMO operation. This value is a function of the average group size, but also takes into account the percentage of symbols that are transmitted in MU-MIMO mode and the fact that the modulation mode is typically lower in grouped transmissions compared to ungrouped transmissions.

% of SMs with one/two paths (MIMO-A): percentage of SMs using MIMO-A modulation modes. This field corresponds to the % of SMs with one/two paths (MIMO-A) in the LINK BUDGET tab.

Avg DL/UL Capacity: downlink/uplink capacity of the sector, taking into account the percentage of users using each modulation and each SM antenna system, and also the percentage of users using MIMO-A and MIMO-B modulations.
The assumption is that SMs with antenna types with higher gain are deployed farther from the AP, while SMs with antenna types with lower gain are deployed closer to the AP. Considering four concentric rings centered at the AP (where each ring can have area equal to zero if the corresponding percentage is zero), the innermost circle includes the locations of all SMs using an integrated antenna. The outer three rings include the locations of all SMs using a CLIP antenna, a reflector dish and/or PMP 450d, or a connectorized SM, with order depending on the gain of the connectorized antenna. For example, if the connectorized antenna gain is higher than the CLIP gain but lower than the reflector dish, the order of the rings (starting from the AP) is: integrated, CLIP, connectorized, reflector dish and/or PMP 450d. Note that the reflector dish and the PMP 450d are grouped in the same ring as their antenna gain is the same.
The CLIP and PMP 450d are only available in the 5 GHz band.
The distribution of the SM antenna types in the sector is shown by the plot.

Avg Tot Capacity: total (downlink + uplink) sector capacity of the sector, taking into account the percentage of users using each modulation and each SM antenna system. This is the sum of the Avg DL Capacity and the Avg UL Capacity fields.

If PMP 450m is selected as AP model in the LINK BUDGET tab, an additional section titled "With MU-MIMO" becomes visible. This section shows the Average DL/UL/Total Capacity when MU-MIMO operation is enabled in PMP 450m. Note that the above DL/UL/Total Capacity is still valid for a 450m AP but only when MU-MIMO operation is disabled.

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Monthly Service Plans

There are five types of plans: Plan A, Plan B, Plan C, Plan D and Plan E. The user enters the percentage corresponding to each type of plan
For each plan, the user inputs the downlink and uplink requirements for three types of traffic: VoIP, browsing and streaming.
VoIP traffic is typically transmitted on high priority VCs, and it is not MU-MIMO groupable. Browsing and streaming are typically transmitted on low priority VCs and are MU-MIMO groupable. The groupability comment applies to 450m AP operation only
For each traffic type, the user inputs the corresponding oversubscription rate

Number of DL/UL plans: number of plans that can be offered considering only the DL/UL plans' requirements, for each plan level

Total plans: lower number between the number of DL and UL plans

Number of SMs: Sum of total plans

In the bottom section of the tab, the SM modulation distribution is input directly

SMs DL modulation: number of SMs operating at each modulation level in the DL direction. For 450m operation, this is the MU-MIMO mode.

SMs UL modulation: number of SMs operating at each modulation level in the UL direction. For 450m operation, this is the MU-MIMO mode

Avg DL/UL group size: average expected DL/UL group size in MU-MIMO mode
This field is valid only if PMP 450m is selected as AP model in the LINK BUDGET tab

% of time for BC/MC traffic: percentage of the downlink time used on average to transmit broadcast and multicast traffic

DL/UL/Total Average Capacity: Calculated DL/UL/Total sector capacity using the SM modulation distribution input in this section. The top values do not consider MU-MIMO operation, while the bottom

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values consider the grouping gain for MU-MIMO. The bottom section is visible only if PMP 450m AP is selected as AP model in the LINK BUDGET tab

Monthly service plans: This section calculates the number of SMs that can be supported by the AP, with similar calculation as done in the top part of this tab
The inputs are the types and percentages of plans, and the corresponding oversubscription rates. The assumption is that the modulation distribution of the additional SMs in the sector is equivalent to the one of the existing sectors.
If the calculated number of SMs is lower than the number of SMs input in the modulation section, the number appears in red, indicating that it is not possible to support all the SMs in the sector with the selected distribution of plans.

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SECTOR THROUGHPUT CALCULATOR

The SECTOR THROUGHPUT CALCULATOR allows the user to input the exact distance of all the users from the AP.

This tab is visible only if Mode in the LINK BUDGET tab is selected as "PMP"

In the SUBSCRIBERS' LOCATIONS section the user inputs the values in the green cells. The white cells show calculated values.

SM distance: distance between the AP and the SM under consideration. Any number of SMs can be input up to the [illegible] maximum number of [illegible] available in the PMP 450 system (which is 238). The distance can be input either in miles or kilometers, depending on the selection of the Range unit parameter in the LINK BUDGET tab. A blank cell indicates the corresponding SM is not used.

SM antenna system: selection of the antenna system used for the SM under consideration. The available options depend on the selected band, and the [illegible] option is shown only if the [illegible] field in the SYSTEM CONFIGURATION section in the LINK BUDGET tab is selected as "Yes".

Mode: Transmission mode of the SM under consideration. Options are "MIMO-A" or "MIMO-B".

DL Modulation: modulation mode that can be supported by the SM in the downlink direction at the distance input by the user and with the SM antenna system selected by the user.

UL Modulation: modulation mode that can be supported by the SM in the uplink direction at the distance input by the user and with the SM antenna system selected by the user.

DL Throughput: downlink throughput supported by the SM at the modulation mode indicated in the DL Modulation field.

UL Throughput: uplink throughput supported by the SM at the modulation mode indicated in the UL Modulation field.

Total Throughput: sum of DL Throughput and UL Throughput.

SMs per DL modulation: number and percentage of SMs that can communicate in the downlink direction in each of the modulation modes, based on the distance input for each SM and the SM antenna selection.

SMs per UL modulation: number and percentage of SMs that can communicate in the uplink direction in each of the modulation modes, based on the distances input for each SM and the SM antenna selection.

Avg DL/UL group size: average expected DL/UL group size in MU-MIMO mode. This field is valid only if PMP 450m is selected as AP model in the LINK BUDGET tab.

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DL Average capacity: downlink capacity of the sector, taking into account the percentage of users using each downlink modulation, under the assumption that the users are distributed in the covered area as indicated in the SUBSCRIBERS' LOCATION section and that they all generate the same amount of traffic. Calculations for determining this field are done in the same way described in Appendix A.

UL Average capacity: uplink capacity of the sector, taking into account the percentage of users using each uplink modulation, under the assumption that the users are distributed in the covered area as indicated in the SUBSCRIBERS' LOCATION section and that they all generate the same amount of traffic. Calculations for determining this field are done in the same way described in Appendix A.

Total Average capacity: sum of DL Average capacity and UL Average capacity.

DL/UL/Total Throughput per modulation: downlink/uplink/total throughput assigned to each modulation. This is the product of the DL/UL/Total Average capacity and the % of SMs per DL/UL modulation.

DL/UL/Total Throughput per SM: downlink/uplink/total throughput each SM in each modulation group will experience, assuming all SMs are active at the same time. Note that for all modulation modes that are in use in the sector these values are the same for all SMs. The reason is that it is assumed all SMs generate the same amount of traffic, and therefore they are allocated the same throughput, regardless of the modulation mode they can use for communication.

References

All the detailed information about Cambium Networks PMP Series 450 can be found in the official product documentation available for download from Cambium Networks public website:

[illegible]

[illegible]

Questions/Comments

[illegible]

Appendix A

Example of aggregate capacity calculation

In the aggregate capacity calculation two assumptions are made:

- The SMs are geographically evenly distributed in the covered area
- All SMs generate the same amount of traffic

In this example, the sector only has PMP 450 SMs with an integrated antenna, and the input values entered in the SYSTEM CONFIGURATION SECTION are the following:

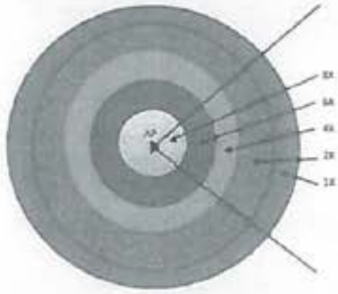
Frequency band	[illegible] [GHz]
Region	[illegible]
AP model	450
Channel Bandwidth	20 [MHz]
Carrier frequency	[illegible] [MHz]
Mode	PMP
AP antenna type	Cambium 90° antenna
Connectorized SMs in sector?	No
AP Transmitter Output Power	[illegible] [dBm]
Fade Margin	[illegible] [dB]
Downlink Data	[illegible] %
Range unit	Miles
Max range	5 [mi]
Contention slots	[illegible]
Environment	LOS
Interference measured?	No
% of SMs with uneven paths (MIMO-A)	[illegible]%
Frame length	2.5 [ms]

These are the steps for calculating the aggregate capacity:

- First, the SMs that are not in a location that requires MIMO-A transmission are considered. The modulation modes supported by these SMs are 256QAM MIMO-B (8X), 64QAM MIMO-B (6X), 16QAM MIMO-B (4X), QPSK MIMO-B (2X) and QPSK MIMO-A (1X). The QPSK MIMO-A mode is also considered here because this mode is used not only in propagation conditions when the received signals strength is very different between the two branches, but also to extend the range. In this case the diversity gain increases the system gain and extends the range. The Potential Range for each modulation is limited by the Max range field in the SYSTEM CONFIGURATION section.
  Example with Max range set at 5 miles and integrated antenna.

Modulation mode	Potential range	Actual range
8X	0.4 miles	0.4 miles
6X	1.6 miles	1.6 miles
4X	3.2 miles	3.2 miles
2X	6.4 miles	5 miles
1X	9.1 miles	5 miles

- Calculate the area (in square miles) covered with each modulation.
  The modulation and coding level supported by each SM in LOS conditions depends on the distance between the AP and the SM. SMs closer to the AP can support higher modulation modes, while SMs farther from the AP can only support lower modulation modes.
  This figure shows the area covered by the AP and the five rings corresponding to one of the modulation modes supported by the PMP 450 system.



Assuming a 90° sector antenna at the AP and considering the percentage of SMs not in MIMO-A modulation (80%), the areas covered by the AP at each modulation level are shown in the next table.

Modulation mode	Area (square miles)	Area (%)
8X	0.15	0.69%
6X	1.34	6.02%
4X	3.48	25.18%
2X	12.23	58.11%
1X	0.00	0.00%

The area calculated for modulation mode 1X is equal to 0, because the sector under consideration is limited at a range of 5 miles, so the assumption is that there are no users (and therefore no area covered) beyond 5 miles.
The same table also shows the percentage of the total area (within the 5 mile range) covered with each modulation. Since all SMs are assumed to be evenly distributed in the covered area, these percentages also represent the percentages of SMs communicating at each of the modulation modes.

Calculate the DL time and the UL time allocated for each modulation mode
The time in the DL and UL subframes is divided among SMs (and therefore MCS levels) proportionally to the percentage of users communicating at each modulation mode. The following table shows the DL and UL times which are calculated as
DL (UL) time for mode X = % area for mode X / DL (UL) throughput for mode X

MCS level	DL time (s)	UL time (s)
8X	0.000072	0.000175
6X	0.001106	0.001668
4X	0.005213	0.008504
2X	0.023185	0.087042
1X	0.000000	0.000000

Repeat the above calculations for the 10% of SMs using MIMO-A mode. These lead to the following table:

MCS level	DL time (s)	UL time (s)
4X	0.000015	0.000039
3X	0.000246	0.000371
2X	0.001156	0.001990
1X	0.005152	0.019343

Calculate the DL, UL and total capacity
The DL (UL) peak capacity is the inverse of the sum of the DL (UL) times allocated for each modulation mode (MIMO-A and MIMO-B). The peak capacity is then multiplied by a factor (equal to [illegible]) to take into account the AP antenna pattern and the fact that the users are evenly distributed in the covered area.
*DL (UL) capacity = 1/sum of all DL (UL) times per modulation mode * antenna factor*
The total capacity is simply the sum of the DL and UL capacities.
DL Capacity = 21.5 **Mbps**
UL Capacity = 7.1 Mbps
Total Capacity = [illegible] Mbps

From: [redacted]
To: NBP Mailbox
Subject: Zero Response from Eir
Date: 25 September 2019 16:33:45

Sir or Madam,

I recently signed up with Eir, on the promise that my premises would be connected to the fibre network.

Since then, it has been crickets.

I am a short distance from the road along which the fibre cable is laid, so I know that I need to lay and pay for the connection from my house to the road. But I need to coordinate this with Eir, and Eir is simply not available to discuss it - there is no-one to talk to, and the e-mails I send to "fibrerollout" remain unanswered.

I operate an international consulting business from my premises, and a reliable fibre connection would be valuable to my business.

Sincerely,

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

From: [redacted]
To: NBP Mapping
Subject: Submission
Date: 03 August 2019 15:54:27

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

[redacted]

Dear Ms Dormer

My home is in a Blue area on the NBP map, but I have been unable to access speeds of more than 1.5 Mbps from any provider using OpenEir's network - with the service provided often being far below this maximum.
While I cancelled my fixed line broadband service in 2018 and moved to a mobile broadband service instead, my line still has telephone services and still shows a 2 Mbps maximum when I check fibrerollout.ie or digiweb.ie.
No other fixed line wholesale network (e.g. Virgin or Siro) is available in the area.

My line appears to be connected directly to the [redacted] exchange (c.4km). This may be because I purchased services from BT/Vodafone until 2016. Neighbours with Eircom/Eir were connected to a cabinet at [redacted] (c.3km) in 2015 and received an improved service (c.10 Mbps).
I transferred to Eir in 2016, but despite extensive telephone contact with their retail and engineering divisions in 2016/17, I was unable to persuade them to do anything to improve my service.

The update to the NBP map has identified neighbouring properties as requiring intervention, but not mine - possibly because I no longer have a fixed line broadband service. I am aware of a neighbouring property which is also without a fixed line service and which is also not marked on the new map.
Please add my address to the list requiring intervention.

Thanking you

[redacted]