THE INVESTMENT GAP TO FULL 5G ROLLOUT

Report for the Digital Connectivity Forum

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EXECUTIVE SUMMARY

5G is the current generation of mobile technology that both supports ever increasing demand for capacity and the development of innovative use cases through the deployment of advanced technical features. However, our work suggests that there is a significant gap between what the UK industry can be expected to deliver under the status quo and the level of investment required to achieve world leading 5G networks.

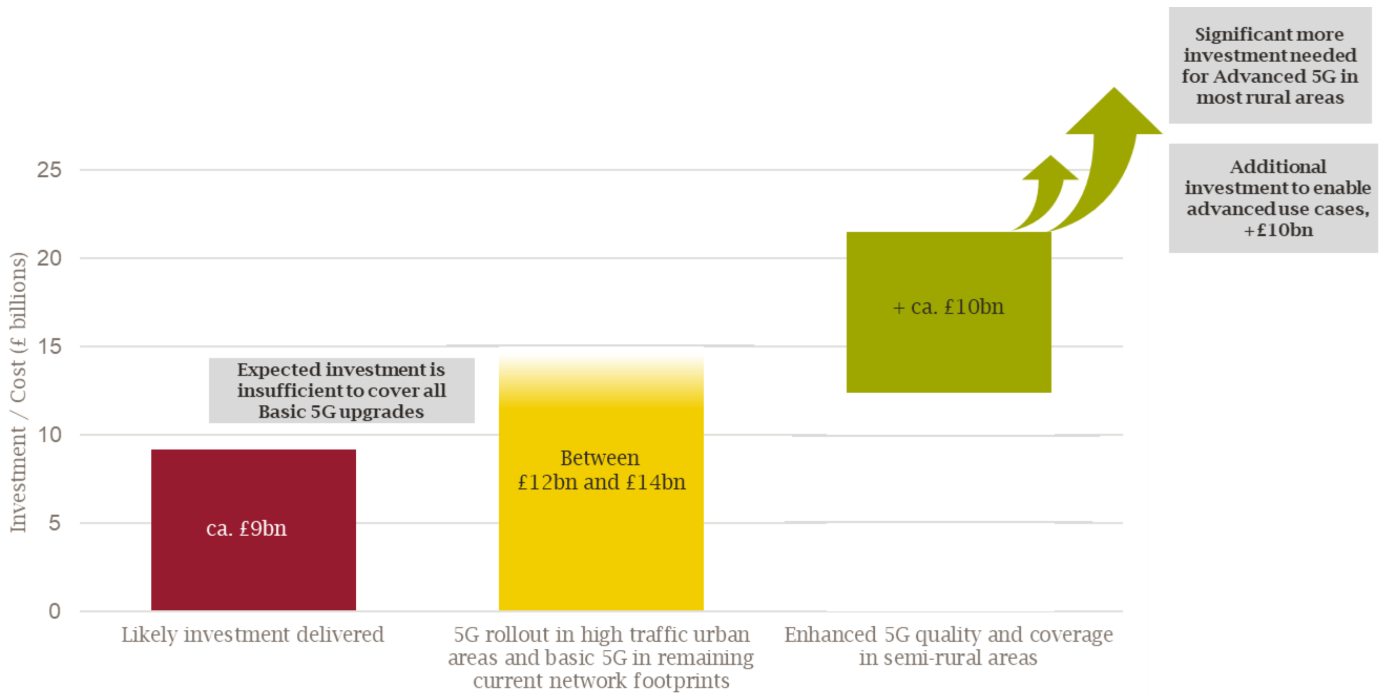
Our key findings, as illustrated in the chart below, are the following.

(i) The industry is projected to invest approximately £9bn for 5G purposes by 2030.

(ii) This investment can deliver substantial 5G investment to increase capacity to meet the continued increases in traffic demand. However, the costs of deploying networks sufficient to meet both expected traffic demand and UK-wide deployment of basic 5G functionalities across the existing mobile network footprint could lead to a £3 billion to £5 billion investment gap for the industry by 2030 – this likely means that the UK wide rollout of 5G will not be achieved by 2030.

(iii) Deploying networks with enhanced 5G quality and coverage to semi-rural locations (i.e. beyond the existing mobile footprint in those areas) would require an additional £10 billion investment - significantly increasing the investment gap.

(iv) To deliver the full capabilities of 5G by investing to enable all advanced 5G use cases in urban locations (e.g. those relying on ultra-low latency) or bringing reliable 5G connectivity to the rest of the UK would imply still larger investment gaps.



5G and the Wireless infrastructure strategy

The Government wants to position the UK as a global leader in digital connectivity to allow businesses and consumers across the UK to take advantage of the social and economic benefits of advanced wireless networks.[1] 5G is also at the heart of the Government's agenda for levelling up and achieving the UK's net-zero targets. Its widespread deployment will, therefore, be necessary to meet the Government's goals.

In order to support this objective, the Government is developing a Wireless Infrastructure Strategy (WIS) to set the framework to support the deployment of 5G and future wireless networks. In 2021, it held a consultation to seek the views from stakeholders on the WIS. The Digital Connectivity Forum (DCF) has subsequently commissioned this report to provide further information to the Government as it develops the WIS.

While the mobile industry has been successful in the past in meeting the demands of consumers and the broader economy, 5G raises new investment challenges due to the uncertain commercial viability of nascent innovative 5G uses. The focus of this report is to understand these challenges to quantify the gap between industry investment and the Government's goals for advanced 5G rollout, and to identify policy levers that could narrow this gap.

Operators face choices in where they direct their 5G investment

In order to understand the degree to which the industry can be expected to meet the challenge of delivering 5G, we estimate the investment gap under three scenarios:

- a "**basic 5G capacity**" rollout that focusses on the upgrade of the existing network, delivering additional capacity to satisfy a base case growth in traffic (40% per year using Ofcom forecasts);
- a **"basic 5G coverage"** rollout that in addition to meeting future traffic demand ensures that the 5G network coverage matches the 95% population coverage[2], but without necessarily providing significant increased capability in more rural areas; and
- an "**advanced 5G**" (or full 5G) rollout that provides enhanced 5G quality and coverage over a greater geographic area and enables advanced ultra-low latency 5G use cases (such as driverless cars or other autonomous technologies) in urban locations, which will likely bring along a fuller range of social and economic benefits.

We assume that operators will have a strong commercial incentive to invest to meet the 'basic 5G' capacity scenario, in order to satisfy the increase in traffic demand and continue to compete for existing customers. However, due to the high costs of rollout we would expect operators to focus on rolling out 5G to locations

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[1] For example, a recent UK government report estimated that £1 of investment in 5G will generate about £15 worth of benefits due to the ability of 5G to enable earlier adoption of technologies within the healthcare and manufacturing sectors, see https://www.gov.uk/guidance/5g-programme-findings

[2] We focus on 95% as this represents the target of the Government for 4G coverage by 2025 under the Shared Rural Network (see https://www.gov.uk/government/news/shared-rural-network) although we recognise that this may be a conservative assumption as some mobile operators may want their 5G networks to cover the entire UK population. This still implies a considerable lack of geographic coverage across the UK.

where the existing networks are likely to face capacity limits in the near future (generally in dense urban areas).[3]

The UK's mobile operators and infrastructure providers have already begun deploying 5G networks and their underlying infrastructure that focuses on these dense urban areas. However, it is less clear that widespread 5G geographic coverage will be a sufficient competitive differentiator to result in operators prioritising investment to provide basic 5G across the UK. In addition, this becomes even less plausible in a scenario in which 5G is not delivering innovative services on top of those that can be achieved on 4G – in other words, consumers will be less willing to pay for 5G if they cannot see the potential benefits of 5G.

For advanced 5G, we then estimate the cost of expanding the network to deliver enhanced 5G quality and coverage in semi-rural[4] areas and advanced use cases in urban locations. This scenario is more consistent with the Government's ambition for the UK being a global leader in 5G.

The investment that the industry is likely to deliver may be sufficient for meeting future capacity requirements but at the expense of basic 5G coverage across existing networks

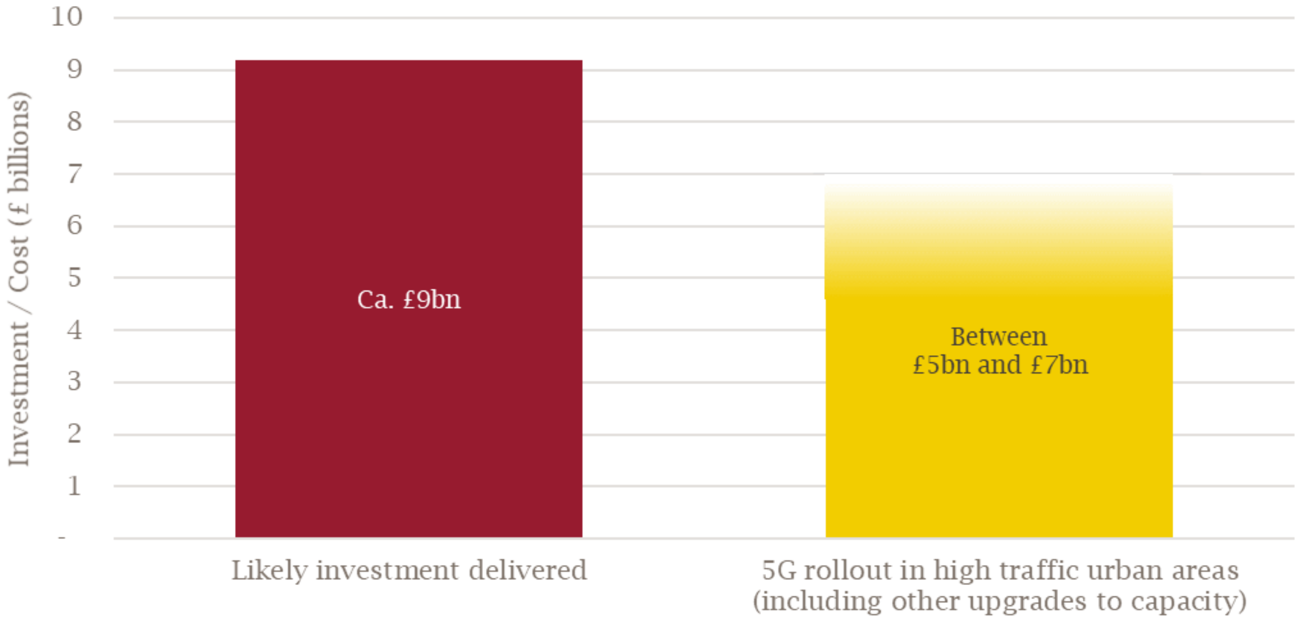
Under the "basic 5G capacity" scenario, our results suggest that the industry is likely to have sufficient funds to upgrade network capacities to meet future traffic demand with the investment required for this upgrade ranging from ca. £5 billion to £7 billion compared to a likely investment delivered by the industry of ca. £9 billion.[5]

[3] We acknowledge that in practice operators' rollout decisions may cover a range of different investments across the stylised scenarios considered in this report. However, given the fixed capacity to invest by 2030, an investment in one type of rollout limits operators' investments in the others.

[4] I.e. areas more sparsely populated than urban and suburban areas but denser than the most rural areas in the UK.

[5] As part of our calculation for the likely investment delivered by the industry (i.e. £9 billion), we have assumed that industry revenue will remain constant over time. We recognise that this may be an optimistic assumption given that mobile industry revenues have historically fallen over time but also reflects potential general upsides from strong demand growth and benefits from 5G.

THE INDUSTRY IS LIKELY TO MEET THE COSTS TO COVER BASIC 5G CAPACITY UPGRADES

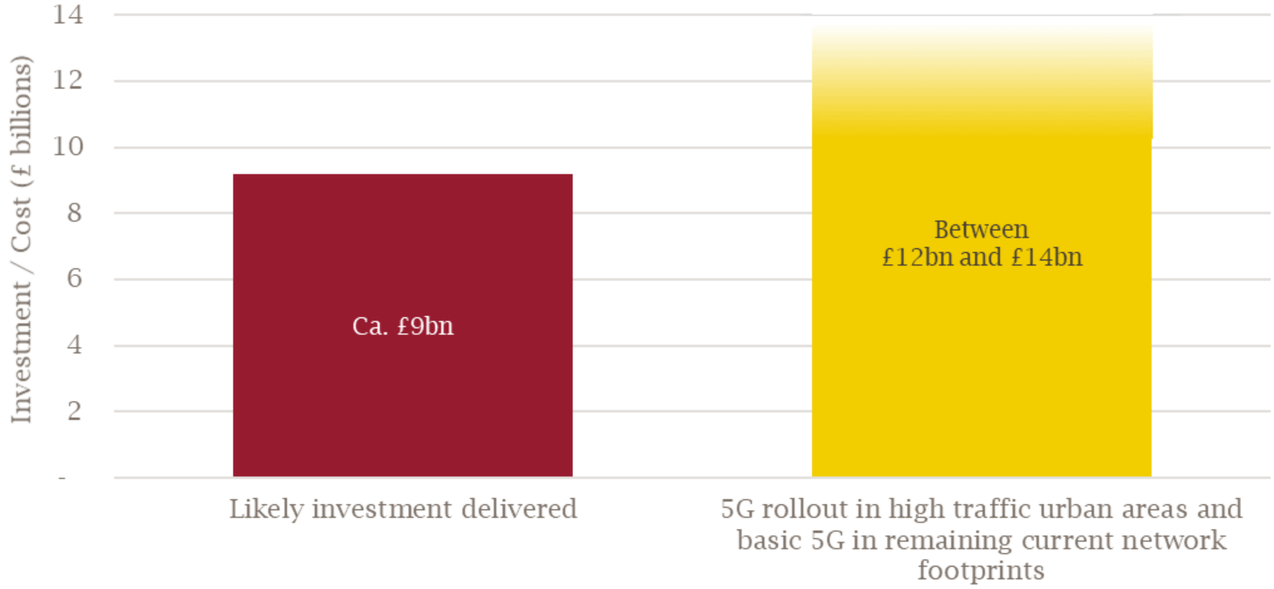


Given the strong commercial incentives to meet customers' growing demand for traffic, we would expect this to be the industry's initial priority for investments. Although based on stylised rollout assumptions, which may differ in practice, the level of cost of the basic 5G capacity scenario would suggest that this capacity related investment could be delivered by the industry.

This investment could imply additional operating expenses (OPEX) for the industry (as discussed in the context of the subsequent scenario) but, given that the total capital expenses are within the likely investment by the industry, it is difficult to distinguish between incremental OPEX due to 5G and OPEX that would be incurred by the operator anyway to maintain the existing network. However, any incremental OPEX incurred as a result of basic 5G upgrade would mean further challenges for the industry unless revenue opportunities improve in kind.

However, the considerable costs of delivering capacity-related upgrades are likely to make further investments in the broader rollout of basic 5G functionality across the footprints of current networks challenging (i.e. investment in upgrading the active equipment to 5G). The chart below shows the investment needed to upgrade networks to meet traffic demand and cover 95% of the population with basic 5G – this leads to an investment gap of ca. £3 billion to £5 billion by 2030.

THE INDUSTRY IS UNLIKELY TO MEET THE COSTS OF UPGRADING CAPACITY AND 5G COVERAGE



Meeting both objectives would also result in incremental OPEX for the industry of up to £500 million per year by 2030. It seems likely that the industry would also find it challenging to finance this level of additional OPEX given current revenue trends.

This suggests that, absent policy intervention, the divide between the quality of networks delivered in urban and rural areas would likely increase over the next decade.

The investment gap for advanced 5G is likely to be even greater

With basic 5G rollout already posing a challenge for the industry, the additional costs to enable advanced 5G capabilities is likely to imply a significantly larger investment gap. To some degree, any estimate of the gap is somewhat speculative given the uncertainties over the requirements of future use cases, the development of technology and hence the infrastructure and equipment required. However, in order to produce an indicative estimate of the gap for **"advanced 5G"**, we have estimated the incremental infrastructure and equipment that may be needed to deliver high quality 5G connectivity.[6]

We start with the investments required to satisfy the traffic growth forecast on which our basic 5G rollout cost estimates are based. We then consider two areas of improvements:

- to provide enhanced 5G quality and coverage in semi-rural areas[7]; and

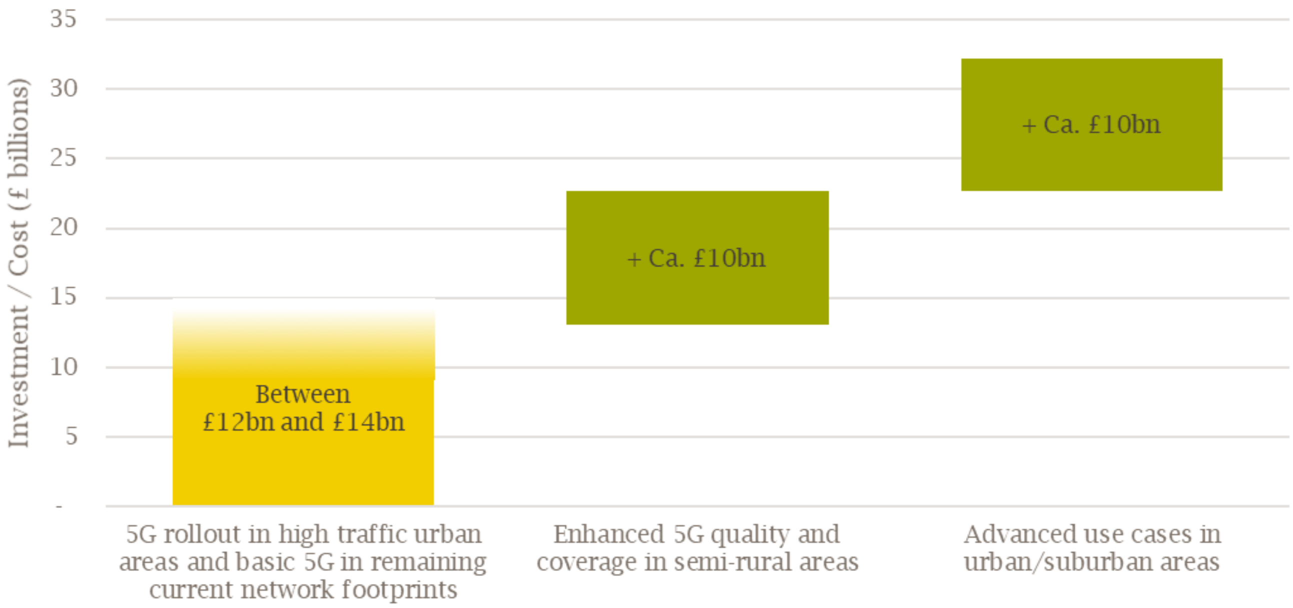
[6] In so doing we rely to some extent on public information on the types of network rollout that could be considered and our own assumption but note that this is only an indication and the industry may ultimately develop different network architectures for the rollout.

[7] The upgrades considered to deploy basic 5G to rural areas are not sufficient to provide the same level of performance in rural areas as the 5G upgrades will provide in urban areas (e.g. stable and high capacity connections). This is because of the low density of existing sites in rural areas. Therefore, under this scenario, we consider the costs of rolling out a network in semi-rural areas capable of delivering a similar quality 5G service as those in urban/suburban locations. This upgrade does not provide any advanced capabilities, such as low latency connectivity.

- to roll out specific equipment to enable low latency use cases in urban and suburban areas.

Below we illustrate the additional investment that could be required to achieve these improvements.

THE COSTS OF ADVANCED 5G ROLLOUT IMPLY A SIGNIFICANTLY LARGER INVESTMENT GAP



Given the substantial investment gap for all advanced 5G scenarios, there is a significant risk that businesses and consumers will not be able to access advanced use cases and benefit from advanced digital connectivity across large parts of the UK. On top of this, we estimate that the industry would incur a substantial increase in industry OPEX of up to £3 billion per year.

In fact, even the rollout of enhanced 5G service (excluding advanced use cases) to semi-rural areas would still imply that the vast majority of the UK land mass (70% of its geographic area) would not benefit from a stable high capacity 5G service. It would also imply no 5G rollout to the 5% of the population in the most sparsely populated areas. Further expanding the 5G rollout to improve both would significantly increase the investment needed and hence the gap to achieve it.[8]

The role of policy in narrowing the 5G investment gap

The analysis above suggests that, under the status quo, there is likely to be a significant gap between the capacity of the industry to invest and the investments needed to meet the Government's objective for the UK to become a global leader in digital connectivity. Thus there is a clear need for policy intervention.

Given the scale of the gap, this may require more fundamental policy shifts than interventions and public funding to date which, while welcome, have focused on marginal reductions in the cost of network rollout. The success of the Future Telecom's Infrastructure Review (FTIR), in incentivising fibre rollout through a combination of commercial investment and public funding of rollout in rural areas, is a helpful precedent.

[8] The investment gap is estimated at £37 billion (on top of the investments for advanced use cases) to serve just half of the remaining rural areas.

Potential policy levers which could have a material impact on investment incentives and capabilities can include:

- **Direct public funding of infrastructure** (which is unlikely to be provided by private investment) or **provision of low interest loans** to improve the industry's ability to fund investments. The Shared Rural Network (SRN) programme pioneered these types of public intervention[9] but, given the size of the gaps identified, the scope of a similar intervention in relation to 5G (in geographic and monetary terms) would need to be much greater. On top of this, policy makers could also consider redirecting the industry's annual licence fee (ALF) payments to contribute towards the rollout of 5G or providing incentives to invest in mobile infrastructure and equipment through tax policy, for example by extending the super-deduction.

- Ensuring regulation of services delivered over mobile networks (e.g. **net neutrality rules**) is fit for purpose, providing investors in mobile networks and infrastructure certainty that they can earn sufficient returns on investments in new use case.

- **Spectrum policy** to ensure that operators have certainty that they can acquire spectrum they need to meet 5G use cases, thereby reducing the need for additional infrastructure and providing an incentive to invest in the required infrastructure.

- **Changes in industry structure**, such as consolidation, and **supporting the growth of infrastructure models** (including Neutral Host wholesale providers), where this can deliver more efficient infrastructure investment and promote competition and investment in network densification and extension.

- Continuing to **reduce rollout barriers** (such as via the barrier busting task force) to forestall increases in the costs of rollout and suboptimal geographic rollout.

- **Public procurement of 5G services** and support for advanced use cases in order to reduce the uncertainty of future revenue opportunities.

[9] See https://srn.org.uk/

1 INTRODUCTION

5G is the current, fifth, generation in mobile technology, that is expected to be a key technology in satisfying ever increasing capacity needs in the next decade. More importantly, 5G can bring, social and economic benefits through its ability to increase digital connectivity and unlock advanced use cases. For example, the UK Government has estimated that every £1 of investment in 5G will lead to £15 of benefits due to the ability of 5G to accelerate the adoption of new technologies within healthcare and manufacturing.[10]

The Government is therefore developing a Wireless Infrastructure Strategy (WIS) to set the framework for the deployment of 5G and future wireless networks (e.g. 6G) to 2030.[11] The aim of this strategy is to enable the UK to become a global leader in digital connectivity and to support the levelling up process. The strategy should allow businesses and consumers across the UK to take advantage of the social and economic benefits of advanced wireless networks. The latter is particularly important as the underlying economics of less urban locations (e.g. towns and rural villages) will mean that these locations will unlikely benefit from commercial 5G rollout and the additional benefits that 5G enables without any Government support and intervention.

The Government[12] conducted a consultation in late 2021 to seek the views from stakeholders on how best to design the WIS. The Digital Connectivity Forum (DCF), which exists to support seamless digital connectivity (thereby driving positive social and economic change across the UK), has subsequently commissioned this report to provide further information to the Government as it develops the WIS. In particular, the report covers:

- The connectivity needs in relation to advanced 5G use cases;
- The extent to which the industry (mobile operators and infrastructure provider) is able to meet those needs, and
- Policy levers that can be used to close any potential investment gap.

Our report addresses these points based on a quantitative analysis of rollout costs and levels of investment. Given our finding that there is likely to be a gap between the investment that the industry is likely to deliver and the amount of investment needed under a number of different scenarios,[13] we set out a range of potential policy levers that policy makers can consider to close the investment gap.

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[10] https://www.gov.uk/guidance/5g-programme-findings

[11] https://www.gov.uk/government/consultations/wireless-infrastructure-strategy-call-for-evidence/wireless-infrastructure-strategy-call-for-evidence

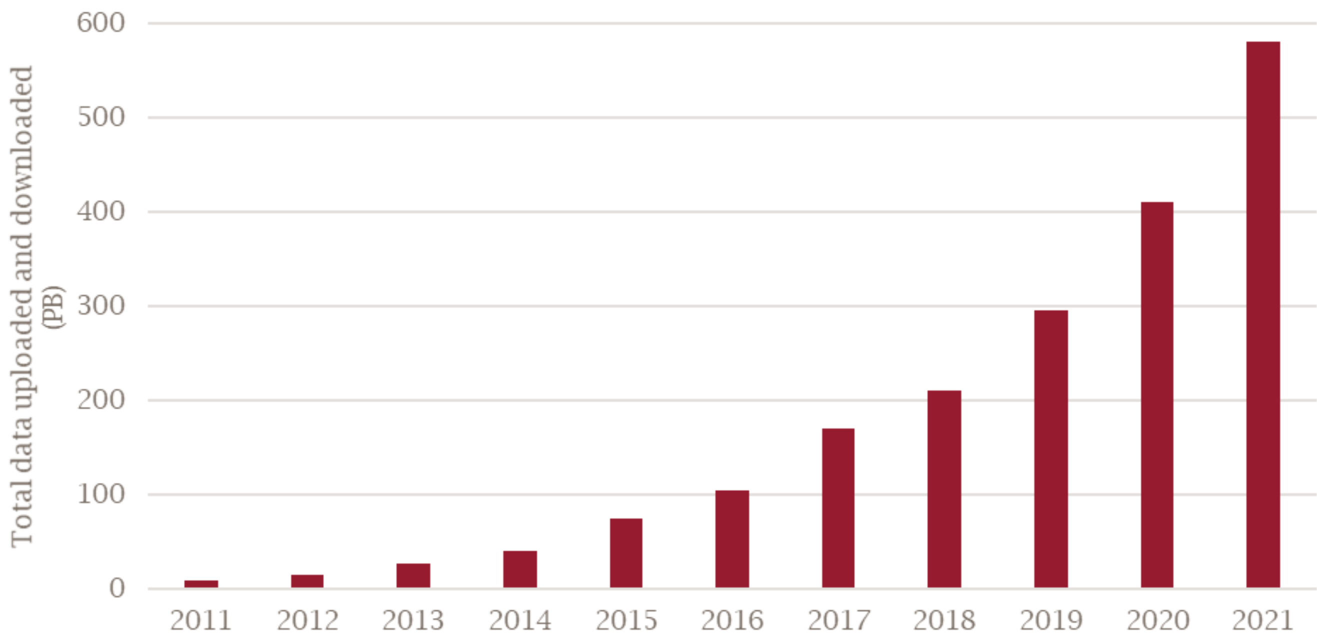
[12] The Department for Digital, Culture, Media and Sport (DCMS)

[13] We focus on the rollout of public mobile networks but we acknowledge that some of the advanced 5G use cases can be satisfised by rolling out private mobile networks.

2 5G WIRELESS CONNECTIVITY NEEDS

Mobile data traffic has increased exponentially in the last decade. This has been driven by the development of new internet-based applications and changes in consumer behaviour. This is highlighted by Ofcom[14] who noted that mobile data traffic has increased by around 40% per year. This is illustrated in Figure 1.

FIGURE 1 GROWTH IN MONTHLY DATA DEMAND



Source: Ofcom

Mobile data traffic is expected to increase further as more data intensive applications are developed and as more consumers use these applications. Ofcom note that innovative consumer applications in the form of higher video quality, mobile online gaming, augmented reality (AR), and connected devices & wearables will continue to drive data traffic in the future.[15]

New mobile technologies have been developed to both satisfy the growth in capacity requirements and deliver new use cases. These technologies are developed in ‘generations’ to ensure common standards both within and across countries. This allows users to have confidence that they can access advanced mobile services across a wide geography and provides benefits from economies of scale. 5G is the current, fifth, generation in mobile technology, and is expected to be the key technology in satisfying the increasing capacity needs until 2030 and after. It has also been designed to further enable the development of new use cases through advanced technical capabilities. These are discussed in more detail below.

2.1 CAPACITY IMPROVEMENTS OF 5G

5G technology can provide significantly more capacity than 4G technology as it can use more spectrum and use this spectrum more efficiently than 4G and earlier technologies. A recent report found that, under

[14] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

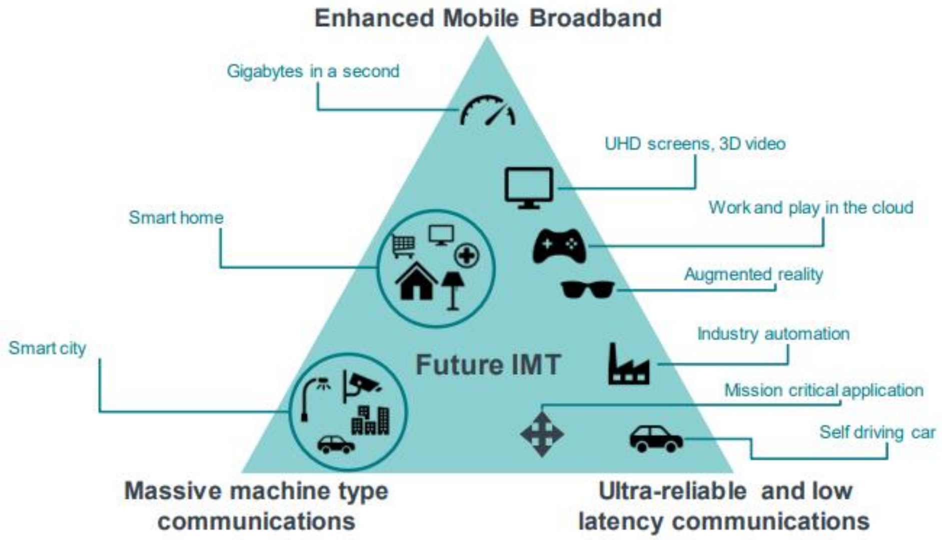
[15] Ibid

reasonable baseline assumptions, 5G is able to deliver a 53% increase in downlink spectral efficiency.[16] 5G is also designed to use the so-called millimetre wave spectrum (mmWave) (26 GHz, 40 GHz and 66 GHz) thereby enabling 5G to utilise less crowded spectrum bands with much higher capacity potential.[17]

2.2 ADVANCED 5G CHARACTERISTICS

5G enables specific use cases through advanced technical capabilities. 5G has the potential to unlock new advanced use cases in relation to **enhanced mobile broadband** (such as increased mobile download speeds, regular use of augmented/virtual reality), **massive machine type communications** (faster, more reliable connection for a large number of internet of things devices), and **ultra-reliable low latency communications** (enabling faster response times). This is done by delivering major improvements to latency, concurrent connection capacities and connection density among others.

FIGURE 2 5G USE CASES



Source: Frontier Economics

A summary of possible use cases is set out in the Figure below

FIGURE 3 EXAMPLES OF POTENTIALLY REVOLUTIONARY USE CASES

SECTOR	POSSIBLE USE CASES
Automation, Transport, logistics, IoT	• Driverless vehicles • Remote drone operation • Cooperative farm machinery • Real-time control over automation
Health and wellness, smart cities	• Remote healthcare and assisted surgery • Smart transmission grid

[16] https://www.5g-networks.net/5g-technology/spectral-efficiency-5g-nr-and-4g-lte-compared/

[17] https://www.ofcom.org.uk/__data/assets/pdf_file/0015/202065/5g-guide.pdf

	• Time-critical feedback for small cities
Media and Entertainment	• Live streaming in crowded locations • Augmented and virtual reality • Collaborative gaming

Source: https://www.etsi.org/deliver/etsi_ts/122200_122299/122261/17.10.00_60/ts_122261v171000p.pdf

Given the use cases above, we consider that the most relevant technical characteristics of full 5G are:

- Low latency – for use cases such as mission critical measurement and automation (1ms) autonomous vehicle control (5-10ms)[18], remote drone operation and cooperative farm machinery (10-30ms), remote healthcare and assisted surgery (100ms)[19], vehicle to everything communication (20-100ms)[20] and high performance machine-type communications (1ms)[21];

- Subscriber connectivity >100Mbps – to ensure significant increase in download speeds compared to 4G for mobile broadband users; and

- Massive device density – e.g. for hosting large outdoor events (4 subscribers per m^2), smart city applications (20,000 devices per km^2) and media on demand (4,000 devices per km^2).[22]

2.3 5G UPGRADES

The upgrades that are needed to deliver more capacity and capabilities for advanced use cases will require significant changes across the entire mobile networks[23]:

- Radio access network (RAN) - this includes the passive and active mobile equipment used to send and receive transmissions from mobile devices;

- Backhaul network – this provides capacity to the RAN by connecting it to the core network; and

- Core network – this provides the link to other parts of the network and directs traffic to users.

[18] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/577965/Exploring_the_Cost_Coverage_and_Rollout_Implications_of_5G_in_Britain_-_Oughton_and_Frias_report_for_the_NIC.pdf

[19] https://www.etsi.org/deliver/etsi_ts/122200_122299/122261/17.10.00_60/ts_122261v171000p.pdf

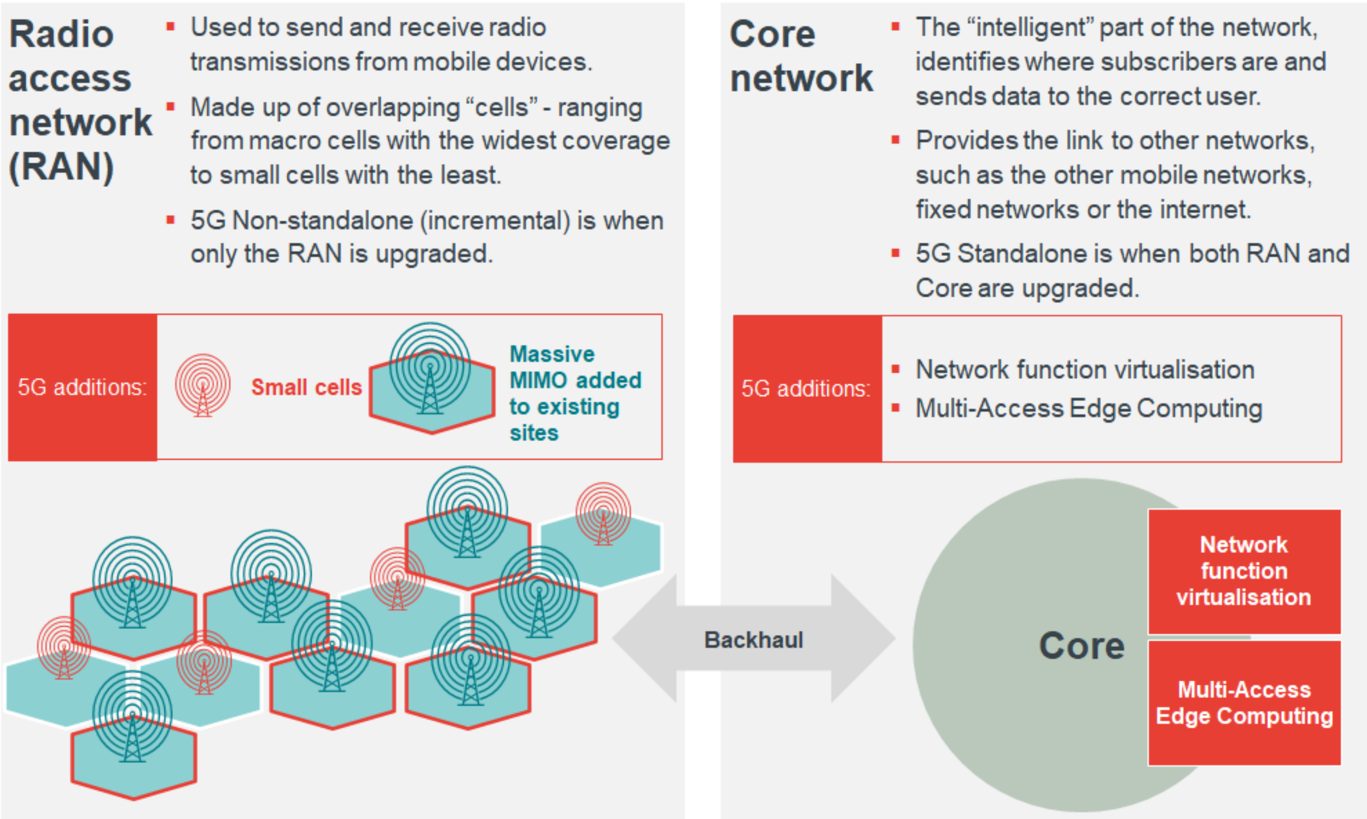
[20] https://www.etsi.org/deliver/etsi_ts/122100_122199/122185/14.03.00_60/ts_122185v140300p.pdf

[21] https://www.ericsson.com/en/blog/2015/5/5g-radio-access-for-ultra-reliable-and-low-latency-communications

[22] https://www.cio.com/article/230940/5g-connection-density-massive-iot-and-so-much-more.html

[23] We focus on the main upgrades to the network that will deliver 5G capability and coverage to end-users. We recognise that there are additional upgrades that may be needed for specific use-cases such as investments to improve network security and introduce Internet Protocol version 6 (IP6) but we do not propose to cover these within the scope of the report as these will require a more detailed assessment.

FIGURE 4 5G NETWORK OVERVIEW



Source: Frontier Economics

In particular, mobile operators may choose to invest in the following upgrades to the RAN and core networks:

- **Radio Access Network**
  - **Deployment of 5G on existing sites and equipment.** This involves upgrading the equipment and/or software of each site so that it can use existing bands including 4G spectrum that has been refarmed for 5G purposes.[24] This will likely lead to a lower cost of 5G deployment (compared with other options within this list) but may not lead to a significant increase in capacity as the amount of additional spectrum deployed (e.g. 700 MHz) is low and the spectral efficiency of 5G is similar to that of 4G in these bands.
  - **Deployment of active 'massive' MIMO antennas on the existing network.** This involves upgrading the infrastructure over existing sites by installing new radio equipment and antennas. This will bring two benefits:
    - allowing the sites to take advantage of additional 5G spectrum in the 3.4 to 3.8 GHz band; and
    - offering a significant increase in spectral efficiency on those frequencies.

[24] This may not be an option for all MNOs.

Both will lead to a significant increase in capacity although coverage may be limited by the distribution of existing sites and reduced reach of the spectrum bands suitable for massive MIMO deployment.[25]

- **Densification of macro cell sites.** This could increase the number of sites thereby allowing the mobile operator to provide more capacity and coverage but is only feasible in areas where space for additional sites is available which is more likely in suburban / rural areas than denser urban areas.

- **Rollout of mmWave small cells.** mmWave frequencies offer very large spectrum allocations at much higher frequency. These cells have a much smaller radius than existing macro-cell sites and may be used where locations for new macro sites are limited, demand is highly localised or for the support of specific 5G use cases as discussed later in this report.[26]

- **Fronthaul/backhaul Network**

  The requirements of 5G mean that a high-performance network is needed to connect sites to RAN equipment (fronthaul) and the RAN to the core network (backhaul) – this can be achieved by connecting each site to a fibre link. Upgrades to 5G may also require the network topology to be adapted to meet the increase in performance, e.g. by locating more storage and computing functions closer to RAN sites.

- **Core Network**

  Upgrading the existing core network to a 5G core will increase the capacity and capability of the core through a number of features, including:

  - **Network Function Virtualisation** – This "virtualises" the network by decoupling software from hardware and makes greater use of cloud computing. This may enable easier upgrades and increase the flexibility of the network, enabling on demand responses.

  - **Multi-Access Edge Computing** – This is an evolution in cloud computing that brings the "intelligence" of the core to the "network edge", i.e. closer to end users. Since information travels shorter distances, lower latency and higher reliability can be assured.

It should be noted that the types of upgrades (or combinations thereof) that are suitable depend on geographic conditions.. For example, urban locations may require the rollout of small cells as there may not be enough suitable locations for any further densification with new macro sites. Conversely, suburban areas may be better served by the additional deployment of macro sites given the smaller reach of small cells and more adequate supply of suitable deployment locations.

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[25] We recognise that the ability to install active MIMO at some existing sites may be restricted by the limitations of existing passive infrastructure. For example, there could be a lack of space to install 5G active equipment or the MNO will need to invest to strengthen their existing towers to handle the 5G active equipment or rollout a new site (potentially facing higher costs in doing so).

[26] Based on the public sources available to us for the purpose of undertaking our costing analysis, we focus on macro sites and mmWave small cells. However, we recognise that the type of sites that operators consider in their rollout strategies are much wider, including micro and small cells using mid band spectrum. This is not reflected in our stylised costing, which is why the actual costs that the industry is likely to incur will also depend on many more practical considerations that impact on and will be reflected in actual industry rollout plans.

2.4 5G ROLLOUT SCENARIOS

The costs to deploy a 5G network will depend on the extent of 5G coverage across different geotypes and the type of use cases considered in terms of performance requirements. For example, the costs of providing a certain level of 5G coverage to a given percentage of the population will be lower in urban than in rural areas due to the higher population density in urban areas. However, the provision of adequate performance may be harder to achieve in urban areas where a larger number of users generate much more traffic in a given area than more sparsely distributed users in rural ones.

The following section will first examine the upgrades that are required to achieve a minimum level of 5G rollout (referred to as "**basic 5G**"). This is defined as upgrades to the RAN of the existing network and upgrades to the capacity so that Ofcom's medium traffic demand forecast can be met. We will then consider specific scenarios where the network dimensions are driven by the need to cover more rural locations with enhanced performance and the need to offer advanced 5G use cases to urban/suburban locations (referred to as "**advanced 5G**"). In other words, we consider rollout scenarios of advanced 5G characteristics that cannot met with the minimal rollout designed to meet basic capacity and coverage requirements.[27]

[27] We acknowledge that in practice operators' rollout decisions may cover a range of different investments across the stylised scenarios considered in this report. However, given the fixed capacity to invest by 2030, an investment in one type of rollout limits operators' investments in the others.

3 METHODOLOGY

This section describes the methodology to determine the scale of the investment gap for both basic 5G and advanced 5G scenarios, first by discussing the methodology for estimating the costs of the investments needed and outlining the level of investment that the industry can be expected to deliver. The specific inputs used in the calculations are covered in Annex A.

3.1 THE COSTS OF ROLLOUT

We first assume a hypothetically efficient operator that is vertically integrated so we capture investment in both equipment and infrastructure.[28] We then estimate the incremental costs of 5G deployment between 2022 and 2030, i.e. a brown field deployment of 5G. In other words, we first use the infrastructure of a hypothetical existing mobile network and then focus on the additional equipment and infrastructure (and their costs) needed to deliver 5G. The approach involves the following 4 steps:

- We first define a series of geotypes;
- Second, we define the existing network infrastructure within each geotype (along with the proportion of the passive network that is shared) of a hypothetically efficient operator;
- Third, we define the incremental infrastructure and equipment that is needed to satisfy each scenario;
- Finally, we apply our assumptions on unit costs to the existing and incremental infrastructure in order to calculate the incremental costs of 5G network deployment. We then assume a four player market and scale up the costs to an industry level.

3.1.1 GEOTYPES

The required upgrades or combination of upgrades will depend on the local demand and cost conditions in the areas in which they are deployed. We therefore define a number of geotypes to describe at a high level the characteristics of different areas in the UK. For this, we have used Ofcom's definition of geotypes used within the modelling to support the most recent Mobile Call Termination Market (MCT) Review but aggregate Ofcom's Rural geotypes 2-4 into a single Rural 2 geotype because these areas cover a relatively small proportion of the UK population and sites (but the majority of the land mass) – this is shown in Figure 5 below.

FIGURE 5 OFCOM GEOTYPES

GEOTYPE	MINIMUM POPULATION DENSITY (PEOPLE PER KM^2)	PERCENTAGE OF POPULATION IN GEOTYPE	PERCENTAGE OF AREA IN GEOTYPE
Urban	7,959	6.0%	0.1%
Suburban 1	3,119	30.0%	1.5%

[28] Although we recognise that, in reality, a towerco will have been separated from the rest of the business.

Suburban 2	782	32.8%	4.6%
Rural 1	112	21.2%	18.4%
Rural 2[29]	0	10.0%	70.2%
Highways	N/A	0%	4.4%
Railways	N/A	0%	0.8%

Source: Frontier Economics based on Ofcom's MCT model

3.1.2 EXISTING NETWORK INFRASTRUCTURE

We then consider the existing network topology of the hypothetical network operator that Ofcom models in its MCT model where we use the estimated network dimensions of an operator in 2022/23[30]. Figure 6 below shows the number of macro, micro and pico sites in each geotype.

FIGURE 6 OFCOM'S ESTIMATED NUMBER OF SITES BY 2022/23

GEOTYPE	OFCOM'S ESTIMATED NUMBER OF MACRO SITES	OFCOM'S ESTIMATED NUMBER OF MICRO/PICO SITES
Urban	1,249	426
Suburban 1	5,882	2,041
Suburban 2	1,399	551
Rural 1	1,544	
Rural 2	3,111	
Highways	1,266	
Railways	424	

Source: Frontier Economics based on Ofcom's MCT model

Ofcom assumed that 90% of any new network infrastructure is shared with another operator.[31] We reflect this in our cost estimate by only using half of the passive infrastructure costs for those sites that are shared.

3.1.3 INCREMENTAL INFRASTRUCTURE

We then define the incremental infrastructure that is required under basic 5G and advanced 5G – this is based on our discussions with stakeholders and Ofcom's spectrum demand report. The incremental infrastructure for basic 5G and advanced 5G are discussed in more detail in Section 4 and 5 respectively.

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[29] Categories Rural 2-4 according to Ofcom MCT model.

[30] Ofcom's model estimates the amount of network equipment required based on forward looking demand assumptions and network engineering rules. In light of the model reflecting a hypothetical network operator, the network dimensions modelled are likely to differ from those of any existing MNOs in the UK.

[31] <Unit investment> tab of "3-cost" workbook. https://www.ofcom.org.uk/consultations-and-statements/category-1/mobile-call-termination-market-review

3.1.4 INCREMENTAL 5G COSTS

We then apply the unit costs in relation to active, passive, backhaul and core network elements to the existing and incremental network sites (see Annex A). As part of this, we also account for the fact that 90% of the passive network is shared.[32] This means that we take 10% of the total passive costs and half of the remaining 90% of passive costs.

We further make a deduction to reflect the existing investment that an operator would have made for 5G purposes between 2019 – 2021. For this, we use the total industry expenditure on 5G RAN between 2019-2020[33] and an assumption for total industry spend on 5G for 2021[34] – this roughly equates to ca. £300 million between 2019 and 2021.

This then produces our estimate of the incremental costs for a hypothetical operator. We then assume there is a 4 player market (i.e. the number of MNOs in the UK) and convert this into a total mobile industry level cost by multiplying the incremental costs by 4.

3.2 THE LEVEL OF INVESTMENT THE INDUSTRY IS LIKELY TO DELIVER

To estimate the potential investment gap, we have to understand the scale of investment that industry can be reasonably expected to make in new technologies by 2030. To do this, we rely on historic levels of investment intensity, i.e. the proportion of revenues spend on capital expenditure, and apply this to a forecast of future revenue.

We first estimate investment intensity (measured as CAPEX as a percentage of revenue) – we consider this ratio to be reasonable as it reflects the amount of investment that can be made under the current policy environment. We also assume that 5G will not contribute to a major increase in revenues but rather that the evolution to 5G maintains the operator's ability to satisfy a mobile demand broadly similar to today's but with significantly higher traffic / capacity requirements. That is, we assume that for now, there are no significant revenue opportunities from the rollout of 5G through entirely new use cases.

For our measure of investment intensity, we use the total network related investment by all MNOs in 2019 (£1.5 billion)[35] and divide this by the total industry wide revenue for mobile services (£12 billion)[36] – this produces an investment intensity of around 12.5%.

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[32] We expect that the percentage of shared sites will fall over time due to EMF implications from operators deploying more 5G equipment and using more frequencies for 5G purposes. This is therefore a conservative assumption as the resultant network costs (due to lower percentage of shared sites) will likely be higher.

[33] This is equivalent to the sum of the total 2019 value (£180 million) and 2020 value (£330 million) divided by the number of MNOs, see Figure 25 https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf

[34] We use the increase between 2020 and 2019 (88%) and apply this to the 2020 value divided by the number of MNOs.

[35] See https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf. It should be noted that we have not used the figure from 2020 as this does not reflect the level of investment that an operator will make under stable conditions (i.e. the 2020 figures reflect investment in 5G and legacy technologies).

[36] This is estimated by first using total UK retail mobile revenue (£3 billion) in Q2 2021 and multiplying this by 4 to obtain an annual revenue figure for 2021 (£12 billion). See https://www.ofcom.org.uk/__data/assets/pdf_file/0019/227323/q2-2021-telecoms-data-update.pdf

We then make a deduction from this investment intensity to reflect the fact that mobile operators may need to use some of these funds for maintaining their existing networks. This deduction is currently based on an assumption of 4 percentage points of revenues for maintenance.

After this, we apply the investment intensity, net of maintenance, (8.5%) to future revenue estimates in order to derive the potential funds that the hypothetical operator will have for investing in 5G technologies under normal operations.

For the future revenue, we assume that this hypothetical operator is able to generate £3 billion per year in retail revenues.[37] We further assume that this revenue remains constant over time (net of inflation which is likely to affect revenues and costs similarly and not materially affect the ability to invest).

Multiplying the expected revenues by the benchmark investment intensity then leads to a total investment of around £2.3 billion for the hypothetical operator or an industry wide figure of £9.2 billion which we consider to the amount that we can expect the industry to invest in the period 2021-2030.

[37] This is calculated as £12 billion divided by the 4 MNOs.

4 THE INVESTMENT GAP FOR BASIC 5G BY 2030

For assessing the investment gap, we first look at the costs for the basic 5G scenario as we assume that operators will have strong incentives to focus on satisfying the increase in traffic demand before investing in delivering advanced 5G rollout and use cases. In this section, we cover the incremental infrastructure under basic 5G, the incremental costs and the implications of the investment gap.

4.1 INCREMENTAL INFRASTRUCTURE UNDER BASIC 5G

In our basic scenario, we consider rolling out basic 5G to 95% of the population based on the existing footprint of the hypothetical operator.[38] We therefore include all macro, micro and pico sites within Urban, Suburban 1, Suburban 2, Rural 1 geotypes[39] and half of the sites within Rural 2[40]. We also include the macro sites along highways and railways. This is summarised in Figure 7 below.

FIGURE 7 NUMBER OF SITES INCLUDED WITHIN THE BASIC 5G SCENARIO

GEOTYPE	OFCOM'S ESTIMATED NUMBER OF SITES (2022/23)
Urban	1,675
Suburban 1	7,923
Suburban 2	1,950
Rural 1	1,544
Rural 2	3,111
Highways	1,266
Railways	424

Source: Frontier Economics based on Ofcom's MCT model

The basic upgrade is one where the current active equipment is replaced or upgraded to facilitate the native connectivity of 5G devices without necessarily a material increase in the performance obtained through this connection (e.g. a minimum throughput above that offered by 4G). In other words, we do not consider the upgrades that is required to bring about widespread advanced 5G use cases (such as those shown in Figure 2 and 3 above) – these are discussed in the next section.

We first consider the upgrades that are necessary to ensure that basic 5G functionality is available to 95% of the population plus highways and railways (although this partly depends on the frequencies on which 5G is offered). For this, we apply the costs to upgrade the RAN of the existing mobile network[41] - see the second column of Figure 7 above.

[38] We focus on 95% as this represents the target of the Government for 4G coverage by 2025 under the SRN (see https://www.gov.uk/government/news/shared-rural-network) although we recognise that this may be a conservative assumption as some mobile operators may want their 5G networks to cover the entire UK population.

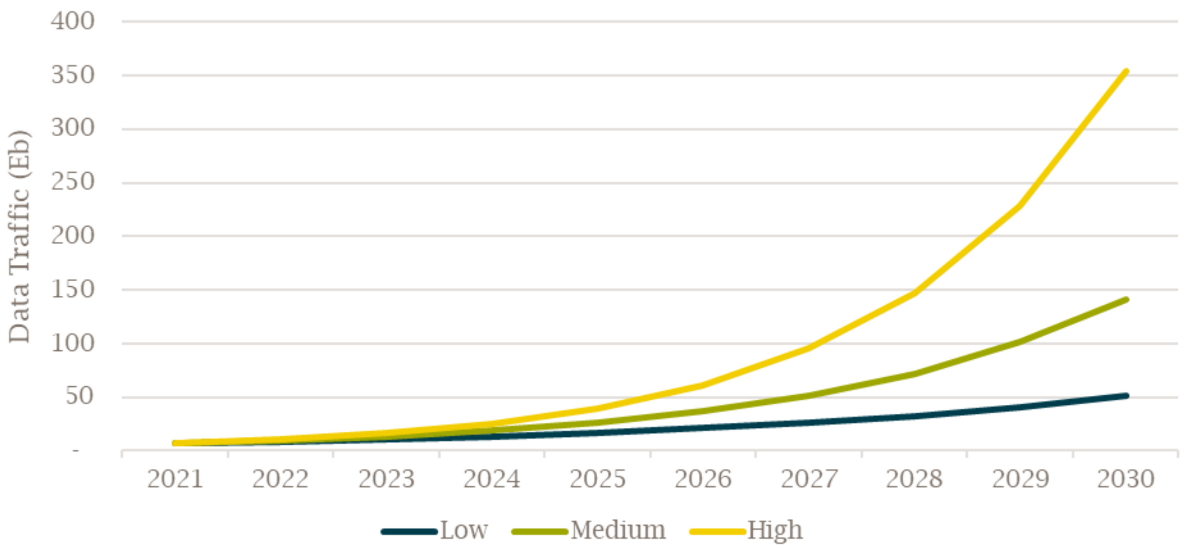
[39] Urban, Suburban 1, Suburban 2 and Rural 1 roughly account for 90% of the population

[40] Ofcom estimated that 1744 sites is required to cover 7% of the population within Ofcom's Rural 2 geotype – we therefore consider that ca. 1500 sites approximately covers 5% of the population.

[41] In other words, we exclude upgrade costs to the backhaul and core networks.

We also assess, as part of the basic 5G scenario, the extent of additional costs that are required to ensure that the network in dense urban areas is able to support the increase in capacity demand based on Ofcom's medium traffic growth scenario (40% growth in traffic per year[42] - see green line in Figure 8 below alongside Ofcom's low and high demand scenarios for reference).[43] This means that we also consider capacity related upgrades to the backhaul and core networks within dense urban locations under this scenario.[44]

FIGURE 8 OFCOM'S TRAFFIC DEMAND FORECASTS (EXABYTE PER YEAR)



Source: Frontier Economics based on Ofcom demand forecasts

Ofcom has considered various approaches to satisfy the increase in traffic under its medium growth forecasts. We therefore present a range for the likely costs under the basic 5G scenario based on two of these approaches:

- **Basic 5G - site densification**: Ofcom considered that one potential option would be for the operator to double the number of existing sites in "busy dense urban" and "urban" areas.[45] Ofcom's definition of "busy dense urban" and "urban" areas are unclear so we have assumed that this refers to the Urban geotype from Ofcom's MCT model and have doubled the number of sites in those areas. This means that we apply the cost of upgrading the capacity on existing sites (second column

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[42] This is based on a continuation of the year on year growth in recent years, see: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf.

[43] Defined as 25% and 55% increase in traffic per year respectively.

[44] In this section and subsequent sections, we apply the RAN and capacity upgrades to the existing number of sites along railways. However, we would expect mobile operators to have to invest in a significant amount of incremental infrastructure in order to provide consistent 5G services to these locations due to the size of the rail networks and the challenges in providing a signal to fast moving carriages.

[45] In this section and subsequent sections, we primarily focus on changes to the network infrastructure rather than the release of additional spectrum. Future release of spectrum is uncertain and we consider that any release of additional spectrum is likely to improve the capacity on given sites, i.e. improve the quality delivered by the existing network, but not materially impact the number of additional sites needed to satisfy the significant additional capacity or geographic coverage requirements.

in Figure 9 below) and the cost of passive infrastructure rollout and full active equipment to the additional sites (third column in Figure 9 below).[46]

- **Basic 5G – small cell rollout**: Ofcom considered that another option would be for the operator to roll out "many thousands of small cells" by 2030 in "busy areas" and 30,000 to 50,000 by 2035. We understand from DCF stakeholders that operators need to deploy a significantly higher amount of small cells to satisfy the medium growth in traffic due to the limited coverage that small cells provide have therefore assumed that the lower end of that range (30,000) would be required by 2030. This may also reflects that Ofcom considers that by 2030, an additional 10,000 small cell sites may be required in its high traffic scenario and the likelihood of being in either scenario is not known with certainty. Ofcom's definition of "busy areas" is again unclear so we have assumed that this refers to the Urban geotype, This means that we apply the cost of upgrading the capacity on existing sites (second column in Figure 9 below) and the cost of small cell rollout to the new small cell sites (fourth column in Figure 9 below).

FIGURE 9 ADDITIONAL ROLLOUT TO MEET OFCOM MEDIUM DEMAND FORECAST

GEOTYPE	EXISTING MACRO SITES	ADDITIONAL MACRO SITES UNDER BASIC 5G - SITE DENSIFICATION	ADDITIONAL SMALL CELLS UNDER BASIC 5G – SMALL CELL ROLLOUT
Urban	1,675	1,675	30,000
Suburban 1	7,923		
Suburban 2	1,950		
Rural 1	1,544		
Rural 2	3,111		
Highways	1,266		
Railways	424		

Source: Frontier Economics

4.2 INCREMENTAL COST FOR BASIC 5G

We use the approach set out in Section 3.1 and the incremental infrastructure for site densification and small cell rollout above to calculate a range for the basic 5G scenario, see Figure 10. As part of this, we further split out the costs into the capacity related investment (i.e. investments on the core, backhaul and network expansion to handle the extra traffic) and basic 5G functionality investment (i.e. investments to upgrade existing active equipment to 5G).

[46] Additional RAN rollout is likely to require additional deployment of core network sites too. While this is not specifically reflected below, it is approximated in the costing by a markup applied on additional RAN site costs and may be higher where specific 5G core equipment is needed to enable advanced use cases.

FIGURE 10 BASIC 5G COSTS FOR THE INDUSTRY

GEOTYPE	BASIC 5G CAPACITY UPGRADE	BASIC 5G COVERAGE UPGRADE
Basic 5G – lower bound	£4.8 billion	£7.0 billion
Basic 5G – upper bound	£7.2 billion	£7.0 billion

Source: Frontier Economics

4.3 INVESTMENT GAP FOR BASIC 5G

Our results for the basic 5G scenarios suggests an investment gap that is between the range of £2.7 billion to £5.0 billion, see Figure 11.

FIGURE 11 INVESTMENT GAP FOR THE INDUSTRY UNDER THE BASIC 5G SCENARIOS

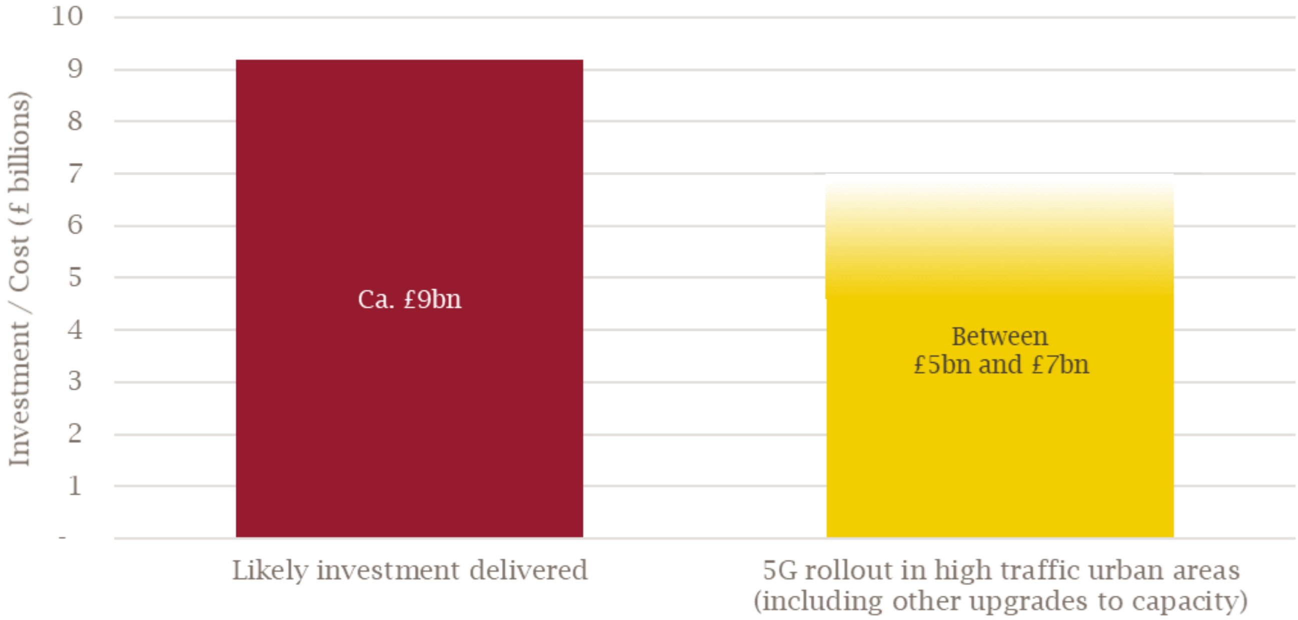
	UPGRADE COSTS	INVESTMENT POTENTIAL	INVESTMENT GAP
Basic 5G – lower bound	£11.9 billion	£9.2 billion	£2.7 billion
Basic 5G – upper bound	£14.2 billion	£9.2 billion	£5.0 billion

Source: Frontier Economics

4.4 CONCLUSION ON BASIC 5G

Under the basic 5G scenarios, the industry is likely to have sufficient funds to upgrade network capacities to meet future traffic demand with the investment required for this upgrade ranging from ca. £5 billion to £7 billion compared to a likely investment delivered by the industry of £9.2 billion.

FIGURE 12 LIKELY INDUSTRY INVESTMENT AND COSTS OF BASIC 5G CAPACITY UPGRADES



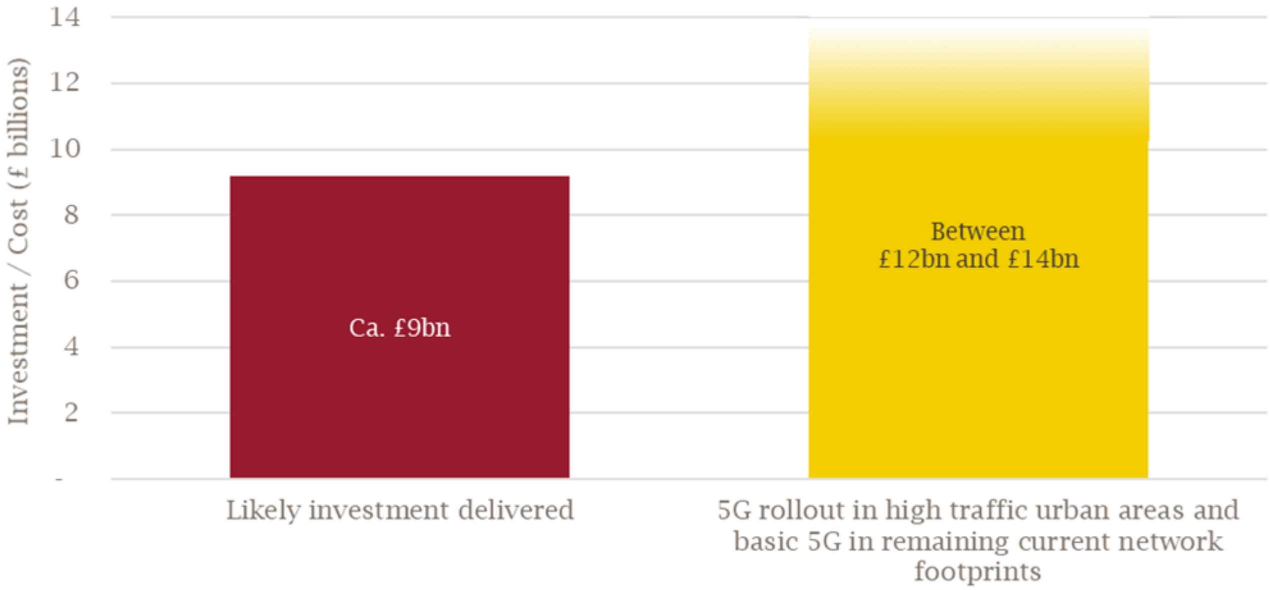
Source: Frontier Economics

Given the strong commercial incentives to meet customers' growing demand for traffic, we would expect this to be the industry's initial priority for investments. Although based on specific rollout assumptions, which may differ in practice,[47] the level of cost of the basic 5G capacity scenario would suggest that this investment could be delivered by the industry.

However, the considerable costs of delivering capacity upgrades are likely to make investments in the broader rollout of basic 5G functionality across the footprints of current networks challenging. The chart below shows the investment needed to upgrade networks to meet traffic demand and cover 95% of the population with basic 5G in the current network footprints. The chart shows that attempting to upgrade the network in this manner would imply an investment gap of £2.7 billion to £5.0 billion by 2030.

[47] The rollout assumptions to meet basic traffic demand growth are based on Ofcom estimates using population density as a driver. However, capacity requirements may not be fully explained by population density but could also be driven by other user gatherings, for example along rail and road transport routes, shopping centres or event locations.

FIGURE 13 LIKELY INDUSTRY INVESTMENT AND COSTS OF BASIC 5G CAPACITY AND COVERAGE UPGRADES



Source: Frontier Economics

We have also conducted some indicative analysis on the likely incremental operating costs (OPEX) that would be incurred by the industry to deliver the basic 5G scenarios above.[48] This suggests that meeting both objectives above (i.e. to deliver capacity and basic functionality) will result in a total OPEX of up to £1.5 billion for the industry per year. If we assume that the proportion of additional OPEX that the industry will incur as a result of 5G (i.e. on top of 4G) is equal to the proportion of the investment gap out of total investment costs, then the incremental OPEX could amount to up to £500 million per year. It seems likely that the industry would also find it challenging to finance this level of additional OPEX given current revenue expectations. This suggests that, absent policy intervention, the divide between the quality of networks delivered in urban and rural areas would be likely to increase over the next decade.

5 THE INVESTMENT GAP FOR ADVANCED 5G SCENARIOS BY 2030

We use the same approach as above for costing advanced 5G scenario. That is, we use the same network, geotype and population assumptions as above but assuming further incremental rollout to achieve additional benefits from 5G.

5.1 INCREMENTAL 5G INFRASTRUCTURE

We first extend our analysis to consider the incremental rollout that is required to align the 5G performance in less populated areas with those in more urban locations – i.e. rollout to deliver enhanced quality and coverage of 5G connections in semi-rural locations.[49] We consider that mobile operators will

[48] For this, we use publicly available information from 5G NORMA (see http://www.it.uc3m.es/wnl/5gnorma/pdf/5g_norma_d2-3.pdf) and apply this to the required additional 5G infrastructure under the "basic 5G" scenarios.

[49] These upgrades are on top of the upgrades in basic 5G discussed above.

likely focus on these locations first given the need to reduce the divide in the quality of connection between urban and rural locations.

In particular, we consider that the average distance between base stations in rural areas is likely to imply that the quality of 5G is not consistent across rural areas (i.e. degrading in some parts) and that the maximum throughput achieved by users in rural areas does not match that in denser areas because only a basic upgrade of actives is used. For this, we assume that the average radius in Rural 1 areas needs to be reduced from 3.39km to 1.51km of sites in Suburban 2 areas – this leads to an additional 6.3K macro sites and this is shown in the third column in Figure 14 below. We further consider that the active equipment in Rural 1 locations needs to be upgraded to those that are used in more dense locations to consistently achieve high capacity connectivity through mMIMO and beam forming – this means that we apply an upgrade to full 5G to the existing 1.5K sites and the new 6.3K sites in Rural 1 areas.

FIGURE 14 NUMBER OF SITES FOR ENHANCED 5G IN SEMI RURAL LOCATIONS

GEOTYPE	EXISTING SITES	ADDITIONAL MACRO CELLS NEEDED TO ENHANCE 5G IN SEMI-RURAL LOCATIONS
Urban	1,675	
Suburban 1	7,923	
Suburban 2	1,950	
Rural 1	1,544	6,270
Rural 2	3,111	
Highways	1,266	
Railways	424	

Source: Frontier Economics

Finally, we consider another extension to the above. The incremental infrastructure considered above may only be able to satisfy traffic demand and improve the coverage with 5G outside urban areas. However, it may not be sufficient to satisfy advanced 5G characteristics. In particular, we consider, as one specific scenario, the rollout of low latency (5- 10ms) capability (e.g. for the widespread adoption of driverless vehicles or other types of autonomous technologies such as delivery robots). This can only be achieved through mmWave small cells as mmWave spectrum allows small cells to support larger sub-channels / carrier spacing than technologies that rely on low or mid-band spectrum. In light of these factors, we consider the additional infrastructure that is required to achieve full coverage within denser populated areas of Urban and Suburban 1. Such a rollout is also likely to satisfy any requirements in user capacities of 100Mbps, massive device density and traffic demand for Ofcom's high demand scenario.

Small cells in the mmWave range of spectrum are likely have limited coverage given the propagation characteristics of the spectrum. We therefore use a stylised assumption for the average radius of the cells of 150m.[50] We note that this is already covered by our basic 5G scenario in Urban locations so we focus on the rollout of a substantial amount of mmWave small cells in Suburban 1 locations of 66.5K.

FIGURE 15 NUMBER OF SITES UNDER ADVANCED 5G SCENARIOS

GEOTYPE	EXISTING SITES	ADDITIONAL MACRO CELLS NEEDED TO ENHANCE 5G IN SEMI-RURAL LOCATIONS	ADDITIONAL SMALL CELLS NEEDED TO DELIVER ADVANCED USE CASES IN URBAN / SUBURBAN LOCATIONS
Urban	1,675		
Suburban 1	7,923		66,494
Suburban 2	1,950		
Rural 1	1,544	6,270	
Rural 2	3,111		
Highways	1,266		
Railways	424		

Source: Frontier Economics

In relation to other advanced 5G characteristics, we note that this extensive rollout using mmWave small cells is also likely to satisfy any requirements in relation to high user capacities of 100Mbps (and more) as well as massive device density in Urban and Suburban 1 areas. That is, we assume that the low latency of 5-10ms is the binding characteristic for the rollout of additional 5G equipment in these areas.

5.2 TOTAL COSTS AND INVESTMENT GAP

Given that the advanced 5G scenarios includes the investment that is needed to deliver the basic 5G scenarios, we present the incremental investment gap that is on top of the investment gap range that is required to deliver basic 5G in Figure 16 below.

[50] We note that the radius of small cells is in the range of 80m to 120m but we consider a longer distance of 150m may be a reasonable in suburban areas as the line of sight is higher in these areas than urban areas. See https://www.commsupdate.com/articles/2022/07/01/vmo2-claims-lead-in-small-cell-deployment-as-it-details-london-rollout-progress/#:~:text=Virgin%20Media%20O2%20(VMO2)%20has,live%20sites%20across%20the%20capital. We also note that the additional small cells of around 65K is consistent with Ofcom's estimate that operators may require over 100K small cells by 2035 under the high demand scenario.

FIGURE 16 INCREMENTAL INDUSTRY INVESTMENT GAP FOR ADVANCED 5G SCENARIOS

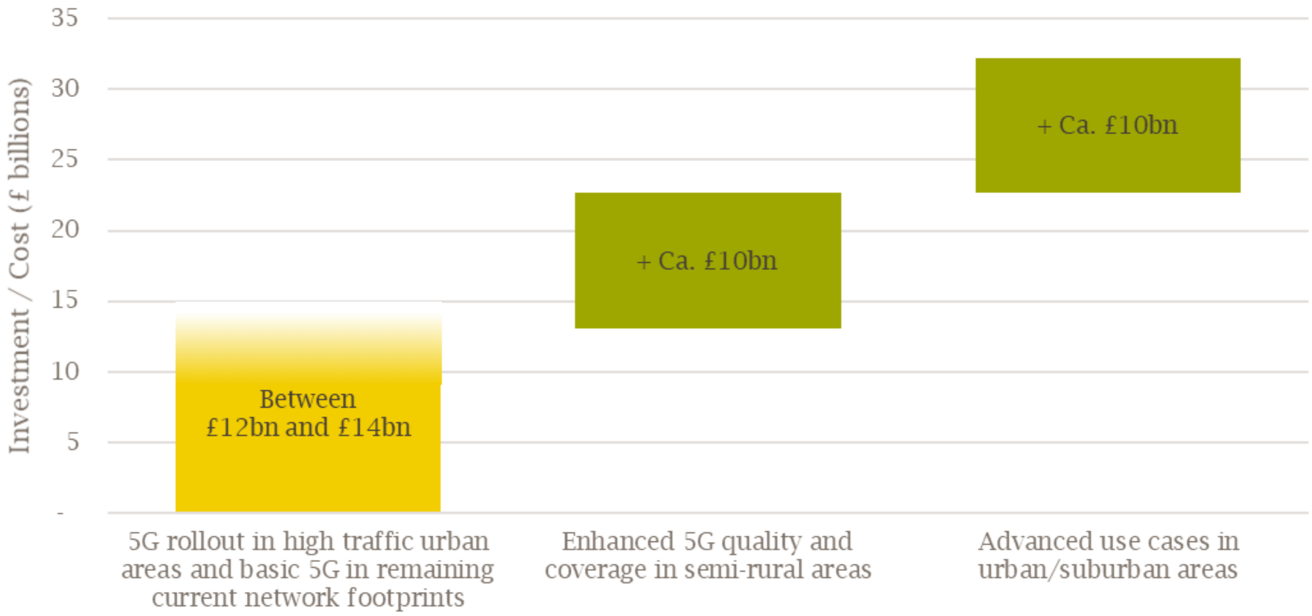
	Investment gap
Basic 5G	£2.7 billion - £5.0 billion
+Enhanced 5G quality and coverage in semi-rural locations	+£9.7 billion
+Advanced use cases in urban/suburban locations	+£9.5 billion

Source: Frontier Economics

5.3 CONCLUSION ON ADVANCED 5G

Overall, these results show that the hypothetical operator will not be able to provide sufficient capacity or advanced use cases for the vast majority of the UK population due to the substantial investment gap across all advanced scenarios. There is a significant risk that businesses and consumers will not be able to access advanced use cases and benefit from enhanced digital connectivity across large parts of the UK. On top of this, using the same methodology detailed above, we estimate that the industry would also incur a substantial increase in OPEX of up to £3 billion per year if the advanced 5G investments were made.

FIGURE 17 THE COSTS OF ADVANCED 5G ROLLOUT IMPLY A SIGNIFICANTLY LARGER INVESTMENT GAP



Source: Frontier Economics

In fact, even the provision of enhanced 5G quality and coverage (excluding advanced use cases) to semi-rural areas would still imply that the vast majority of the UK's landmass (70% of its geographic area) would not benefit from significant improvements in 5G use cases. It would also imply no 5G rollout to the 5% of the population in the most sparsely populated areas. Further expanding the 5G rollout to improve both would significantly increase the investment needed and hence the gap to achieve it.[51]

Our results rely on a number of public sources on costs, generally referring to generic network upgrades. We recognise that in practice, unit costs are likely to be more varied and may also have changed over time given some of the inputs are a number of years old. For instance, we do not assume any upgrades to passive elements of the existing sites when upgrading active equipment but some DCF stakeholders suggest that site owners may still need to strengthen existing passive installations to mount the 5G equipment. However, we also note that there are other factors that suggest that costs could be lower. For example, active equipment costs (based on 2016 prices) may have decreased as the deployment of that equipment has considerably increased and may have resulted in price reductions.[52] As another example, passive infrastructure costs may also vary significantly with some DCF stakeholders suggesting that passive costs at some new sites could be lower as operators could choose to deploy smaller rooftop or *mini macro* sites rather than large rooftop sites or towers. Overall, having considered a number of sensitivities on our assumptions, we conclude that the fundamental results of our analysis do not change and a considerable gap remains despite changes in key assumptions.

[51] The investment gap is estimated at £37 billion (on top of the investments for advanced use cases) to serve just half of the remaining rural areas. However, this assumes a uniform geographic coverage across the remaining 70% of the UK area which is unlikely to be required. We note that the optimal geographic coverage depends on many more specific factors that cannot be considered within this study.

[52] We do not consider this alone to be sufficient to change our analysis above. For example, reducing the active unit costs by 20% will still lead to an industry investment gap for the enhanced 5G quality and coverage in semi-rural locations of around £12 billion.

6 CONCLUSION AND POLICY OPTIONS TO OVERCOME THE INVESTMENT GAPS

The previous sections set out that 5G can be expected to be a key technology in satisfying the increasing demand for mobile traffic and for delivering social and economic benefits through its ability to increase digital connectivity and unlock advanced use cases. However, while the industry has been successful in the past in meeting the demands of consumers and the broader economy, we find that 5G raises new challenges in terms of the level of investment required. In addition there is considerable uncertainty attached to the business case mobile operators investing to support innovative services.

This is supported by our analysis in the previous sections which shows that, under the status quo, there is likely to be a significant gap between the capacity of the industry to invest and the investments needed to meet the Government's high level objective to enable the UK to become a global leader of digital connectivity, and to further allow businesses and consumers to benefit from the social and economic benefits of advanced wireless networks.

Given the scale of the gap, this may require more fundamental policy shifts than interventions and public funding to date which, while welcome, have focused on marginal reductions in the cost of network roll out. The success of the Future Telecom's Infrastructure Review (FTIR), in incentivising fibre rollout through a combination of commercial investment and public funding of rollout in rural areas, is a helpful precedent.

6.1 POLICIES THAT COULD REDUCE THE COSTS OF DEPLOYMENT

Spectrum policy. Policy makers could consider accelerating the release of additional spectrum for mobile use in order to support the higher demand for traffic and the development of advanced use cases. For example, the 600 MHz and U6 GHz[53] spectrum bands are currently being considered to support 5G deployment across Europe[54] with Ofcom also considering other higher capacity spectrum bands within 7 – 20 GHz and above 100 GHz spectrum ranges.[55] This may be particularly important in urban areas as the lack of space to install additional sites means that mobile operators could use more spectrum to provide capacity (instead of further densification of sites) and in rural areas to improve quality of coverage. As such, we consider that a supportive spectrum policy to address the needs of mobile operators could have a significant impact on the gaps already identified and help avoid future investment gaps.

Network sharing. Sharing network infrastructure and equipment reduces the overall cost to the industry by removing duplications of fixed costs. There is scope for policy to further simplify or promote network sharing through updating the guidance on the assessment of joint ventures and define broader exceptions (similar to those for the Shared Rural Network) where joint development is permitted.[56] This could include the deployment of neutral host active networks, allowing mobile networks to deliver services over a single network operated by a third party.

Consolidation. Consolidation of mobile networks would remove the need to duplicate mobile infrastructure, thereby reducing the fixed costs of roll out between the two merging operators. Policy makers should therefore take this into account as part of their assessment of any potential mergers.

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[53] I.e. 6 GHz made available for mobile

[54] As part of preparing for the ITU World Radiocommunications Conference 2023

[55] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

[56] https://newscentre.vodafone.co.uk/press-release/vodafone-and-o2-finalise-5g-uk-network-agreement/

Equipment costs: Mobile operators are also concerned with the lack of choice among equipment vendors as this increases the cost of equipment. OpenRAN could be an option to improve this situation as it enables interoperability between different hardware and software vendors, thereby leading to an improvement in choice, competition and innovation. Therefore, a potential lever for policy makers, although one that is unlikely to immediately impact on the ability to invest in light of a lack of concrete solutions to deploy, is to provide more support and funding to accelerate the development and use of OpenRAN.

Other rollout barriers: We understand from stakeholders that practical rollout barriers (that can result in suboptimal rollout and hence increases in costs or inability to rollout) have to some extent been dealt with. Recent policy decisions such as the DCMS and MoHCLG (now DLUHC) led reforms to permitted development rights and the Government's barrier busking task force have greatly improved the ability to rollout. In the context of further enabling the efficient deployment of networks, planning decisions could place greater emphasis on efficiency by considering the extent of parallel rollout and highlight to permission seekers where opportunities for joint infrastructure use may exist.

6.2 POLICIES THAT INCREASE THE COMMERCIAL VIABILITY OF 5G

Government subsidies, Licence fees and taxes. Direct financial support to network operators and infrastructure owners or collaboration in the form of a public private partnership could help increase the deployment of 5G networks across the UK. This may be particularly important for rural or harder to reach areas as funding in these areas is unlikely to displace any private investments. The existing SRN programme for 4G is a helpful precedent but, given our earlier cost analysis, the required intervention for 5G would be likely to expand beyond the existing level of SRN support. For example, the SRN programme was only designed to increase 4G coverage to cover hard to reach areas whereas our advanced 5G scenarios above does not cover the costs that is needed to provide geographic coverage for 70% of the UK. In the provision of these direct subsidies, the Government should also note the diverse industry landscape and the synergies that actors can contribute to the efficient deployment of 5G, from equipment vendors (OpenRAN) to TowerCos (single site sharing) and MNOs (joint 5G rollout and service provision). Policy makers could also consider providing mobile operators with low interest loans to support deployment. For example, the Government could consider using some of the funds from the Infrastructure Bank to finance 5G deployment as 5G could be a key enabler of economic growth across the UK.

Network operators pay annual licence fees (ALFs) for spectrum after the end of the initial term of auctioned licence. While in theory these fees should not affect operators' investment incentives (as they are effectively a sunk cost), they do reduce the operating cash flow available for investment. For example, the mobile industry currently pays £325 million per year in ALFs[57] and some of this could be reinvested to support network deployment.

Tax policy can also be used to incentivise investments. For example, the business rates fibre relief granted to new fibre investments or the super-deduction[58] for investment is a template policy makers can apply to 5G investments.

Unlocking new use cases. A less direct approach to improve the revenue side (or the certainty of future revenues) relates to the viability of use cases and policy makers can explore ways to support the

[57] See https://www.ofcom.org.uk/__data/assets/pdf_file/0023/226085/bt.pdf

[58] See https://www.gov.uk/guidance/super-deduction

development of new 5G use cases by directly promoting the technologies that rely on the infrastructure. For example, public sector migration to 5G, promoting IOT in public functions (such as traffic management) and promoting other technologies (such as driverless vehicles and other mobility use cases) could increase the commercial viability of operators to invest in 5G. This may also require addressing potential 'hold up' problems where potential gatekeepers in the supply chain could capture the majority of the value enabled by the mobile industries investment in advanced 5G capabilities.

Net neutrality. Net neutrality rules can restrict mobile operators' ability to set specific tariffs which provide enhanced services for certain applications or users. This may be problematic for some advanced 5G use cases which require the operator to treat and prioritise traffic differently between different use cases (e.g. mobile internet traffic vs traffic from driverless cars). This means that more targeted forms of net neutrality could be explored to promote the ability of telecommunication operators to set optimal tariffs which could expand output of new use cases and telecommunication services, and thereby incentivise further investment in 5G. This could include the greater use of effects based tests[59] to determine if any practices should be prohibited and avoidance of formalistic rules to determine whether a practice is prohibited by net neutrality.

[59] These refer to tests that determine the net impact on consumers.

ANNEX A - INPUTS TO COST CALCULATIONS

We have used a number of public sources to identify the unit costs of 5G network assets – these are discussed below and in Figure 18:

- **Passive costs** – we assume that any new site in Urban locations will be a rooftop site due to the lack of space to install towers. We further assume that towers will be used as new sites for all other geotypes.

- **Actives** – we assume that 5G active equipment in Urban and Suburban locations will use the full range of spectrum (i.e. sub 1 GHz, low band[60] and mid band[61] spectrum) in order to handle the increase in traffic in these areas. On this, Ofcom notes that "dense urban" and urban" areas will be capacity limited by 2025-2030 in their medium growth scenario while other areas will likely be capacity constrained after 2030.[62] For all other locations, we assume that 5G active equipment will only rely on sub 1 GHz spectrum as refarming 4G spectrum may be sufficient to satisfy basic capacity requirements in those areas. For the active costs of each site, we assume that these costs relate to antennas and active electronic equipment and the cost of installing these.[63]

- **Small cells (operating in the mmWave spectrum) –** we assume that small cell costs relate to sites, antennas and active electronic equipment as well as the costs to install the equipment.

- **Core** – relates to software and hardware upgrades in the core of the network, e.g. routers and network controller.

FIGURE 18 UNIT COSTS PER SITE

COST TYPE	COST (£/SITE)	SOURCE (DATE)
Installation of a new passive - towers	93,000	Ofcom MCT Model (2022/23)[64]
Installation of a new passive - rooftop	46,000	5G NORMA (2017)[65]
Installation of new 5G actives per new and existing site – urban/suburban	147,000[66]	Frontier Economics based on 5G NORMA

[60] This refers to 1800 MHz, 2100 MHz and 2600 MHz spectrum

[61] This refers to 3400 MHz and 3600 MHz spectrum

[62] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

[63] These costs will likely be conservative as they do not take into account of costs to replace vendors.

[64] <Unit investment> tab of "3-cost" workbook. https://www.ofcom.org.uk/consultations-and-statements/category-1/mobile-call-termination-market-review

[65] Table 11-10 http://www.it.uc3m.es/wnl/5gnorma/pdf/5g_norma_d2-3.pdf

[66] Active costs are calculated using information on the costs of RF Frontend and baseband processing units as well as assumptions of spectrum that is available for each type of actives (e.g. sub 1 GHz, low band and medium band). http://www.it.uc3m.es/wnl/5gnorma/pdf/5g_norma_d2-3.pdf. We also focus on active costs only for each site although we recognise that this may be a conservative assumption as mobile operators may need to also invest to strengthen the existing sites to handle 5G active equipment.

Installation of new 5G actives per new and existing site – rural/highways	37,000[67]	Frontier Economics based on 5G NORMA
Installation of a small cell site	14,000	Frontier Economics/DCMS (2017)[68]
5G Core upgrade	10% of RAN and backhaul costs[69]	Oughton and Frias (2016)[70]

Source: Frontier Economics based on public sources

In terms of fronthaul/backhaul related costs for both macro sites and small cells, this can be split into two separate components:

- The first one refers to the cost of upgrading the existing bandwidth for each site so that additional capacity can be offered for 5G purposes. For this, we assume that 5G will require a high capacity 10 Gbit/s Ethernet fixed connection and that all sites will require this upgrade[71]. We then use the annualised depreciation costs from Ofcom's indicative dig distance model and multiply this by an assumed asset life of 10 years in order to calculate total investment costs.[72] This is shown in the second column of Figure 19 below.[73]

- The second one refers to the cost of installing a fibre cable for each site. For this, we use the passive costs by route distance from Ofcom's indicative dig distance model[74] and apply these to a series of assumptions on the average dig distance for each geotype (see third column below)[75] and

[67] See above

[68] Figure 25 – sum of costs of (i) site acquisition and civil works, (ii) antenna, (iii) feed install, test and commission; and (iv) actives: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728816/Frontier_report_on_Mobile_Market_Dynamics.pdf.

[69] It is unclear what type of upgrades are included under this assumption but we consider that this can include the costs to adapt the core network topology to better cope with the increase in capacity (e.g. installation of more core nodes). It may further capture some additional investments that support specific use cases (e.g. support for ultra-reliable low latency communications, URLLC, and multi-access edge computing, MEC).

[70] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/577965/Exploring_the_Cost_Coverage_and_Rollout_Implications_of_5G_in_Britain_-_Oughton_and_Frias_report_for_the_NIC.pdf, Table 7.

[71] We have assumed that the hypothetical operator does not have any sites currently connected to a 10 Gbit/s backhaul connection because Ofcom has assumed in the MCT model that the hypothetical operator on legacy technologies will only require a maximum backhaul of 500 Mbit/s.

[72] We assumed an asset life for active electronics of 5 years. Given that we are focusing on costs of investment over a longer time horizon (i.e. 2022 – 2030), we assume 10 years, i.e. implying a further upgrade after the first 5 years in the period up to 2030.

[73] In line with Ofcom, we use an average of £795 and £1,193. Table A10.3, https://www.ofcom.org.uk/__data/assets/pdf_file/0028/154594/pimr-bcmr-llcc-final-statement-annexes-1-25.pdf

[74] Specifically, the passive cost per metre. Table A10.4, https://www.ofcom.org.uk/__data/assets/pdf_file/0028/154594/pimr-bcmr-llcc-final-statement-annexes-1-25.pdf

[75] The assumptions on dig distance by geotype in Figure 11 are based on https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/577965/Exploring_the_Cost_Coverage_and_Rollout_Implications_of_5G_in_Britain_-_Oughton_and_Frias_report_for_the_NIC.pdf.

assumptions on the availability of new ducts versus the need to dig new ducts[76] (see fourth and fifth columns below). The backhaul costs is then shown in the sixth column below.

We further adjust the total backhaul costs depending on whether it is an existing site or a new site:

- **New sites**: we assume that a fibre connection will need to be installed for all sites so these costs are shown in the sixth column below.
- **Existing sites**: these costs will depend on the existing backhaul technology for each site as those sites with an ethernet connection will already have ducts in place for the backhaul upgrade. For this, we note that Ofcom has assumed in its 2018 MCT model that 67%[77] of sites have an ethernet connection – we therefore use this figure and reduce the cost of backhaul (sixth column) by 67%.

FIGURE 19 BACKHAUL COSTS PER SITE AND ASSUMPTIONS[78]

GEOTYPE	10 GBIT/S HIGH CAPACITY CIRCUIT (£/SITE)	ROUTE DISTANCE (M/SITE)	DISTANCE OF EXISTING DUCTS (M/SITE)	DISTANCE OF NEW DUCTS (M/SITE)	AVERAGE COST FOR NEW SITES (£/SITE)
Urban	9,940	1,000	1,000		4,400
Suburban 1[79]	9,940	2,000	2,000		8,500
Suburban 2	9,940	4,000	4,000		17,000
Rural 1	9,940	8,000	7,000	1,000	115,000
Rural 2	9,940	20,000[80]	16,000	4,000	410,000
Highways	9,940	8,000[81]	6,000	2,000	34,000
Railways	9,940	8,000[51]	6,000	2,000	34,000

Source: Frontier Economics based on public sources

[76] We essentially multiply the cost per metre of "*Network extension (new duct required)*" and the assumed distance of new ducts. We then add this to the product of the average cost per meter of "*Duct connected with tubing*" and "*Duct connected without tubing*"; and the assumed distance of existing ducts.

[77] <Params - other> tab of "2 - Network" workbook. https://www.ofcom.org.uk/consultations-and-statements/category-1/mobile-call-termination-market-review

[78] This is an approximation of backhaul costs for mobile operators as the exact costs for each operator will depend on the operator's network topology and investment strategy. For example, operators may incur different costs subject to whether they invest in their own network (alone or shared) or rely on active or passive third partly rentals.

[79] Ofcom provides estimates up to 2,000m – we used the same cost per metre estimates for the longer distances as we would not expect the cost per metre to change significantly over longer distances. This is because change in cost per metre has reduced significantly by 2000m - for example, the rate of decline has fallen from 31% between 10m and 20m to less than 1% between 1000m and 2000m..

[80] This is an average of the distances for geotypes Rural 2 – 4.

[81] We assume that this is the same distance as Rural 1.