5G RuralDorset WP6 Neutral Host

Task 5: Business Study

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Executive Summary

Deliverable T4 provided a detailed technical overview on the use and availability of spectrum for new players entering the mobile network market, with particular focus on a potential Neutral Hosting (NH) eco-system. This deliverable (T5) will build upon these challenges and focus on the commercial viability, opportunities and considerations for potential rural NH providers. NH has been demonstrated to be commercially viable in ultra-dense environments backed by large established companies, in locations such as large shopping centres and public buildings. However, rural commercial deployments remain elusive as the existing market demand is insufficient for existing mobile operators to generate adequate returns on investment (ROI) at a price point affordable to consumers. This creates an untapped market for rural connectivity as demand both exists and will grow over time. But regulatory, technical, security and business issues restrict smaller operators from filling the void.

Connectivity costs more to deliver in rural areas for several reasons – backhaul is required over longer distances to reach remote cell sites, undulating terrain creates localised areas of poor coverage, requiring more cell sites to be installed for coverage infill, and there are often challenges to mast locations based on environmental and/or aesthetic concerns. Plainly put to provide reliable rural connectivity, either costs must fall, revenues rise - or both. Other approaches, including the current 4G Shared Rural Network actually serve to undermine the economics of NH and require additional Government intervention.

This paper studies the business and commercial aspects of a NH operator, the practicalities of creating a commercially viable rural NH operator at-scale, and some of the key enabling steps which would be required to support this, as an alternative connectivity solution at potentially lower cost. It also provides some practical recommendations for action, in particular, positive regulatory discrimination for rural areas to reduce the digital divide in line with Ofcom's existing statutory duty[1].

One way to reduce the cost of deploying connectivity in rural areas is to avoid inefficient allocation of capital, commonly manifested as "over-build", where multiple operators each incur their full costs of site build-outs. A move to a model of rural "shared infrastructure", which could be manifested as a rural NH service, would allow for the costs of infrastructure to be shared by all operators benefiting from coverage provided by a NH operator. Another way of reducing the effective cost is sharing the costs over a larger number of users. Therefore, the paper also analyses potential revenue streams through taking conservative estimates for consumers such as smart agriculture, local authorities, social care and in-fill coverage, and comparing these against the potential costs of providing such as a service: spectrum, equipment and backhaul.

Critically, many of these use cases cannot by themselves support the cost of connectivity they require, nor can they tolerate the traditional pricing model employed by Mobile Network Operators (MNOs) (recurring revenue scaled by usage based on population density). Our analysis has demonstrated that rural NH providers could be financially viable if policy changes were made.

1 https://www.legislation.gov.uk/ukpga/2003/21/section/3

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Introduction

Because of the lower population density of users, the economic case for delivery of coverage in rural areas is considerably weaker than that in urban ones. Basic residential population density modelling has in the past always provides a good approximation of the business case for previous generations of mobile networks. With 5G, however, arriving at a time where increased use of "smart" technologies across verticals are all requiring connectivity, population density no longer reflects an approximation of "all" users (as we explore later). Many rural areas lag behind their urban compatriots on productivity and other key economic measures[2], which can make the case for improved connectivity more challenging today due to the continued use by Mobile Networks of this "population density" investment case approach. This will change over the medium term, but today we are nowhere close to seeing this.

One obvious way to reduce connectivity deployment costs in rural areas is to avoid inefficient allocation of capital, commonly manifested as "over-build", where multiple operators each incur their full costs of site build-outs. A move to a model of rural "shared infrastructure", which could be manifested as a rural NH service, would allow for the costs of infrastructure to be shared by all operators benefiting from coverage provided by a NH operator. It remains the case today however that Ofcom regards overbuild in all areas as evidence of healthy competition, failing to grasp that whilst true in urban areas, in rural areas "any" service at all, let alone a competitive one, is typically welcomed by digitally deprived rural communities who can only dream of the quality problem of overbuild… A "one size fits all" regulatory approach is actually now exacerbating the situation as Ofcom is not releasing fallow spectrum to those in rural areas and thereby perpetuating the digital divide, notwithstanding its statutory duty to cater for the needs "… of persons living in ***rural*** and urban areas" (emphasis added).

NH is not a new business model, but in the context of rural areas it remains unproven. Traditional NH models have generally been trialled in dense urban environments where the population density and demand for extra capacity create commercial incentives for players' interests to align around delivery of a better service quality, which can be a competitive differentiator. In rural areas, where neutral hosting is more about delivery of basic coverage, with an inherently lower number of customers, the business case for delivery of even regular coverage at any speed is a challenge, let alone the business case for integration of a new business partner for service of a limited number of customers in a rural area. The limited number of customers means there is little value in attempting to deliver better service as a competitive differentiator, as it is not perceived as likely to yield a return on investment. At the root of the problem is the simple economic fact that the numbers just do not add up.

In this analysis, we explore some of the practical commercial concerns and advantages likely to be experienced by a NH operator attempting to provide a mobile service in rural areas. We start by briefly introducing the fundamental requirement for any wireless communication system – spectrum. A previous report produced as part of this work package explained this requirement in detail, but as a fundamental requirement it is important to provide an outline within this report. This is followed by a

2https://www.ncl.ac.uk/mediav8/nicre/files/What%20is%20the%20contribution%20of%20rural%20enterprise%20to%20Levelling%20Up,%20and%20how%20can%20this%20be%20further%20enabled.pdf focus on the commercial model, structural barriers and challenges to the economics of providing a neutral host system. This was conducted by first examining state-of-the-art project proposals of shared mobile infrastructure and detailing their likely associated financial models. As all these state-of-the-art examples rely on high population density, we then focus on the potential revenue streams and considerations for NH implementations in sparely populated areas. This will include analysing the business risks and technical challenges for a NH provider deploying in a rural environment. Finally, as this only represents one side of the coin, we focus on how a NH provider may interact with an incumbent mobile network operator, detailing their potential incentives, considerations and practicalities.

The idea of NH is not as fanciful as some in the industry portray it – Ofcom's then-CEO, Sharon White, said in a speech[3] on the topic of reaching 100% coverage as recently as 2018 that; "Our view is that some form of cross subsidy would be necessary to do this. To keep costs down, there would be a strong case for contracting a single operator to build and operate masts where there are currently none, which all customers could then use."

This paper therefore seeks to resume progress where Ofcom left it, since the model proposed to have one entity "operate" masts makes clear that the active radio equipment would be common across operators, giving rise to rural NH services as explored in this paper.

Spectrum

As the use of spectrum is fundamental, the reliance and reliability of this resource is included within our analysis as a business risk, since without spectrum any form of active NH can't work. Today spectrum is controlled by Ofcom, and not enough is available on acceptable terms to help rural areas. This must mean that a market failure exists because rural spectrum is typically unused and so is being sub-optimally utilised. This is, prima-facie, in contravention of Ofcom's statutory duty to secure its optimal use because demand exists which that spectrum could serve - that is going unsatisfied. To date nobody has tested this matter. The danger is that they would end up in expensive litigation with Ofcom, with the MNOs potentially being interveners in any proceedings brought. Unsurprisingly, no such actions have occurred.

In Ofcom's defence, mobile-harmonised spectrum is scarce in urban areas, with demand commonly outstripping available supply due to the high density of users. Although demand is much lower in rural areas, the most common spectrum allocation used by Ofcom to date in the UK is a 'nationwide or nothing' approach. Individual operators (to date always MNOs) invest heavily in nationwide "mobile" spectrum to utilise this resource in all areas, but in practice typically leave rural areas underutilised as there is not the demand to justify the additional investment in the hardware required.

Perhaps to improve things, spectrum could instead be divided into "rural" and "urban" usage to positively discriminate using regulation in recognition of the market failure. This is partly what Ofcom's shared access scheme was designed to help achieve. However, this introduces the complication of interference between different spectrum users. If a single operator controls all the spectrum within a particular frequency range across a wide geographic area, they can manage any potential interference internally, resulting in an understandable reluctance from in incumbents to consider local spectrum

3 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/solid-progress-further-to-go-for-connected-britain

allocation models in "their" bands. The standards used in mobile networks are designed to handle frequency re-use by one operator, through cell-edge interference coordination standards. It is worth noting however that other technologies (for example Wi-Fi) have shown that high performance connectivity is possible without coordination between users operating on the same frequency.

Modern mobile communications networks are divided up into "cells", each of which has a base station reasonable for their area of land. To maximise land coverage the base station is generally mounted on a high point of land, and it transmits to devices within its area of coverage. The frequency of the signal affects the propagation and therefore the cell size. For example, C-Band frequencies of around 3.5GHz achieve cell sizes of 10km^2 or lower, while 700 MHz cells can provide 140km^2.[4]. The trade-off of using lower frequency is that there is less capacity due to the limited amount of spectrum available in these bands, after it is split between the MNOs.

In practice, in rural areas lower frequencies are commonly employed as less equipment is required to deliver connectivity across the same area. This holds true for both existing MNOs and potential NH providers, but large cells blur the line between 'rural' and 'urban', as radio waves do not respect geographical boundaries. One potential option could be to restrict rural NH providers to using mid-band spectrum with less favourable propagation to mitigate the interference risk. The downside of this approach is more equipment would be required at mid-band rather than low-band frequencies, pushing the cost up for a NH operator to provide a comparable service and provide in-fill coverage. Unless NH providers can get access to the same low-band spectrum as used by MNOs, they start at a disadvantage.

From a commercial perspective, if rural NH operators' access to spectrum continues to be limited by regulation to higher frequencies, it is unlikely that they will be able to deliver widespread coverage on a commercially viable basis. MNOs continue to hold a monopoly on (generally under-utilised or un-utilised) low frequency spectrum and would thus be able to over-build an NH operator with lower costs "at will". A stronger regulatory requirement to deliver connectivity in rural areas would create potential demand for rural NH service provision, but if the regulatory environment remained structured to restrict rural NH providers into a limited area of higher frequency spectrum, this would simply not be economic for them. We are in a "chicken and egg" situation where deployment of an NH service *could* satisfy pent-up demand for connectivity, but unless the rules change this fundamental hurdle remains.

Device Ecosystems

It is often assumed that handsets and modems are readily available in all bands/frequencies. This is simply wrong. Devices evolve over time, generally lagging the mobile standards by 18 to 24 months. The size, style, functionality, capabilities, emission levels, power consumption, and security and safety levels are totally different today to those of the 1980s. In particular, with the advent of LTE and carrier aggregation, the device and modem ecosystems have become even more tightly coupled – to get the best service on a 4G network, user handsets will typically need to work on 3 or more bands (in the UK, this is often bands, 1, 3, 8 and 20). This trend is continuing within 5G with Qualcomm recently

4 https://www.gsma.com/spectrum/wp-content/uploads/2013/07/ZTE-LTE-APT-700MHz-Network-White-Paper-ZTE-June-2013.pdf

demonstrating a record breaking 5 GBPS downlink but requiring 8 x 100 MHz + 2 x 20 MHz carriers all aggregated together requiring a total of 840 MHz [5] of spectrum.

Originally, band compatibility provided a regional market differentiation factor to discourage "grey box" imports of handsets. Now however, band compatibility is shifting again towards more global use of specific 5G pioneer bands (for example, the 3.3 to 4.2 GHz band). Despite this, the device ecosystem often lags the network infrastructure, especially absent major commercial deployments that would drive device demand sufficiently to interest manufacturers. For example, band N77, which encompasses the Ofcom shared spectrum band (3.8 to 4.2 GHz), has only become more readily available in wireless modules in the second quarter of 2021. On the other hand, N78, which is a subset of the N77 band incorporating the commercial 5G deployments in 3.4 to 3.8 GHz, has been readily available in handsets since 2019.

To provide a commercial telephony service to a device (other than through unlicensed spectrum options like Wi-Fi), specific harmonised spectrum must be used – spectrum which has historically been exclusively licenced to the mobile networks, and to which only they generally have access. Unlicensed spectrum (like that used for Wi-Fi) has historically not been useful for this. As outlined in a previous paper[6], technology is evolving with 5G to make it feasible to operate a 5G network entirely in unlicensed spectrum; something not possible in the 4G era.

Nonetheless, from a commercial business study perspective, the potential of success for a NH provider will be determined by their access to market, and their ability to convert passers-by from "potential" users to "actual" users. Where NH services are operated on unusual bands that are not widely available on consumer handsets, most users will not be able to connect. User adoption and access to technology is notorious in telecoms – in late 2019, a Tech UK report[7] highlighted that "Until VoLTE is universal, there will be a need for 4G circuit-switched fallback (CSFB) to 2G or 3G networks. At present there is still a significant volume of non-VoLTE-enabled 4G devices relying on 2G/3G for voice."

In the same vein, user handsets need to support the bands used by a neutral host, or their service will not be usable in the short term, undermining any investment case. Given the lack of support for unlicensed 3GPP bands in standard retail handsets at present, it is therefore likely that neutral host operators will need to provide a service on harmonised, licensed spectrum.

As part of the shared access framework, Ofcom permits the sharing of licenced spectrum through the local access licence scheme, something we touched on earlier. However, if neutral host operators have to individually negotiate their spectrum access with MNOs, it is likely they would end up effectively squeezed out of the market in the long term – an operator could raise the price the neutral host pays for spectrum and reduce the price they are willing to pay for provision of connectivity, as the same mobile operators sit on both sides of this transaction. Therefore, neutral host operators would likely need regulatory protection to make them commercially appealing propositions for external investment given the ease with which their margins could be squeezed by existing operators.

5 https://www.qualcomm.com/news/releases/2021/01/19/telstra-ericsson-and-qualcomm-achieve-world-first-record-5gbps-5g-download

6 https://5gruraldorset.org/app/uploads/2021/07/5G-RuralDorset-WP6-Neutral-Host-Task-4-Spectrum.pdf

7 https://www.theregister.com/2019/10/18/dont_switch_off_2g_report/

In summary, to ensure a neutral host provider can provide a reliable and consistent service they must have reliable access to *all* the resources they require to provide the service. This includes availability of suitable devices as well as suitable spectrum and a stable regulatory environment (this gives manufacturers confidence to produce devices for given bands in quantity – otherwise they will not).

Architecting a Neutral Hosted Radio System

Assuming consistent and reliable access to spectrum and a device eco-system, it is likely that a NH host operator will want to operate in a single frequency band to minimise equipment costs. For each different frequency band used, there will need to be a separate radio-head or small cell, and a separate antenna. This will rapidly increase the cost of each site by a factor of N, where N is the number of bands used. There are also likely to be cost implications on software licences for the software stack used to implement the 3GPP 4G/5G stack. The key properties of spectrum that matter to a neutral host operator are the frequency band it sits in (some popular bands like B3 and B20 may have widely available small cell systems), the propagation characteristics of that spectrum, and the handset ecosystem around it. A neutral host operator is unlikely to be competing with others in the same building or environment - a neutral host service is likely to be used either to provide coverage in a rural area where it is not viable for each operator to cover, and therefore the market can probably not sustain competitive neutral host provision, or an in-building setup, where the building owner or operator will be coordinating neutral host provision themselves.

Assuming that one frequency band is used to deliver the neutral host service, the next relevant factor is the carrier width that is required to deliver the service, and whether one shared carrier is used for all operators (with multi-PLMN broadcast being used), or whether a series of individual carriers must be broadcast from the one small-cell base station. This in turn leads to one of the more fundamental questions around a neutral host business model – how spectrum is allocated, apportioned and used, where multiple operators' customers have access to a shared base station.

Three recent high profile shared infrastructure announcements within the UK were the Shared Rural Network (SRN), the Transport for London & BAI Communications underground mobile connectivity and the Emergency Services Network (ESN). We analysed the business model of each of these deployments and then compared them to how a rural NH operator might operate.

Shared Rural Network

The Shared Rural Network (SRN) project, announced in March 2020, set out a joint position between MNOs and Government to deliver improved rural coverage through infrastructure sharing in areas which were either total or partial not-spots. MNOs would fund partial not-spot coverage, while Government would fund total not-spot coverage through building shared infrastructure for all four MNOs to use [8].

These sites would otherwise not be commercially viable for the MNOs to serve. This makes it very challenging for a NH operator to consider any financial business model as it would be competing against both MNO and Government. A further unintended impact of the SRN on rural connectivity is the availability of 5G services to rural users. We note that the SRN project only aims to deliver 4G connectivity. This may both distort the market for commercial rural service provision unless you are an MNO, whilst simultaneously delaying the impact that leapfrogging directly to 5G would have – including any cost savings from so-doing.

8 https://srn.org.uk/

This may, for example, have a material adverse impact on the business case for delivery of better quality 5G NH services in rural areas, since mobile operators will have a part-subsidised 4G network in these locations, and little commercial competitive driver to deploy 5G in these areas, since none of their rivals are likely to do so either. This could end up leading to a further digital divide in SRN areas, where they remain on 4G as the rest of the country moves on to 5G.

From a value-for-money perspective, policy makers must consider "in the round" the consequences of various strategies (including SRN) to address the market failure in their Regulatory Impact Assessments (which are mandatory). They obviously felt SRN was the best approach. However, this sends a very negative signal to investors in possible NH players. In many rural areas, local wireless ISPs and alternative network providers already have infrastructure in place, including masts, fibre backhaul, and power supplies. In some areas, commercial rural NH provision is already happening on an experimental level, including in Wiltshire as part of the 5G MONeH project, and Dorset, as part of the 5G RuralDorset project.

Ensuring that mobile operators are not subsidised to over-build local or regional providers is an important priority to preserve the business case of NH operators, which can go further than the SRN network ever could – *SRN is still expected to leave 5% of the UK's landmass unserved by the end of 2025*. There is therefore a strategic "levelling up" imperative to ensure that subsidised 4G coverage does not hold back areas of the UK which actually need the most investment in the latest technology, in order to catch up with urban areas on productivity and GDP per capita. Existing evidence shows that Gigabit fibre connectivity increases rural GVA and productivity by £1,390 per firm per year[9].

To make a rural NH model commercially viable in the SRN world, much more regulatory certainty would stimulate investments. Today, none of the dedicated shared access spectrum licence options would be viable for creation of a long-term NH service, due to the current restrictions and available frequency bands. While local access licences may well be suitable, this would require working with mobile operators to gain access to their spectrum, without assurance of longevity of tenure. As outlined in our previous report on the spectrum policy required to enable NH, we believe that this is being fuelled by a "scarcity-driven" approach to spectrum allocation being taken by Ofcom, which leads to spectrum being left un-utilised, rather than risk there being any actual use of spectrum, and someone who arrives later potentially being unable to access spectrum. The end result is that there is very limited spectrum use, which could be used to deliver on Government's Gigabit broadband priorities, as a result of the regulatory restrictions on it.

For a rural NH business to be an investable proposition by the private sector, there would need to be an ability for a rural NH to gain a level of longevity of tenure in the spectrum they need which is at least long enough to execute their business plan, and the ability to operate radio equipment at a power level more akin to that of a traditional mobile network operator. By aggregating demand from multiple operators, a rural NH operator would be able to deliver coverage at a lower cost than any one operator could, and *without requiring public subsidy*, as SRN does. This may well deliver a better value-for-money solution. Additionally, to be a viable investment, rural NH operators would have to have specific regulatory certainty that they would not be forced by Government or Ofcom to grant an

9 https://www.vodafone.com/sites/default/files/2021-06/Enhancing_Rural_Connectivity_Report.pdf

incumbent mobile operator access to their passive infrastructure on a wholesale basis, which would undermine their ability to aggregate demand and make a profit on provision of connectivity.

To redress this balance and introduce a new level of dynamism around the SRN, one option could be to consider the targeted re-farming of legacy generation spectrum, (which we set out in our previous spectrum-focused paper). If re-farmed 2G and 3G spectrum was selectively retained by Ofcom for local allocation and made available to new entrants in areas where the MNOs had failed to utilise their existing spectrum holdings effectively for the last 30 years, this would deliver a commercial opportunity with potential for profitable returns, stimulating private investment.

Access in particular to lower-band spectrum (such as 900 MHz holdings) would enable longer-range 5G services to be offered by localised rural NH providers, without the fear of immediate over-build by incumbent mobile operators. This would allow a rural NH operator to leverage this spectrum access that enables them to deliver a commercially viable service that an MNO would wish to access on a commercial NH basis, without having to fear an MNO seeking to squeeze their margins by over-building and using their existing un-utilised spectrum to "crush" their innovative smaller rival.

London Underground

Transport for London and BAI communications have entered into a 20-year deal to provide NH mobile communications in the London Underground. This system will expand the existing coverage within the Jubilee Line, where a combination of leaky feeders and a Distributed Antenna System (DAS) provide coverage for all four mobile operators. The limited physical space available and extreme density of people shows that sharing hardware elements can produce a cost-effective solution to providing coverage. Within the Jubilee Line trial, each mobile operator has deployed within their own spectrum allocation which will ensure a comparable quality of service for each of their consumers to that they would experience above ground from a macro mast. Each of the operators has also deployed their lower frequency spectrum allocation in the tunnels for better propagation, coupled with their higher frequency spectrum allocation in the stations for additional capacity. For example, Vodafone have deployed 900 MHz UMTS and 800 & 900 MHz LTE in the tunnels and 2100 & 2600 MHz LTE in the stations.

The BAI communications deal is estimated at £1 Bn and will expand this trail to the entire underground network deploying 4G & 5G, with the first phrase rolling out similar multi-carrier equipment to that demonstrated on the Jubilee line. As part of this deal there are no predicted capital costs for Transport for London, suggesting that BAI communications will fund the service through service revenue.

The density of the underground network provides a clear scale benefit to a providing a communication network, the tube transits 1.35bn passengers per year through the 270 stations and 402km of track with 3.7 million daily journeys. Taking these 3.7 million passengers as unserved mobile users, an analysis using the mobile infrastructure project[10] (MIP) can be undertaken to determine the estimated operational costs.

10 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651008/MIP_Impact_and_Benefits_Report.pdf

The Jubilee Line 4G trial demonstrated that a single low-energy eNodeB and a leaky feeder antenna could provide SISO (single input single output – where neither transmitter nor receiver have multiple antenna) coverage for 1.5km of track. Therefore, installing similar systems for each part of track, combined with eNodeBs for each station would require an estimated 550 eNodeBs, resulting in an estimated operational yearly cost of £4.95M. The actual electrical costs would likely be lower as newer more energy efficient equipment will be used and at lower transmit powers, however, these savings may be offset by the additional ventilation requirements of the underground, therefore they have been kept consistent for a worst-case scenario. However, even with these considerations the operational and capital costs per daily passenger fall significantly lower than the running costs for the Government funded Mobile Infrastructure Project (MIP) sites, £1.33 OPEX per person per year compared to £10.70 in MIP.

To estimate the required capital costs the Jubilee line trial was used as the complexities of installing equipment in the underground would likely exceed the capital costs for installing a macro cell, again assuming a worst-case scenario. The full trial consisted of several eNodeBs within each of the Waterloo and Bank stations and leaky feeders within the tunnels. This represented approximately 1% of the entire underground network, and cost 10m. Scaled to the entire underground this would suggest £1 bn in capital costs.

Economies of scale and findings from the trial are likely to reduce these costs, however, 20-years' worth of operational costs would offset many of these savings resulting in the agreed £1 bn figure agreed between TFL and BAI communications. The majority of the capital expense is expected to be undertaken by 2024, when the network is due to be fully operational, this would require 3.5 years of capital investment upfront to be paid over the 20-year agreement.

Over the 20-year agreed funding period, the service would have to provide an estimated income of £64.6m per year to pay back, the operational cost, the initial investment, and average returns of 7% for investors.

This would mean charging an additional £17.40 per year to the 3.7 million repeat underground consumers or charging 5p per journey for the 1.35bn annual passengers. This additional cost could also be covered through roaming charges with the high number of tourists who use the underground every year. Vodafone recently announced the re-introduction of EU roaming charges for their consumers of a minimum of at least £2 per day, which if a similar scheme was employed for the underground would be an additional source of revenue.

As part of the London 2012 Olympic offers, the London underground offered Wi-Fi within all the stations provided by Virgin Media. This service can be accessed through a pay as you go fee of £2 per day, £5 for a week's access, or £15 a month. Previously the four UK mobile network operators provided free access to their consumers as part of packages, however, recently, Vodafone have pulled out of this agreement citing cost concerns. This demonstrates a prior willingness on the part of the MNOs to engage in paying a third-party provider to provide connectivity on the Underground, and this allocation may get redirection to providing 4G/5G service through the BAI communications deal.

As part of the BAI communications deal, additional fibre infrastructure is along expected to be installed along with the underground mobile network, therefore, the exact split between mobile and fixed fibre costs is not known. However, this analysis demonstrates that financial funding would be available with competitive returns for a suitable deployment.

Emergency Services Network

The UK Government's Home Office is currently leading a programme to deliver a mobile based communication network, the Emergency Services Network (ESN). The system will replace the current Airwave service currently used by first responders for critical communication. The upgrade to a 4G based mobile system will allow the transmission of data rather than just voice to provide data and images in life saving situations. The service is being deployed using EE's existing mobile network where there is existing service, and 300 additional masts will be built to extend coverage to some of the most remote parts of Great Britain. As EE is providing commercial service alongside ESN, this will also enable members of the public to make 999 calls in previous not-spots of the country. These masts will simultaneously broadcast EE's and ESN's PLMN codes and each service will be routed back to a separate core network. This therefore provides a Neutral Hosting service.

The 2019 cost estimate for this 20-year programme was £7.9 bn by 2037. This includes both capital and 20 years of operational costs. A large cost of the ESN programme is transitioning from the previous communication system, Airwave, with the other main costs listed below.

Service	Cost £ (Millions)
Mobile communication service	1,672
User services	1,192
Delivery partner	162
Project management and integration	286
Coverage	696
Other	117
Devices	1,070
Usage (phone calls and data)	470
Transition from previous service	156
Control rooms	62
Transition service (Airwave)	2,921

The 'Coverage' category, includes the cost to upgrade EE's existing 20,531 masts to support Neutral Hosting and ESN, the creation of 401 additional EE sites, 292 Home office sites, and various other sites to remove blackspots, such as within tunnels. This also includes the cost of validating coverage models and ensuring signal is available where expected. The 'Mobile communication service' is the cost of providing priority service on EE's network for 20 years and represents a per user annual cost of £301. Including 'Usage' costs of £84.80 per year, results in an APRU for priority mobile service of £32 per month. This is notably higher than the APRU for regular consumer service of £15, which EE is able to provide through NH albeit with varying priority. Moreover, the ESN service itself is expected to be 'rented' to non-emergency service users, providing a more comparable business model to a regular NH provider.

This non-emergency service is estimated to generate £254 million over the 20-year life expectancy. Equating to £12.7 million per year, this can be shared equally between all the 20,531 masts within the emergency service network, giving an additional revenue of £618 per mast per year. As this is not sufficient by itself to cover the running costs of the masts, this is a prime example of a consumer who would not be able to financially justify their own mobile network, yet through sharing infrastructure these non-emergency users are able to gain connectivity, while simultaneously providing the ESN network with additional revenue.

The split between EE and the Home Office built masts also demonstrates one of the benefits of Neutral Hosting - the availability for a third-party provider to expand MNO network coverage when the market economics do not work for the MNO to provide such a service.

Neutral Hosting Financials

Potential Income Streams for a Neutral Host Operator

These previous examples detail the scale of the finances required to undertake a NH service ~£1 Bn. As this is unviable for a small local provider, we will now explore the potential income or revenue streams which could be realised by a smaller NH operator in pursuit of a sustainable business model.

On an ongoing basis, a neutral host operator will need to pay for backhaul connectivity and power, site rental, replace damaged or malfunctioning equipment, software licences and support costs, and preserve access to the radio spectrum required to deliver a neutral hosted service. Therefore, to build a sustainable business, the neutral host operator will require income through one or more revenue streams, in order to fund their outgoings and service their debt, and to deliver a return to their investors. Absent this, a neutral host business would be unsustainable.

Potential revenue sources as a neutral host operator could include some of the following. Note that we do not propose these are all attractive or feasible, rather we aim to identify the breadth of possibilities, then explore how feasible and viable these may be in subsequent sections:

- Agreed "coverage rates" paid by an operator each month for provision of coverage to a given area.
- "Inbound user" rates paid by an operator based on their users' use of the neutral host provider based on metered metrics (i.e. radio resource block usage, or backhaul bandwidth, or megabytes of data used).
- "Roaming credit sharing", where operators share roaming rates received from overseas users' operators with the neutral host operator.
- "Semi-private network" service provision by the neutral host operator to nearby businesses as an additional revenue stream.
- "Data-driven" revenue streams, such as insights about user trends.

Breaking these down more generically into categories, there are 3 main types of revenue stream we can envisage – coverage-based revenue, traffic/usage-based revenue, and other innovative revenue models. Hybrid models based on combinations of these would also be possible.

Coverage-based revenue would be an attractive proposition for a rural neutral-host operator, as it would yield a predictable revenue stream based on the coverage offered by their network to each operator they serve. Since rural areas have a lower population density, and often have highly seasonal variations in usage (i.e., coastal holiday resorts in the busy summer period, vs. the quiet winter period), there is likely to be some desire from rural neutral host operators to see a coverage-based revenue component. From a mobile operator perspective, paying a third party to provide coverage where there are no (or limited) users is not an appealing proposition, unless an MNO were to be incurring costs greater than the costs borne by the neutral host operator, at which point it would make commercial sense and be more appealing to remove and de-commission their own assets, and pay the NH provider to deliver coverage in that area. The imposition of stringent coverage obligations on operators by Government would be one way to stimulate this.

Mobile operators have recently been increasingly seeking to capitalise on their infrastructure assets and shift these from their balance sheet to unlock their value for shareholders – Vodafone's spin-out of their stake in their joint-venture CTIL tower company into Vantage Towers, separately floated on the stock exchange recently, is an example of this. One option which operators could consider in a world of neutral hosting would be the liquidation of their existing passive or "passive-plus" infrastructure through sale to neutral host operators on a localised basis. The operator could then lease-back active neutral-hosted infrastructure in rural areas where demand is lower and the operator sees no significant competitive differentiation in the coverage they offer.

One challenge of this approach is that the savings and economies of scale in neutral hosting arise from the delivery of multiple operators' coverage through one set of infrastructure – it is unlikely that a neutral host operator will be able to beat a mobile operator's economies of scale to deliver coverage on a local basis. On the other hand, a local operator who is able to aggregate service provision on behalf of 3 or 4 MNOs is likely to be able to offer a cost saving to each operator, while also making a profit. This is the model employed in both ESN and SRN.

A potential impact on this topic is around the proposed 2G and 3G "legacy switch-off", which the Minister for Digital Infrastructure said would be explored over the summer of 2021, with a strategy to be announced going forward. Today, in rural areas, 2G provides a lifeline layer of basic connectivity across a far wider footprint of the country than the 3G or 4G networks.

From Ofcom's Spring 2021 Connection Nations Update, 9% of the UK's geography is not covered by any operator on 4G, but only 5% of the UK's geography is not covered by any operator on 2G or 3G. In Scotland, which generally has the poorest coverage of UK nations, 19% of the geography is not covered by any operator on 4G, with 11% of the geography not covered by any operator on 2G or 3G.

It is possible that neutral hosting could be used as part of a wider proposal to the telecoms sector around 2G/3G switch-off, to ensure that rural communities do not lose access to what little connectivity they have when the older networks are switched off. To address this, 4G and 5G infrastructure will need to be brought to these areas and, as the 5G RuralFirst and 5G RuralDorset testbeds have both shown, local communities themselves are well-placed to deliver affordable and viable connectivity to these kinds of challenging areas, while breaking down traditionally perceived cost barriers. As such, network operators could partner with local neutral host providers before being given approval to cease provision of 2G and 3G service in a given area, in order to demonstrate equivalent 4G and 5G coverage has been introduced through a NH provider.

Mobile operators have demonstrated in recent years their relative comfort with the model of spinning off capital investments in towers - Vantage Towers, and tower-share joint ventures between Vodafone and O2, and EE and Three respectively. These models illustrate how economies of scale are leveraged in the industry to avoid perceived inefficiencies from each operator paying for their own towers. If operators align their cell grids, they can share towers, and therefore require fewer towers (and therefore incur less maintenance and site rental costs). An extension of this is to share active components, as is seen in the O2-Vodafone shared Beacon network initiative, where one of the two operators provides the radios for different zones of the overall network. Following this trajectory, there is a desire in the industry to reduce capital expenditures, and "spin off" stakes in capital assets through joint ventures[11]. Were this trajectory to continue, the observation made by the GSMA that "RAN sharing is gaining commercial traction"[12] may prove to rapidly come true. Sharing of radios has been predicted to give reductions in the number of required sites and masts to deliver the same coverage, a reduction in both CAPEX and OPEX due to sharing of backhaul, and a reduction in environmental and visual impact due to fewer towers and radios being present. Neutral hosts could provide suitable vehicles to act as independent infrastructure operators (like spun-out tower companies), in order to serve multiple operators using one set of infrastructure. Rural NH is therefore simply a logical extension of existing RAN sharing, but applied in a way that makes the most sense in rural areas.

Internet of Things

Innovations such as the IoT (Internet of Things) represent one of the innovative revenue streams for NH operators. Many aspects of IoT-based service models challenge the traditional MNO model. In a world of IoT, infrastructure, safety or security equipment, traffic lights and agricultural machinery are the user, rather than people. The financial challenge these services have is that many of these use cases cannot bear the existing average cost of a connection (£15 per device per month), traditionally used by mobile operators to model the cost-benefit analysis of building a new tower. However, the flip side to this is that, in order to realise many of the benefits of IoT, cost effective ubiquitous seamless connectivity is required - in the same way that nobody wants to listen to a radio programme that keeps on being interrupted due to interference and static noise, few will want to use an IoT service that only connects successfully in certain places or at certain times. For use-cases enabling key public services, connectivity needs be reliable.

This is in part why the uptake of alternatives services such as LoRaWAN have been successful in capturing the IoT market, and the deployment of cellular IoT services have been stunted. LoRaWAN operates in the ISM band at 868 MHz and only requires comparatively inexpensive base stations (~£1500) with minimal power requirements. Therefore, if a consumer is unable to achieve consistent coverage to match their requirements, they can simply deploy additional base stations themselves.

The reduced capital and on-going operational costs of deploying a network also result in reduced costs of connectivity. The Dutch operator KPN deployed a nationwide LoRaWAN network connecting 1.5 million devices. The pricing model for devices is based on usage, but for infrequent sensor usage an estimated €0.35 per month per device is employed. This sets a marker for how much individuals may be willing to pay for IoT device connectivity. Importantly this price is lower than the cost of comparable cellular connectivity.

This opens an opportunity for a NH operator to provide in-fill coverage at a lower cost than a traditional operator would be able to do. As a bonus of deploying 3GPP technology rather than a bespoke LP-WAN solution, is it is possible for the NH to serve both traditional consumer use of connectivity, (mobile phones) as well as IoT devices (sensors) using the same set of infrastructure at a lower cost than a traditional operator would be able to provide.

11 https://telecoms.com/506770/three-could-become-the-latest-telco-to-cash-in-on-its-towers/

12 https://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Mobile-Infrastructure-sharing.pdf

This ability to rely on existing coverage and supplement If required, would grow confidence within the industry and expand the overall cellular IoT ecosystem to in turn grow consumers and users for IoT services for all connectivity providers.

Deploying a Rural Neutral Host Service – Case study

The Mobile Infrastructure Project (MIP)[13], provides a widescale example of the commercials required to operate a rural mobile service. 75 macro sites were deployed at circa £550,000 per site each with a yearly operational cost of £9,000. These 75 sites provided coverage for a total of 7,199 premises. However, as 84% of the sites cost more than the likely income over the 20-year lifespan of the infrastructure, without intervention these sites would not been of built. Moreover, in most instances, rural sites will be under-utilised, a tri-sector 2 x 10 MHz 800 MHz rural cell can provide 2 Mbps connectivity for 1020 domestic premises[14], notably more than the average 95 premises covered by each MIP mast, demonstrating that the potential users of rural masts fall short of the available capacity. Recent technological innovations such as AgriTech, to make farms more intelligent, could fill this excess capacity. However, as the cost of MNO connectivity commonly exceeds the possible benefit to the farmer, these rural sites are not financially viable for the farmer or the MNO.

Instead, private rural networks have been proposed where a local operator could deploy high-capacity mid-band spectrum to provide rural connectivity. We have previously explored this option extensively in our spectrum paper, however, discovered that practical and regulatory restrictions meant that on average each mast would only cover 40 premises. Thereby, also not presenting a financially viable solution.

As neither operator can independently deploy a viable connectivity solution, we now explore the possibility of a NH deployment where assets and resources are shared between a local operator and a national operator. Local operators can employ community knowledge and assets to reduce the cost of deployment, while a national operators can share their spectrum to enable the local provider to achieve sufficient coverage to offset the initial costs.

This combination would expand a MNO's coverage at a lower cost, than they would commonly be able to deploy themselves, enabling them to reach more mobile consumers, while simultaneously enabling a local provider to reach sufficient coverage to present a viable agriculture network. Two important considerations are that, as detailed above, there is likely capacity remaining in the cell, thereby not negatively effecting the primary spectrum holder's consumers through sharing their resources, and agriculture use cases would struggle to support the target APRU of MNOs. Thus, offering a beneficial solution to both parties. However, as the success of this deployment relies on the spectrum and license conditions currently only available to the incumbent MNOs, we will now focus on the incentives, concerns and state of the art for national operators to enter into a NH agreement.

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13 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651008/MIP_Impact_and_Benefits_Report.pdf

14 https://www.ofcom.org.uk/__data/assets/pdf_file/0026/71468/real-wireless-cost-analysis.pdf

What is the Commercial Incentive for an Operator to do Active, Real, Neutral Hosting?

One of the most significant business risks in attempting to build a neutral host network is around finding suitable commercial incentives for an incumbent mobile operator to use shared active radio infrastructure. Similarly, there is also a business risk for a smaller, local, potentially niche player, who may feel they are "letting the fox into the hen-house" by forming an enduring commercial relationship with a larger provider.

From a business perspective, one of the biggest advantages for an operator "consuming" a neutral host service is that they can present a single, consistent and coherent, branded service to customers under their own trading name, even where users sit beyond the reach of the operator's own physical network. This could be attractive for smaller new market entrants and help them to rapidly establish a coverage footprint in the market. Similarly, an existing operator would be able to use this to deliver a branded service in rural communities where they had limited infrastructure. This could be particularly attractive in 5G networks, where poorer RF propagation in rural environments means that denser cell grids would be required, which cease to be attractive at a national-scale operator's cost base. Employing multi-operator shared infrastructure could reduce the required CAPEX by between 35% and 65% per MNO[15] where capacity would not be the constraining factor. Moreover, sharing assets reduces overbuilding, 29% of UK passive assets are provided by independent infrastructure providers and many of the remaining sites are managed through joint ventures, Cornerstone and MBNL[16]. Similarly, operational costs can be reduced by 3% per mobile operator through sharing existing passive infrastructure. The combination of OPEX efficiencies, shared physical infrastructure, and sharing point-of-presence managed through a single TowerCo, results in deployments that are, on average, 46% more capital efficient, compared to a sole MNO deployment over a 10-year life cycle.

These savings can be amplified through sharing active components, as 'fixed' costs such as electricity are estimated to be between 20-40% of MNO's OPEX[17]. OPEX costs are typically around 70% of the total cost of ownership of a mobile operator within a developed market [18]. Therefore, reducing this cost the OPEX would result in a notable saving. Part of these savings will be provided through advancements in New Radio (NR) technology, which can result in up to 70% energy savings in rural/low usage environments [19]. However, these savings are likely to be offset by the increased number of base stations required to scale with capacity and would still incur 'stand by' costs from the radio transmitting while no revenue-generating users are being served. Instead, sharing activate components through a NH model would split the electricity costs between all the operators utilising the equipment.

The sharing of active components would also enable operators to better utilise existing spectrum. Ofcom's most recent spectrum auction included an overall spectrum limit of 416MHz per carrier.

15 https://www.gsma.com/futurenetworks/wiki/case-study-das-as-a-service/

16 https://assets.ey.com/content/dam/ey-sites/ey-com/es_es/news/2021/02/ey-parthenon-and-ewia-report-on-european-mobile-tower-sector-v2.pdf

17 https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

18 https://www.analysysmason.com/globalassets/x_migrated-media/media/analysys_mason_5g_key_considerations_white_paper_oct20192.pdf

19 Frenger, P. and Tano, R., 2019, April. More capacity and less power: How 5G NR can reduce network energy consumption. In *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)* (pp. 1-5). IEEE.

These allocations are spread through various 3GPP 5G bands - N1, N3, N7, N28, N40 and N78. In extremely high bandwidth areas such as stadia, multiple diverse radio heads within each of these bands are employed to cope with demand. For example, during Super Bowl LV, 55 terabytes of mobile data was consumed [20]. This capacity can be further increased through reducing the cell size as demonstrated at the Wanda Metropolitano stadium in Madrid, where Cellnex deployed a multi-operator DAS system with 250 antennas and 100 radio heads featuring 2G/3G/4G and sufficient capacity for 67,703 fans to get 30mbps throughput each. Such a system can take full advantage of all the available spectrum while offering a strong quality of service to each of the operators' consumers.

Were the UK to see movement of regulation towards tougher MNO coverage obligations, this would be one way in which Government could attempt to incentivise industry to deliver better coverage in rural areas. There would be further incentive to seriously explore the use of NH infrastructure, as it would allow coverage obligations to be satisfied without the same quantity of capital investment being required as for owned-infrastructure deployment.

A key challenge often experienced by operators in rural areas is that of site identification and selection, where sites are likely to be placed in countryside or other natural landscapes, as in Dorset, with their UNESCO World Heritage significance. Moving towards a NH model of service delivery in rural communities could help larger national operators to empower local communities to drive the delivery of mobile infrastructure in their own area and help to reduce objections to sites. A commonly-cited problem is planning permission – by empowering local communities and helping them to become part of the solution for delivery of better coverage by operating a local neutral host network, they become part of the solution – local sensitivities around historic sites and/or views can be respected, while the community itself benefits from better connectivity and potentially income from operating the neutral host service.

A model like this has been seen in the Orkney Islands, where a 5-turbine wind farm is community-owned[21], with the local council as the largest investor, and around 50% of the funds locally financed. This approach of community buy-in and leadership helped the scheme to overcome traditional local objections to large wind farm installations.

Commercial Considerations for an Operator to do Active, Real, Neutral Hosting?

Mobile operators currently control the whole customer experience and are responsible for maintaining quality of service for their consumers. Relying on a third party, such as a NH operator, to ensure these standards are maintained would create a trust and technological dependency. Given this, it is understandable operators would prefer to maintain this ability to maintain their own service. This potential lack of oversight and control also may present technical concerns.

Currently, new mobile masts are tightly integrated with the rest of the operator's network. For example, if a new mast's coverage overlaps with an existing coverage, the existing cell may be modified to reduce its size and encourage device handover to the new cell. This ensures strong and efficient connectivity for users, particularly around the cell edge. This inter-mast communication requirement also introduces potential security concerns for shared infrastructure. Previously isolated

20 https://www.gsma.com/futurenetworks/wiki/case-study-das-as-a-service/

21 http://www.orkneywind.co.uk/hammars-hill.html

networks would be opened through common infrastructure, presenting potential "bridging points" between multiple operators' networks.

MNOs have also invested heavily in the resources required to run a standardised mobile network. While historically many of these resources were specialised heavily on circuit switched telecoms-specific technologies, with the transition to IP based networks this specialisation is eroding away, and new skills requirements are emerging in virtualisation and IT platform security. This reduces the barrier to entry for new operators, but also leads to increased market instability. Previously, entering the market required significant capital, meaning that only large stable companies able to weather market fluctuations risked engaging. This also meant that entrenched companies could depend on the fact that their suppliers would be able to continue to supply and support their needs ensuring a stable and predictable environment. This may cause existing operators some hesitation in selecting newer vendors who may not be as stable, and therefore potentially unable to provide the ongoing support they require.

Similarly, MNOs have allocated significant financial resources to ensuring the continued availability and near-exclusivity of what is needed to run (and compete with) their core business – spectrum. Changes to the perceived value of spectrum, through sharing this resource, may negatively affect the overall market valuation and confidence within the company. For example, if the ability to deliver high-quality service in an urban environment no longer correlates to amount of spectrum exclusively held, what separates providers?

The Realities of Neutral Host for an Operator

Much of the operation of mobile networks is currently outsourced to vendors or other managed service providers, and therefore dependencies already exist on third parties to maintain, operate and update existing infrastructure. This dependency was demonstrated in late 2018 when an expired Ericsson certificate meant that O2 consumers could not access their mobile data [22] [23]. Equipment vendors are often employed to control this equipment due to the complication of managing and orchestrating the active network equipment itself. This is further complicated in a NH environment due to the need to manage interconnections with multiple operators whilst remaining neutral.

These complications are likely to increase with a wide range of potential new suppliers – onboarding, security, commercial issues. These considerations are consistent with existing DAS deployments, such as the London Underground, but this is reduced to a single large and experienced provider. This partly describes why market innovation has struggled to make NH more widespread. The need to be a big player to operate and negotiate at the required scale – hence only really seeing neutral DAS/big-scale providers and other complex scenarios. Operators already deploy multi-security-zone networks – we have seen femto cells and other untrusted access networks connected into operator networks through ePDG (VoWiFi) and to a HeNB-GW (Home eNodeB Gateway) via a SeGW (Security Gateway, IPSec terminator). Given the NCSC Telecoms Sector Risk Assessment highlighted a loss of

22 https://www.ericsson.com/en/press-releases/2018/12/update-on-software-issue-impacting-certain-customers?hootPostID=ef3d37949fba5349b993945f911d89e6

23 https://www.ft.com/content/778469aa-f934-11e8-af46-2022a0b02a6c

domestic capability to run and operate UK networks as a top-5 concern, we anticipate that future trends will aim to address this by reversing the trend of outsourcing and off-shoring network management functions.

Intermediary companies have sprung up to present a unified interface for operators to connect to many smaller operators. However, requiring these intermediaries erodes part of the business case, as makes it NH connectivity provision more expensive, and such intermediaries could favour only connecting with NH operators the intermediary wishes to support. This problem is amplified with the razor thin margins rural providers will likely have to operate within.

Recent innovations such as low earth orbit satellite communications can now provide a potential solution for the most rural fringes of the country with lower latency than was previously possible, where there is no other option. These solutions do not offer the ability to serve large numbers of users with a high quality of service at an affordable price yet, and since uplink and downlink bandwidth are shared across a wide area, they will struggle to deliver high speed connectivity for large numbers of users. It should therefore be considered as a 'when all else fails' option for rural connectivity provision. Consequently, this leaves a significant market of rural consumers in need of improved connectivity, for whom other more conventional solutions, such as rural NH, are likely to deliver better results.

The Risks of Margin Squeeze

One significant practical commercial risk to a rural NH operator's viability arises from a regulatory scenario where the NH operator is expected to gain access to spectrum via localised sharing of operator spectrum on a commercial basis, then has that same operator (and others) as the wholesale users of that spectrum.

In such a case, since the same, considerably larger, MNOs would sit on both the supply and demand sides of a rural NH operator, there is a strong case for active regulatory involvement of Ofcom or the Competition and Markets Authority (CMA) to oversee such a market and avoid anti-competitive activities. There is a strong argument to be made that localised rural operators can deliver more cost-effective solutions, but where they are dependent on their own customers for access to spectrum (without which they are unable to operate), there is a serious risk of being aggressively margin-squeezed by their customer (and spectrum provider) with a view to a larger MNO being able to carry out a low-price acquisition of the business.

The potential for this kind of margin-squeezing to take place is likely to significantly discourage private investment in rural NH operators – anyone carrying out basic due diligence would be concerned by a company which required access to spectrum from the same 4 companies, then sold their services primarily to those same 4 companies. These companies would have visibility of the price paid for spectrum, as well as the price paid for connectivity, and benefit from both their size relative to a local NH operator, as well as their control of pricing, in any commercial negotiations.

Technical Challenges

The Trade-Off of Efficiency and Resilience

One key trade-off which must be acknowledged when considering the economic case and benefits for NH infrastructure providing an aggregated RAN-share service to operators is that there is an inherent loss of resilience to the communications network. For example, where multiple services are provided through one set of radio infrastructure, there is the introduction of a single point of failure around the radios, equipment and physical site, which may disrupt service on all mobile networks. This would have a knock-on impact on users, who would be unable to make even emergency calls in the most rural areas where such a neutral host service would likely be used. An example of this issue can be seen in the Bilsdale Arqiva mast fire[24], where a TV transmitter fire took down Freeview, DAB and FM TV and radio signals for over a million people in North Yorkshire, Teesside and parts of Co. Durham. For many days after the fire, there continued to be significant disruption, with many homes still without TV or radio signal[25]. One shared mast offers practical and economic benefits but means any failure of the aggregated infrastructure will disrupt all services relying on that infrastructure.

This inherent trade-off between cost-efficiency and resilience is a key one – there is a strategic resilience benefit in having redundancy between mobile networks, since all users, whether using UK or overseas SIM cards, can make calls to the emergency services using a signal from any mobile network. While under a neutral hosted network this would continue to be the case in the event of a core network incident, this would not necessarily be the case if there were a power outage or other outage on a mast site, which disabled the base station, radio equipment, or backhaul. There are both technical and organisational resilience factors to consider here – a compromise or failure of the O&M (operation and maintenance) system of a neutral host operator could also cause service disruption, indicating that there may be merit in both NH provider redundancy (i.e. multiple companies running NH infrastructure), as well as geographic provider redundancy (i.e. an area not being served solely by one single NH provider). Alternatively, a specific focus on resilience of NH infrastructure could be considered, with requirements placed on operators to ensure they are able to offer a suitably resilient solution. It is important to note that resilience has an ongoing cost associated with it, and that the margins for rural NH service provision are already thin.

Were operators to see rural NH adoption as a credible way to deliver coverage in rural areas, resilience would likely become an externality that regulators or Government would need to focus on – providing a more resilient service in urban areas with higher customer density and usage makes commercial sense since an unreliable network would be likely to rapidly see churn of customers to their rivals. In rural areas, where there is scarcely the business case to provide a service to users, due to lower population densities, and coverage obligations and other regulatory mechanisms to deliver coverage are required, it is highly unlikely that reputation and threat of user churn would deliver this.

By way of example, Three's own coverage map[26] as of August 2021, did not indicate any 4G coverage being available on the Orkney islands other than on the very southern-most tip of one island. In

24 https://www.bbc.co.uk/news/uk-england-tees-58169501

25 https://www.bbc.co.uk/news/uk-england-tees-58181439

26 http://www.three.co.uk/Discover/Network/Coverage

contrast, coverage reported to Ofcom and made available on Ofcom's coverage checker[27] indicates that there is a 4G service available in many areas. This indicates that, at least for one operator, there is likely to be insufficient commercial case to update the coverage map for this rural area. This is backed up by anecdotal evidence from local residents, stating that O2 offers the best coverage, which in turn would influence any new residents wishing to get a mobile service.

Emergency Calling and Voice Services

Another important consideration for NH service provision is around how access to emergency calling can be provided. As outlined in a Tech UK report from 2019[28], significant numbers of users with 4G phones still rely on the legacy 2G and 3G networks for their voice calls. There are several factors that explain this; sometimes users are not in range of a VoLTE-enabled base station. Other-times, their handset does not have support for the operator-specific "carrier bundle" of configuration files that is required for IMS-based IP voice services to work. This is particularly common among MVNOs. Also, many MVNOs do not provide any IMS-based services, presumably as part of a simplification of their network offering, and a cost-cutting measure. This can be an issue for a NH operator, especially as it may increase the complexity of delivering a reliable emergency calling solution for users. In an analysis we carried out in 2020, the only MVNOs offering IMS-based services were those operating on the Three network.

More generally in the telecoms industry, DCMS' Telecoms Diversification Taskforce has pointed out the challenges of circuit-switched calling more generally on the ability of new vendors to enter markets. If legacy circuit-switched calling is required for voice service, this introduces requirements for a neutral host to implement 2G or 3G infrastructure as part of their deployment. This will place significant constraints on the radios used in the RAN, since multi-generation base stations will be required, and these will need to work across multiple bands, to serve a suitable 2G and 4G/5G signal. As the Diversification Taskforce has pointed out, a requirement to support legacy generations of mobile technology will increase costs of equipment. For a NH operator, it would also increase the costs and complexity of gaining access to spectrum supporting legacy networks, at a time where operators are keen to re-farm existing legacy network spectrum holdings for use with newer network technologies. From a NH perspective, this also introduces spectrum requirements, and there are very few viable options for this, beyond the 3.3 MHz of local access licence spectrum available in the 1800 MHz band. The transmit power limits on this spectrum on these licences are highly restrictive.

We propose that to make NH service provision financially viable, it is necessary to push forward adoption of interoperable and standards-based IMS-based VoLTE/VoWiFi services, which are tested to function on handsets without carrier-specific configuration bundles. A significant footprint of 4G-capable devices do not work with IMS-based voice or SMS services due to handset compatibility and profile issues. This will have commercial implications on operators seeking to partner with a NH provider, since there would be a contingent of users who would require a handset upgrade to gain service in this area. While this is partly a technical issue, and partly a standards and validation issue, it would manifest itself as a commercial issue for an NH operator, since the mobile operator would not

27 https://checker.ofcom.org.uk/en-gb/mobile-coverage

28 https://www.theregister.com/2019/10/18/dont_switch_off_2g_report/

be able to permit handsets to join a NH-provided network that didn't facilitate voice and emergency calling. In any case, it is likely to significantly benefit the UK to resolve this issue for the future, to ease use of IMS-based IP voice for emergency calling.

There are also potential competition issues arising around this – mobile operators favour direct-sold handsets, since they have validated these devices with their IMS offering[29], and often have relatively limited lists of supported devices[30]. Given the relatively fragmented software update ecosystem for Android devices, and the complex inter-dependencies between the underlying operating system and the modem firmware (both of which may require carrier-specific configurations[31] to make IMS work), IMS-based features like VoLTE, VoWiFi and SMS-over-LTE/Wi-Fi are one of the few features in a modern mobile system to not work seamlessly between standards-compatible handsets and networks. This helps to provide a functionality-based moat that discourages switching between operators, which is especially relevant at a time when consumers are increasingly unbundling their handset from their subscription.

In the USA, T-Mobile has already ceased providing 3G voice service, and AT&T is in the process of phasing out 3G calling over the coming months[32], with a limited list of handsets that support VoLTE and VoWiFi on AT&T[33]. This indicates that such a roll-out is feasible, at least in other markets, but that handset compatibility continues to be a challenge. We note that IMS services are provided in a mobile core network, and therefore should, in theory, be radio network agnostic.

29 https://ee.co.uk/help/help-new/getting-started-and-upgrading/using-your-phone-features/how-do-i-use-4g-calling

30 https://www.o2.co.uk/business/support/network-support/wifi-and-4g-calling

31 https://tech.ssut.me/qualcomm-modem-configuartion-mbn-with-carrier-policy-description/

32 https://www.androidauthority.com/volte-att-t-mobile-1148654/

33 https://www.att.com/idpassets/images/support/wireless/Service-Capabilities-Unlocked-Devices-ATT-Network.pdf

Building an Ideal Neutral Host Operator

The London Underground project demonstrated that companies and investors are willing to invest long-term risk-taking capital where there is a strong business case. Reducing the risk (especially regulatory risks) as much as possible is important for an investment perspective, as businesses perceived to be high risk investments will always struggle to access low cost-of-capital financing which in turn would require a higher potential return to deliver a return. These higher costs would reduce, if not remove, a viable business model. Therefore, sufficient clarity about the longevity of the business plan (as well as the regulatory environment) is critical. To that end, the current scheme of a 3-year term, on the local access licences is not sufficient for a long term 20-year investment, and as previously highlighted hardware eco-systems are also critical.

From a user devices perspective, committed orders of at least 100k units per individual SKU (stock keeping unit) is generally required before a manufacturer will typically entertain discussions for operator-specific customisation, thereby, making it effectively impossible to single-handedly develop a new approach to spectrum and service delivery. Consequently, we have assumed that a long-term spectrum licence for existing mobile bands would be available. Noting that the existing licence holders should be fairly remunerated for sub-leasing their spectrum holdings, each of the recent UK spectrum auctions are detailed in the table below, with average price per MHz per mast that national operators employ.

Frequency	Average Paid by for MNO per year	Spectrum Holding	Cost per mast per MHz per year
700 MHz	£14,000,000	2x 10 MHz	£68.18
900 MHz	£19,018,200	2x 17.4 MHz	£53.23
2300 MHz	£10,294,800	40 MHz	£12.50
3400 MHz	£18,912,000	50 MHz	£18.40
3600 MHz	£8,500,000	40 MHz	£10.30

Table 1 – Cost of MNO spectrum per site, by frequency[34] [35] [36]

It is important to note the split between FDD and TDD technology, as FDD requires duplex-paired spectrum to operate, which results in a higher cost per usable MHz. Another notable trend, that lower frequency spectrum is higher priced, is likely due to the favourable propagation properties resulting in reduced deployment costs, and the relative scarcity of this spectrum. Using this pricing model paid by the MNOs plus a liberal 100% administration fee to enable automated interference coordination.

The NH operator would purchase, install and operate all the required telecommunications equipment at costs of £30,500 and £900 per site for capital and annual operational expenditure respectively. This represents the costs, so we'll now examine the potential revenues.

Recent changes to EU roaming agreements have seen charges of £2 per day for UK MNO consumers to use their existing mobile package abroad. This is price is higher than the wholesale cost price paid

34 https://www.ofcom.org.uk/__data/assets/pdf_file/0018/112932/Regulation-111-Final-outcome-of-award.pdf

35 https://www.ofcom.org.uk/__data/assets/pdf_file/0017/192410/annexes-award-700mhz-3.6-3.8ghz-spectrum.pdf

36https://www.nao.org.uk/wp-content/uploads/2019/05/Progress-delivering-the-Emergency-Services-Network.pdf by mobile operators to access roaming services, according to the European Commission's findings 1 year after EU Roam Like Home legislation was introduced. In 2018 they found that "the wholesale price cap [€6 per GB] could be at least 10 times higher than the cost price". This idea has been repeated in the 2020 Q1, International Roaming Body of European Regulators for Electronic Communications (BEREC)[37], which through various estimates found unbalanced roaming, where there is a net imbalance in inbound and outbound roamers' usage, costs to be between €0.6 and €1.53 per GB. This metric of unbalanced roaming is critical for a local NH provider as it is unlikely than the local operator would have many customers to roam onto a national MNOs network, thereby creating a negotiation asymmetry. The average UK mobile consumer uses 4.5 GB per month[38], which could map to €2.70 to €6.88 per month in wholesale costs to an operator. As roaming is a way of an operator's consumer to gain connectivity where the operate does not have a presence, it would be reasonable to assume the same pricing could apply in areas where a NH operator is providing coverage to the benefit of the national operator.

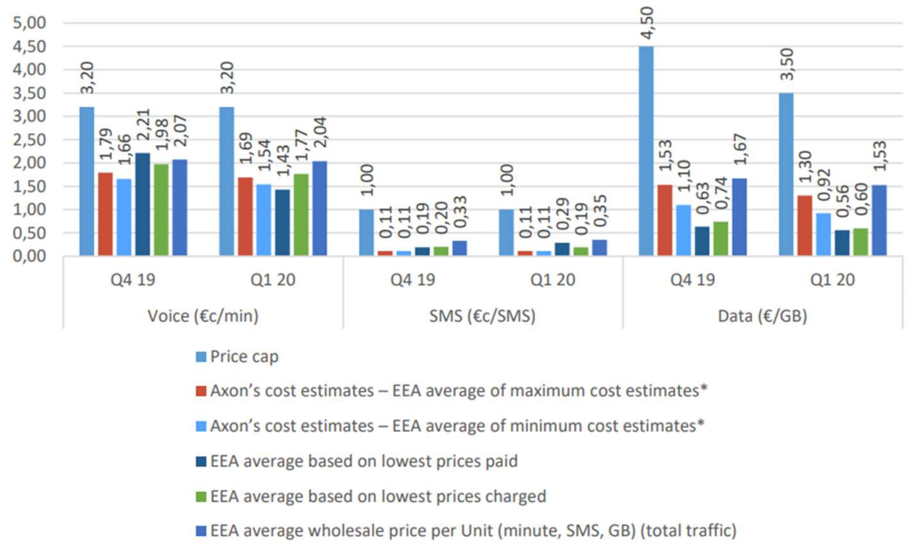

Figure 1 - Mobile wholesale roaming prices[39]

Therefore, a charge of at least 60p per GB per person, could be used as income for a NH operator providing MNO coverage. Assuming a conservative 100 constant users, and 400 users passing through the cell but with minimal data usage, could generate £3500 per year for a NH operator.

A NH operator could also benefit from new business-to-business consumers, including local authorities, public safety network providers, private networks, agriculture and industrial users, a subset of these will now be examined

Smart agriculture is a considerable market, with 9.6m cows, 32m sheep and 5m pigs within the UK. Although mobile cell size varies considerably based on terrain, a conservative estimate for a sub-1 GHz cell is that it could provide 50km^2 of coverage. Similarly, cattle distribution also varies by region and terrain[40]. However, assuming a conservative estimate of at least 75 cattle per km^2, this would

37 https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/9443-international-roaming-berec-benchmark-da_0.pdf

38https://www.ofcom.org.uk/__data/assets/pdf_file/0011/222401/communications-market-report-2021.pdf

39 https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/9443-international-roaming-berec-benchmark-da_0.pdf

40 http://apha.defra.gov.uk/documents/surveillance/diseases/lddg-pop-report-cattle2020.pdf

generate £3750 per year per mast for a NH operator, at a very competitive price point for farmers of £1 per year per animal.

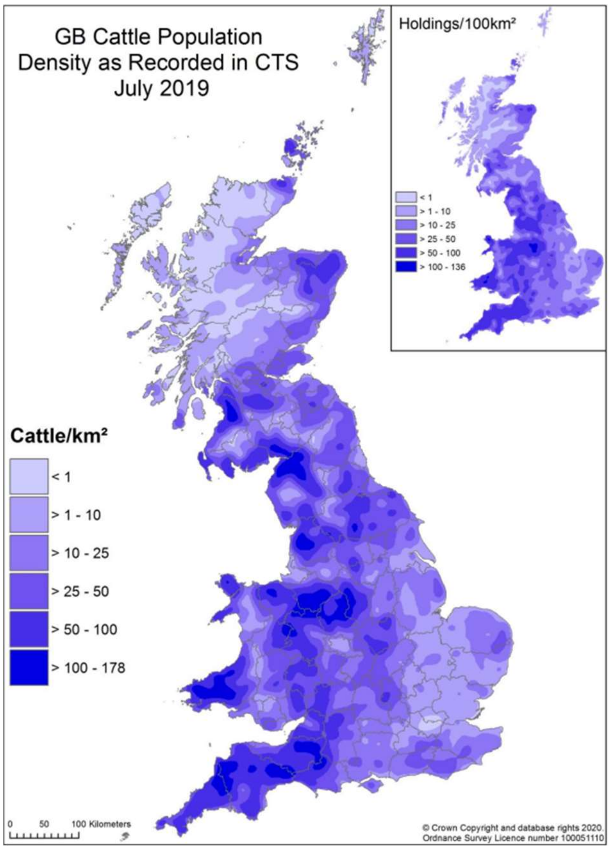

Figure 2 - Great Britain cattle population density (2019)[40]

Arable farming represents another significant potential use case with 43,140 km2 of crops. Autonomous farming robots can increase yields and reduce costs, but require a large amount of data therefore, this represents potential significant consumer for a NH operator, and based on estimates from the 5G RuralDorset project, could generate a comparable level of income to livestock farming from a smaller number of consumers.

Local authorities could also benefit from increased connectivity for their public services - in rural areas where the distances travelled incur additional costs through both fuel and time for services, additional trips should be kept to a minimum. This logic applies to both universal and specialised services. An example of the former would be waste collection - increased recycling of segregated domestic and business waste has driven an increase in the variety of waste bins available: general waste, paper & cardboard, glass, garden, food waste and more. As recycling efforts increase, it is likely this will be further divided, leading to more bins to empty. The utilisation of each of these separate bins will depend on household occupancy and season, therefore, the refuse collection trucks could be reorganised based on demand, to avoid driving to a remote dwelling for a nearly empty bin, or modifying the route of collection trucks in real-time to maximise capacity to reduce transportation time.

Rising social care costs represent a specialised and significant cost for local authorities, as each resident would require a bespoke service and commonly these individuals are in geographically dispersed areas. Rural England & the County Councils Network both detail the challenges and additional costs associated with providing services in rural areas. [41] [42] They highlighted the challenges of travel time and cost of getting between sites and the lack of suitable broadband at residents' homes. A rural NH could alleviate these challenges by providing coverage for emerging health technologies, such as health monitoring to provide additional data to care workers to better advise on preventive care and establish if a resident requires urgent medical care or a false positive has been triggered.

It is also important to note that even as domestic rural broadband increases, it would continue to be advantageous to have a centrally managed and controlled system as domestic equipment could be unintentionally disconnected, whereas cellular technology would be free from such interference, increasing resilience and decreasing complex debugging time. Installation times and the ability to "self set up" systems are increased where there is no physical connection required inside the household.

A rural NH operator would be able to assist in providing both high-capacity connectivity for telehealth. This would likely generate considerable savings for local authorities, however, assuming only a very small number of eligible residents within a cell and thereby generating an additional £2000 per year per cell for a NH operator.

Adding a suitable mix of these potential revenue streams together would generate £9250 per year per cell, outweighing the assumed operational and amortised capital costs with sufficient returns for investors. As set out earlier, the problem is that NH comes in multiple flavours, each with their own strengths and weaknesses. Any business would first want to know the "rules of engagement" with NH before they decided to engage with the process – and the blunt fact today is that they have no clue about what form NH would take – and therefore no way to calculate their likely costs and revenues. Until these answers can be determined it will be challenging to establish a rural NH business model, which has been hampered through SRN.

41 http://www.countycouncilsnetwork.org.uk/download/3806/

42 https://ruralengland.org/wp-content/uploads/2018/01/Launch-Report-Issues-Facing-Providers-Social-Care-in-Rural-England.pdf

Recommendations and Next Steps

The fact that a digital divide exists 37 years after liberalisation demonstrates that historic approaches have failed. "Digital Apartheid" would be a better term, since it attaches the necessary seriousness to an issue that has been left unresolved – and even knowingly ignored on occasion. Ofcom should continue to update the ways in which it makes spectrum available to rural areas in a 5G world. The benefits of utilisation over spectrum waste are huge and the logic to act compelling. Key actions surrounding spectrum include:

- Stop national spectrum pricing in future band releases (leads to fallow wasted spectrum in rural areas and is thus not optimal use)
- Hold a trial "negative auction" that allows local authorities/other local groups to get paid for utilising otherwise fallow spectrum – rather than SRN or similar oligopolistic regulatory approaches that actually deter investment from other parties and perpetuate the status quo that all accept got us to this point of failure and which must change
- Address the technical and operational issues that underpin the total failure of NH in the UK. There is simply no motive for MNOs to allow others on to their networks under the current regulatory regime – just as in the 1980s BT had no incentive to allow other licensed operators onto their fixed network. The pre-existing Joint Operator Technical Standards process is a way to commence the achievement of this goal. It is not the fault of MNOs that NH does not exist in any meaningful way between operators other than themselves.
- Review Local Access Licensing Process. Currently MNOs can charge administration fees to access spectrum, however, these are neither publicly available nor common between them. Therefore, potential connectivity providers cannot assess the feasibility of such an undertaking. This is further complicated by legal costs of operating with MNOs which present a barrier to entry for smaller operators. Open and transparent pricing and commercials for utilization of existing spectrum is required.
- For the Shared Access Licensing Process - review, accelerate, automate (with time-based SLAs), and make far more transparent, with the presumption of awards in rural areas in the absence of publicly disclosed compelling reasons not to do so.
- Another of the major perceived barriers on spectrum sharing are the negative effects it would have on the primary spectrum holders' customers. Thus, conducting a study, on the quality of service for NH users, under sharing spectrum and dedicated spectrum would be able to analyze this further.
- Planning permission and site logistics are a "time-sink", as power and backhaul are key requirements. A publicly available record of wholesale assets - masts, power and fibre would simplify and speed-up this process. This could be developed by 5G RuralDorset, who already have dialogue with NUAR.
- Moving away from the "validated handsets only" model towards standard profiles would ensure NH operators are not disadvantaged due to constructed technological barriers or forced to deploy legacy 2G/3G voice technology, which will be rendered redundant in a few years' time anyway. Thus, legislation could be imposed to ensure that all handsets sold in the UK were tested against a baseline functional NH network profile for voice and data services.

- As no UK company manufactures handsets, we are always "running behind" with no certainty that the UK's policy goals can even be delivered. The move to OpenRAN will make the standards world infinitely more complex. There is a clear need to address this serious systemic weakness with a medium-term strategy that transcends jut the NH issue identified in this paper. DCMS is well placed to explore this area.

Conclusion

This paper has demonstrated through reference to three case studies that active NH business models have considerable potential if applied to rural areas *if* there were sufficient regulatory and consumer protections in place. The fact that potential is not being realised when demand is there confirms market failure. There are consequently no significant at-scale case studies of rural NH, hence this business study. We have illustrated what is technically and commercially feasible where operators and infrastructure providers are suitably incentivised to work towards delivering coverage through NH solutions.

Despite this, rural NH in-and-of itself cannot provide enough of a cost saving to make traditional operators keen to deploy in rural areas, even with the improvements in costs of deployment. This is due to the generally perceived poorer investment case for deployments in rural areas due to lower population densities. This is further exacerbated by the higher frequencies required for high-capacity 5G networks, which travel shorter distances, and therefore require more infrastructure to be deployed to deliver coverage across the same area.

Nevertheless, there is now evidence that based on the potential use-cases which can be “stacked" (including NB-IoT-based public services, smart agriculture, aquaculture, etc.) that *there is a viable commercial model for delivery of rural NH in the UK*. The concept of use-case stacking to aggregate cross-sectoral and cross-vertical demand has been introduced by the 5G RuralDorset testbed. In spite of this, our analysis has identified that there are a number of areas where careful consideration must be given to the regulatory and legislative position around NH operators, to ensure that, if we are to rely on them to deliver rural coverage to areas left behind after SRN roll-out is complete, they present a viable investment opportunity for private investors to fund and see a return on their investment.

In the first instance, we have identified that rural NH operators would, based on current spectrum policy, realistically prefer to use MNO spectrum through a local access licence arrangement in order to gain the coverage required to be financially viable. MNOs are, by their own admission, reluctant to facilitate and support the large numbers of local access licences which would be required to do this. They prefer to get potential users to speak first to Ofcom - and could under the current regulatory regime, easily frustrate attempts to renew licences after 3 years in order to drive down the value of an NH operator, or attempt to squeeze their operating margins. This is particularly pertinent since a rural NH provider would likely rely in part on selling connectivity to the four major UK MNOs, putting them in a commercially precarious position, with MNOs able to apply margin pressure at both sides of the business model.

New players would also require regulatory and financial incentives to drive improved rural coverage, beyond that which will be delivered through SRN, which effectively acts as a subsidy to incumbent operators. A rural NH operator would likely delay their investment and deployment plans until the extent of SRN roll-out is clear in an area, in order to avoid over-build of coverage, since their commercial viability depends on going into areas where other operators have failed to deliver coverage after SRN deployments.

Separating spectrum access mechanisms between rural and urban areas, as Ofcom has recently done with the introduction of shared access licences, generally only made available in rural areas, could present another opportunity to drive innovation in rural NH providers, by making available longer-term access to spectrum that is unutilised or under-utilised under the current national licensing framework used for mobile spectrum. This approach could leverage Ofcom's existing work on shared access licences, by offering longer-term access to "persistently under-utilised" spectrum holdings of operators that have made no attempt to utilise them. In such scenarios, it is likely that the wholesale prices of connectivity through a rural NH would be available to an MNO at a lower cost than the MNO would incur to provide for themselves, making this a commercially viable prospect, as long as there were regulatory or political pressure to deliver blanket mobile coverage of the UK, without leaving blackspots at inconvenient locations where rural NH operators could thrive.

To deliver a viable and usable rural NH solution, there needs to be further enabling work carried out as a matter of priority to ensure that mobile handsets sold in the UK support standardised IMS profiles. This work needs to be carried out as a priority in any case, in order to prepare for the inevitable switch-off of 2G and 3G services, as DCMS has been considering over the summer of 2021. NH operators would need to deploy parallel CSFB 2G/3G voice networks to enable voice calling, including 999 calling, to deliver a viable service at present, since many mobile handsets in use in the UK today still do not support IMS IP-based voice calling.

We have identified that there are unnecessary technical barriers, such as carrier-specific configuration bundles, which would serve to hinder use of IMS in the UK, and which act as barriers to switching a device which does support IMS between operators. While this may not appear directly relevant to a rural NH provider, it is actually very important, since the absence of well-supported IP voice would significantly increase the deployment cost for legacy voice network equipment and damage the investment case.

In summary, this paper has highlighted that rural NH *can* be a viable business proposition, with the right regulatory and political incentives in place, and provided that some work is carried out to streamline IP voice support on existing user handsets where users have moved between operators. As financial data from other infrastructure projects shows, rural NH *can* provide improved connectivity that is likely to be available to operators more cheaply than MNOs can deploy themselves, making this a viable proposition for them as potential customers of the wholesale NH service provision.

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