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A BUSINESS CASE FOR 5G MOBILE BROADBAND IN A DENSE URBAN AREA

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Abstract

5G networks are envisioned to provide consumers and industry with improved transmission performance and advanced communication possibilities. To deliver on this promise of ushering in faster downloads and lower latency, mobile network operators are called upon for substantial investment in network infrastructure. Investors and operators need a clear 5G business case before making such investment. So far, very little research has been published on the topic of the 5G business case. This article studies the impact of different elements driving the business case of a 5G network. The study was performed within 3 boroughs of central London, UK, for the period 2020-2030. 5G-related costs and revenues were calculated to derive the business case. The results show that the business case for a 5G network providing mobile broadband services alone is positive over the time period 2020-2030 but has some risk in the later years of this time period. The business case is also particularly sensitive to assumptions on the revenue uplift and the rate of traffic growth which are inherently challenging to forecast. The sensitivity analysis shows that the return on investment becomes negative if both traffic and costs are significantly higher and revenues increase more slowly than our baseline forecasts. Network sharing helps to substantially improve the business case. Further research is needed to understand the business case on a regional or nationwide basis, and for a network that provides additional services beyond broadband.

Keywords: 5G, business case, mobile broadband, costs, revenues

1 Introduction

The future Fifth Generation (5G) of telecommunications systems will bring new opportunities to citizens in terms of communications possibilities. With the deployment of 5G it is expected that communications will be faster, ubiquitous, more reliable and will enable a number of novel services that will contribute to the economic growth of countries and regions, e.g., vertical industry-grade services and vehicle-to-anything (V2X) communications. Expected technical features of 5G will enable the creation of different business opportunities (NGMN, 2015). For example, 5G is intended to provide end users with an improved user experience with typical user throughputs of at least 50 Mbit/s in downlink and 25 Mbit/s in uplink, lower and stable end-to-end latency below 10 ms, improved coverage outdoors as well as indoors, and higher wide area network capacity. In (NGMN, 2015) it is explained that, for a number of applications, the wireless transmission data rate needs to be in the order of 1 Gbit/s (primarily indoor and/or hotspot areas) and for others a low end-to-end latency down to 1 ms will be needed (e.g. for industrial automation in local areas).

The consideration of revenue generation and social value creation establishes viable value creation potential and propositions for 5G (Rendon Schneir et al., 2018). The introduction of 5G could also have wider socio-economic implications (5G NORMA D2.3, 2017). Further benefits could come from the emergence of disruptive players and innovation in applications and content provision to create even more value for the economy. Importantly however, these benefits will not come at zero cost. The costs of deploying mobile infrastructure capable of delivering these value propositions must be evaluated to establish the business case for investment. The drive towards penetration of adjacent vertical markets and establishing business to business (B2B) and business to business to consumer (B2B2C) opportunities is also an essential strategic element of the nascent 5G business case. The study of economic aspects plays an important role when mobile network operators (MNOs) decide to rollout a specific technology. The analysis of cost, revenues and financial aspects of 5G is therefore a study area that deserves the attention of MNOs, vendors, public authorities, consultancy firms, academia and analysts. One of the most relevant questions associated with 5G is as follows: What is the corresponding business case?

Several authors worked on the prospective economic analysis of 3G and 4G networks before these networks were introduced. A study about a 4G business case was prepared by (Forge, Blackman and Bohlin, 2005). A few scenarios and business models for several 4G possibilities in Europe were also described in (Ballon, 2004). (Cerboni et al., 2000) made a business case analysis for a 3G network in two European countries. To date very few authors have worked on the topics of

5G costs, 5G revenues and how these come together in 5G business cases. The cost of a 5G network to provide national coverage in the United Kingdom (UK) has been examined in (Oughton & Frias, 2018). Rendon Schneir et al. (2017) made an analysis of the cost of a multi-tenant 5G network that is shared by different entities. Also, the cost of various 5G services for a number of scenarios was calculated in (METIS-II D1.2, 2017). However, there are very few studies that have made a serious study regarding the calculation of the revenues that can be achieved. One example, (METIS-II D1.2, 2017) calculated the revenues that can be achieved for a number of services. With regards to the business case of 5G, (METIS-II D1.2, 2017) calculated the business case of a single MNO. According to (Webb, 2016), the cost of rolling out 5G will be high and there are so far no clear benefits for MNOs. Webb argues that a 5G vision is needed that can convince MNOs to make the necessary investment.

The aim of this article is to contribute to the study of the business case of a 5G network. The research question that will be addressed in this article is the following: *What is the business case of an operator that provides users with mobile broadband services through a 5G network in a dense urban area?*

The purpose of the article is to provide an answer to this question by using a business case estimation derived for 5G. The business case analysis employs as input parameters costs and revenues. A cost model has been exemplarily constructed for the study area, which is three boroughs in the centre of London in the UK – this corresponds to a typical dense urban area. The cost model considers a cloudified radio access network (C-RAN) architecture for macrocell sites in the area and a distributed RAN (D-RAN) for small cells. Today's 4G networks are based on a D-RAN architecture whereby the base station equipment is co-located with the antenna and radio frequency (RF) front end equipment on the antenna site. Under C-RAN we consider the case of the antenna site only being equipped with a Remote Radio Head (RRH) and the base station processing to be done in a separate edge cloud site on commercial off-the-shelf (COTS) x86 architecture processors. The 5G-related revenues are calculated for providing a broadband service. This analysis should be understood as a contribution to the creation of a national or regional 5G business case, which is the typical coverage area of an MNO. Note that this article examines the business case drivers and considerations if a 5G network were deployed in the London scenario and timescales studied. It is acknowledged that this scenario could also be served by other wireless strategies including the further expansion of today's Long Term Evolution (LTE) networks in a non-virtualised manner. However, such an alternate strategy might have implications for supporting more bespoke wireless services on the network in future due to the lack of support for network slicing.

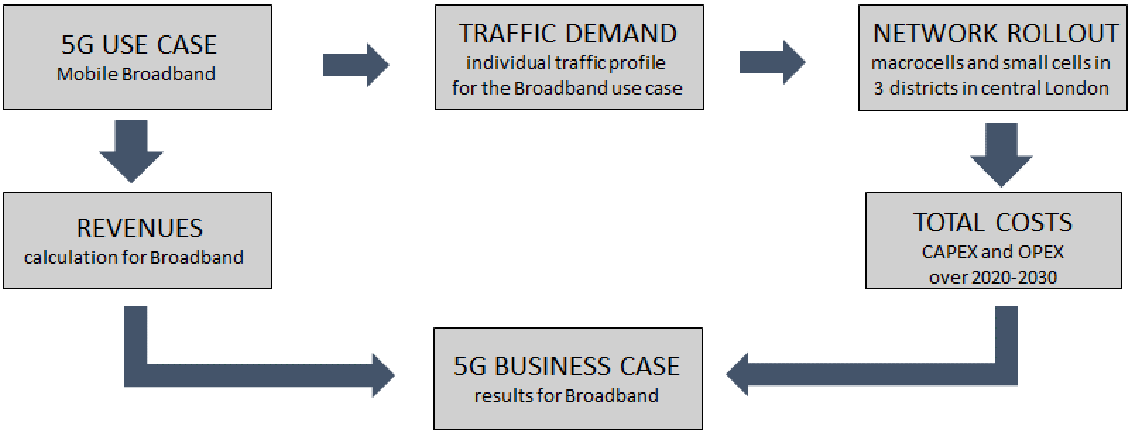
The rest of the article is organised as follows. Section 2 describes the approach employed for the analysis: logic of the business case, study area and 5G rollout considerations. Section 3 presents the features of the cost model and the cost results, whereas the calculation of the 5G revenues is described in Section 4. The results of the business case and the assessment of the results are explained in Section 5. Finally, Section 6 addresses the conclusions.

2 Approach for the analysis

2.1 Overall approach

The techno-economic analysis employed in this article follows the process shown in Fig 1. and is based on the work carried out in the European Union (EU) funded projects 5G NORMA and 5G-MoNArch (5G NORMA D2.3, 2017; 5G-MoNArch D2.1, 2017). First a set of evaluation cases were defined to understand the business case for 5G networks in different deployment approaches. The case focused on in this article is that of providing a high-capacity broadband service in a dense urban area. The mobile broadband service includes legacy broadband and enhanced Mobile Broadband (eMBB). A traffic demand forecast for the broadband service from 2020-2030 was estimated. This traffic demand led to the definition of a network rollout based on the deployment of macrocell sites and small cells to serve the forecast demand. Afterwards, the total cost, which includes capital expenditure (CAPEX) and operational expenditure (OPEX) for the network over the time period of 2020-2030, was derived. These costs were then compared against the range of feasible revenues for the broadband service considered over the same time period to assess several business case parameters for 5G in the study area. Finally, given that the demand for future mobile services is inherently difficult to accurately forecast and because of the uncertainties associated with the evolution of costs, a sensitivity analysis regarding revenues and costs was also done.

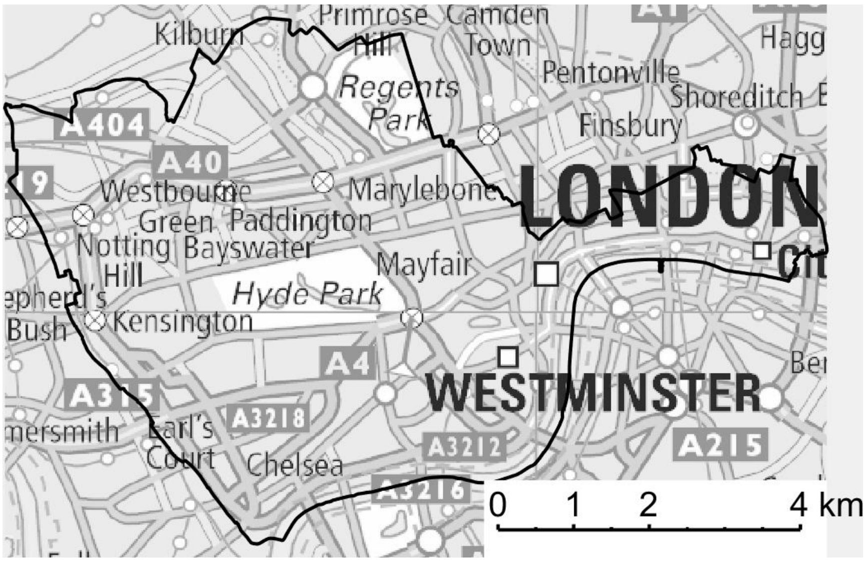
Fig 1. Approach for the elaboration of the business case.



2.2 Study area

This article focuses on the case of using 5G networks to deliver broadband services. The study area consisted of three central London, UK, boroughs (see Fig 2). A buffer area, considered to avoid edge effects, has also been taken into account. The results presented are for a 5G broadband-service network in a study area of 37 km^2 and population in the region of 400,000 residents.

Fig 2. The study area in London. The study area includes residential and business districts.



2.3 Defining 5G

5G is a promising technology that has the potential of enabling several attractive services over time. Because 5G consists of a collection of technology advancements, in this section we make a definition of what 5G is for the business case presented in this article.

It is assumed that an established 2G/3G/4G MNO in a dense urban area already provides voice and broadband services. This MNO then deploys on top of the established wireless technologies a new technology, in this case 5G, which will provide more transmission capacity especially for eMBB services over time compared to former generations. Additional services that could be provided by 5G, such as V2X, Internet of Things (IoT), ultra-reliable low latency communication (URLLC) services, drones, etc., have not been considered in our study. Therefore, applications that require very short transmission latencies below 10 ms like virtual reality (VR) or remote control of equipment, e.g. in a factory environment, are excluded from our study.

It is assumed that there will be a smooth transition to 5G, where the number of 5G connections gradually increases. We considered that the cells could incrementally support an increasing number of 5G-capable antennas. A similar approach was followed for access to spectrum bands, in which we assumed that with time more bands and bandwidth is available for 5G connections. Furthermore, we assumed that a C-RAN scheme is employed for macrocells, whereas small cells will operate with a D-RAN (see Section 2.4 for more information).

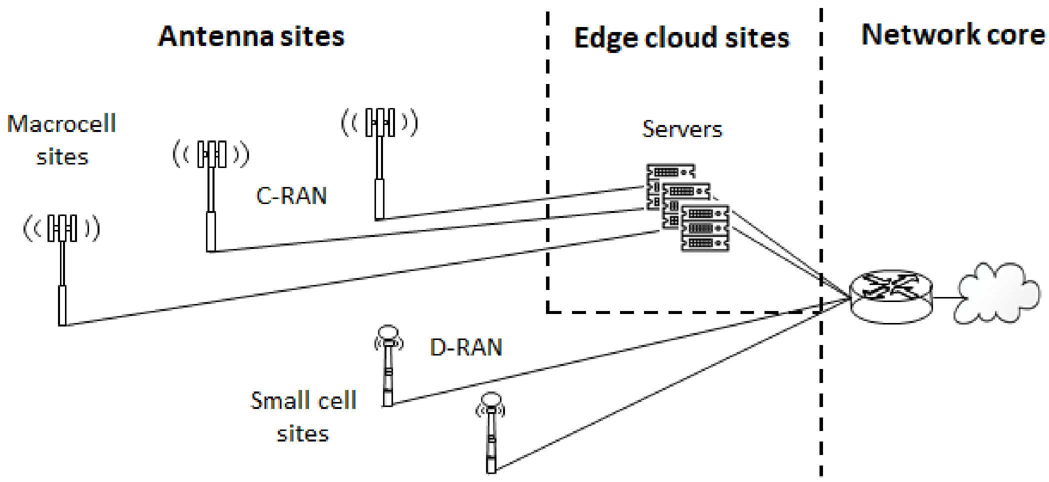
We acknowledge that a real MNO on its evolution path to 5G would transition through several 4G releases, for example LTE Advanced Pro enables some of the features of 5G. From the 3GPP perspective 5G considers both LTE and New Radio (NR) radio access technologies (RATs) for Releases 15+ (3GPP 5G, 2018). For simplicity and for the purposes of this study we modelled the network evolution using the number of antennas and availability of spectrum as a proxy to technology releases. The number of antennas supported over time and access to spectrum bands is discussed further in Section 2.4. The assumed spectrum efficiency associated with the different antenna configurations considered was as given in the 5G NORMA deliverable 2.3 (5G NORMA D2.3, 2017).

2.4 Network implementation of 5G

A novel software defined networking/network function virtualisation (SDN/NFV)-based 5G network architecture that provides broadband services from a single network infrastructure was analysed. This network employs concepts described in the EU funded 5G Public Private Partnership (5G PPP) projects 5G NORMA and 5G-MoNArch (5G NORMA D3.3, 2017; 5G-MoNArch D2.1, 2017). We assumed that the macrocell sites have migrated towards virtualisation, i.e., the baseband processing is centralised at edge cloud sites. We assumed that the macrocell RAN includes the infrastructure domains of equipment at the antenna site, virtualised network functions at an edge cloud site, and the transport links between them. For the purpose of this study the user plane processing incurred across the macrocell antenna sites was translated into general purpose processors (GPP) cores, servers and cabinets at the edge cloud sites (see Fig 3). Such edge cloud sites support the radio protocol stack processing with a given data throughput/capacity and are used in combination with a set of remote radio heads located on antenna sites. This approach is opposed to a traditional D-RAN approach where the complete base station equipment is located at the antenna site. Inter-site connectivity requirements were also considered and costed.

Even though an orchestrator has not been considered in the end-to-end network architecture, several sections of our network are network-slicing capable. A key step to support network slicing and the flexibility required in networks to have slices added, removed and adjusted is the transition to virtualised networks. This is required so that the network functions are no longer defined in dedicated base station hardware co-located with the antennas but softwarised and in more central locations and hence can be more readily updated and adapted to accommodate network slicing. In the results presented here the MNO is providing solely a broadband service but is doing this via a virtualised network which is ready to support in the future a wider range of services via network slicing.

Fig 3. Network Architecture.



For the purpose of our study we cost the network to provide at least a 10 Mbit/s downlink service, considered adequate for high quality video streaming, with 95% location availability. This is the minimum cell edge single user throughput used in the cost model when dimensioning the network for coverage. In practice many users will experience better than cell edge spectral efficiencies which will mean that the average cell throughput is higher than this. This service level is below the 5G user data rates quoted earlier but given that widespread consumer applications requiring such high throughputs, and hence willingness to pay for these, were unclear at the time of this study, this more conservative target appropriate for high quality video streaming has been used as the basis of our analysis. For the simulated eMBB service we did not utilise carrier aggregation, and we did not request it to be delivered with ultra-low latency.

The frequency bands used in total by macrocells and small cells in the analysis are described in the following: a) Sub-1GHz (Frequency Division Duplex, FDD): 700 MHz, 800 MHz and 900 MHz; b) Low-band (FDD): 1800 MHz; 2100 MHz and 2600 MHz; c) Low band (TDD): 2600 MHz; and d) Medium band (Time Division Duplex, TDD): 3400-3600 MHz. For the purpose of this study the spectrum efficiency (SE) values assumed are based on LTE simulations (5G NORMA D3.3, 2017), and we note that 5G NR SEs will be slightly higher than these LTE based values used in our assumptions. More specifically, we considered the same subcarrier spacing

(SCS) as in LTE, i.e. 15 kHz, resulting also in a similar frame structure/orthogonal frequency-division multiplexing (OFDM) symbol length/physical resource block (PRB) size (where a PRB refers to a specific time slot and bandwidth allocation on a cell). We note that in NR there is flexibility that enables lower end-to-end latency, however we did not model URLLC services and thus we did not alter the SCS.

We modelled each communication link and we associated a different SE value to each, depending on the link's multiple-input and multiple-output (MIMO) order. For example, with the same signal-to-interference-plus-noise ratio (SINR) value, with 4 transmit and 2 receive antennas (4x2 link) the associated SE value was higher than that of 2 transmit and 2 receive antennas (2x2 link). We assumed that at the beginning of the study period macrocells and small cells were equipped with cross-polarised antennas and the user equipment (UE) with 2 antennas, thus the links were 2x2 Multi-user MIMO (MU-MIMO) capable. By 2030 the macrocells could, if demand required, be equipped with up to 4 antennas in the sub 1 GHz and low bands and up to a 64-port active-antennas in the medium band. By 2030 the small cells could be equipped with up to 4 antennas in the low and medium bands. For macrocells equipped with a 32- or 64-port active-antenna at 3.5 GHz we assumed elevation beamforming as included as a feature of LTE-Advanced Pro.

In each modelled year, we assumed that the macrocell and small cell sites had a certain number of supported antenna and spectrum configurations depending on technology developments and the spectrum availability anticipated. All sites are assumed to be virtualised by 2020 and making use of an OFDM based LTE like air interface across all frequency bands employed. In 2020 the C-RAN macrocell sites were assumed to be equipped with 2 transmit antennas per frequency band in each of 3 sectors (termed here 2T3S) and had access to 2x20 MHz or 2x40 MHz of radio spectrum at low frequency bands (< 3 GHz). By 2030 if demand required, they could upgrade to 4T3S in the sub-1GHz and low bands and 64T3S in the medium band (3.5 GHz), and have access to 105 MHz for downlink (DL) across all bands. We assumed that the small cells were on different channels from the macrocell layer. For the low frequency bands we assume that the macrocell network uses the FDD frequency bands in this range and the small cells use the TDD frequency bands in this range. In the case of the medium frequency bands all spectrum in this range is TDD and so we assume that part of the TDD spectrum available in this range is used for small cells whereas other 1x20MHz channels are used for the macrocell network. D-RAN small cells are assumed to be 2T2S at low bands in 2020 with the possibility to also use medium band spectrum with this antenna configuration from 2023 onwards. From 2024 onwards it is assumed that small cell products would support 4 antennas and so a 4T2S configuration at low and medium bands for small cells is assumed from this point in time. We assumed that eMBB terminals had 2R (2 receive antennas). Beamforming and MU-MIMO were assumed at the macrocell sites, with up to 8 spatial beams formed by the 32T and 64T port active-antennas.

For the network dimensioning of coverage and capacity requirements the following assumptions were employed:

- Antenna sites are placed from a coverage perspective to ensure provision of the simulated eMBB service. At every 25 m within the study area a link budget is performed in the cost analysis tool (known as CAPisce and described later) to ensure a signal-to-noise ratio (SNR) that would be capable of delivering the simulated eMBB service. This calculation may use up to 65% of the available PRBs on the cell. It was assumed that this is the maximum load that a cell should reach in practice if interference between cells is to be kept at a manageable level. Reliability is considered via the cell-area coverage-confidence applied in the link budget when considering if the location is within coverage. Coverage confidence is a service specific value, for example for eMBB services this was 95%.
- Antenna sites are also placed from a capacity perspective to accommodate the growth in the broadband demand forecast in our study. However, the number of individual users that would be active at any one instant, the contention between these and hence the distribution of user throughputs achieved across the cell in loaded conditions is not considered.

While latency is not explicitly modelled in our study, all antenna sites are connected to nearby edge cloud sites well within the range needed to ensure that the latency requirement of 250 μs of the fronthaul link from the antenna site to the edge cloud site is met – assumed to be based on common public radio interface (CPRI) (CPRI, 2017). As in our modelling the entire radio protocol stack is located at the edge cloud site it would be possible to deliver very low (sub 5ms) latency services over the network deployment modelled. However, we do not explicitly consider services requiring or making use of this low latency.

We do not model broadband traffic consumed inside buildings (indoor traffic) explicitly but focus on broadband traffic consumed outdoors by handheld devices of pedestrians and passengers in vehicles. It was assumed that indoor traffic would be largely offloaded to Wi-Fi and indoor small cells. While a small amount of indoor traffic will be carried by the outdoor macrocells some outdoor traffic will be offloaded to outdoor Wi-Fi access points or picked up by indoor systems when close to buildings and hence the two effects balance out. It was taken into account that at national level and over a 24-hour period, 80% of the mobile demand is consumed indoors, translating to a 1:4 outdoor-to-indoor ratio. The outdoor-to-indoor ratio varies at different hours of the day and at different parts of a country. For example, it is highest during peak commute hours and in big cities. In the case of the central London study area the increase of the outdoor-to-indoor ratio is relatively high due to the large number of commuters (working population) compared to its residential population. We modelled each hour of the day and ensured that the hourly forecast demand could be served by the network (5G NORMA D2.3, 2017).

For the macrocells, a fixed dark fibre fronthaul connection is assumed throughout the analysis to support the CPRI interface required under the assumed C-RAN configuration. As small cells are assumed to be deployed in a D-RAN configuration they can make use of either managed Ethernet or dark fibre products for their site transmission. We did not consider microwave or other wireless site transmission technologies.

3 Cost Analysis

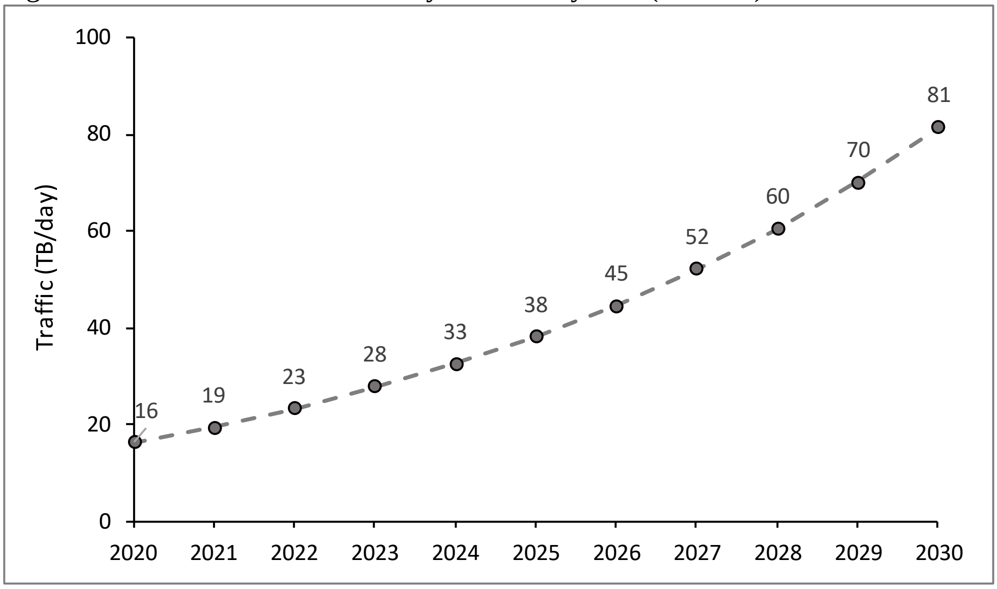
3.1 Costing methodology

The network cost analysis presented in this paper captures anticipated CAPEX and OPEX for a virtualised 5G network delivering the mobile broadband service detailed earlier and considers these over a time period from 2020 to 2030. The procedure employed to calculate the costs is based on the following steps:

1. *Traffic demand*: Understanding and modelling uptake and demand for the mobile broadband service considered in the study area over this time period and understanding the spatial and temporal distribution of this demand. For the traffic forecast we reviewed traffic volumes of previous years for the United Kingdom and also several traffic forecasts for future years. We endorsed the forecast of (Cisco, 2016; Ofcom, 2016a; Ericsson, 2017) up to including 2020. Beyond 2020, it was assumed that the traffic volume grows with a 21% Compound Annual Growth Rate (CAGR) which declines to 16% by 2030. A typical MNO was assumed to provide the infrastructure to support an 18% share of the consumer eMBB market. The market share of the modelled operator is close to the mean value of the market shares of the operators in the UK. Fig. 4 shows the traffic forecast employed for the baseline case in our study. The values shown in Fig. 4 were derived by considering the following assumptions: outdoor demand only; downlink and uplink traffic; it corresponds to the studied MNO with an 18% market share; and it shows the traffic in the study area analysed (the three modelled central London boroughs). The demand of Fig. 4 was apportioned to each hour of the day, taking into account the population density increase due to commuters. Further details of the method applied for distributing demand over the 24 hours of the day and to allow for a higher daytime

population due to non-residents, such as commuters, are given in Appendix B of (5G NORMA D2.3, 2017). Note that while an uplift for the increased daytime population has been applied in the demand forecast and hence network dimensioning and costs, the revenue forecasts given later consider only subscriptions from the residential population in the area as attributing the proportion of commuter subscriptions derived from providing mobile service in the study area is ambiguous.

Fig. 4. Forecast of traffic volume/day in the study area (baseline).



Note that in 2016 the UK ranked 10th in the world in terms of mobile data consumption per user with a typical user consuming on average 1.84 GB/month compared with 10.95 GB/month for the top-ranking country of Finland (Forbes, 2017). This means that the London scenario modelled here is potentially not the most extreme case of mobile demand that might be seen in a European city. It is however, representative of the typical mobile demand per user seen in other major European countries such as France and Germany and will be challenging due to the high residential population density and large increase in daytime population that it experiences due to visitors and workers. Note also that the revenues forecast later for the study area are UK specific and so appropriate for the level of mobile experience expected by UK subscribers.

2. *Assessment of coverage and capacity*: Assessing the coverage and capacity of the existing network infrastructure in the study area and evolving this over time to meet the growing demand from the target mobile broadband service. This evolution of the network was done in the most cost effective way considering, whenever there was a shortfall in network capacity, the options of adding spectrum or antennas to existing sites, placing a new macrocell site or placing a new small cell site. In the case of each expansion option the

corresponding additional equipment set required to support that expansion option was included in the network cost analysis from the point of expansion onwards. Note spectrum costs are not included.

3. *Network elements*: As part of the network dimensioning exercise above, understanding the implications in terms of volumes of antenna sites and edge cloud sites required and dimensioning equipment and site transmission to these requirements. This included understanding processing in terms of GPPs to dimension servers and cabinets required at edge cloud sites as part of the network virtualisation.

4. *Cost calculation*: Based on the site and equipment dimensioning above understanding and capturing the network bill of materials, volume and type of sites and hence the related CAPEX and OPEX over the time period.

The above cost assessment process has been carried out by a network dimensioning and RAN cost analysis tool, CAPisce. An earlier version of this tool has been used by the UK regulator Ofcom to calculate the implications of the timing of the release of spectrum bands in terms of network evolution and potential savings from delaying network densification (Real Wireless, 2012). This tool was then evolved to consider 5G networks to perform the steps outlined above (5G NORMA D2.3, 2017; 5G MoNArch D6.1, 2017). The cost of the RAN, the edge cloud sites and their transport links were modelled by the CAPisce tool in detail.

To determine the evolution of the network in the study area over time and hence number of sites, equipment and corresponding cost, CAPisce considers both the coverage and capacity requirements for the mobile services that will need to be delivered to the study area over a 2020 to 2030 time period. For each given year the tool assesses the coverage and capacity achieved by the network infrastructure already in place. Coverage is determined based on a link budget calculation against the target service requirements and capacity is based on the spectrum efficiency per band, bandwidth per band and the number of sectors anticipated for each site based on the existing site configurations in the area. The existing network is then either densified or the existing sites upgraded to fill any identified coverage or capacity gaps. In the cases of having to fill either coverage or capacity gaps, the chosen network evolution option (e.g. new macrocell site, new small cell site, adding a new frequency band to an existing site etc.) is selected by the tool based on the most cost-effective option from a 10 year total cost perspective. The process is repeated for each year over the period 2020 to 2030 with the tool reporting for each year a set of antenna and edge cloud site locations and an associated equipment list with related CAPEX and

OPEX items so that the CAPEX and OPEX incurred per year can be calculated and translated into total costs for the 2020-2030 time period under assessment.

Table 1a summarises key assumptions in the cost modelling in terms of volumes of macrocell, small cell and edge cloud sites and market share. This table indicates the volume of macrocells and small cells assumed to be present in the network by 2020 and it is assumed that all of these have been incorporated into the virtualised 5G network of the operator by 2020. This 2020 network is based on existing site databases for London evolved to meet the anticipated eMBB demand by 2020 and so is representative of the evolution of legacy network existing site locations. Table 1b summarises the RAN cost elements considered with Table 1c showing unit costs for some example site specifications. In both cases the costs shown are relevant to 2020 unless stated. Network equipment costs were based on industry experience across 5G NORMA consortium partners (5G NORMA D2.3, 2017); they are referential costs that were not taken directly from the partners that work in the consortium. Table 1d shows the site transmission costs which are based on good existing fibre availability as would be found already in London (5G NORMA D2.3, 2017). Based on discussions with fibre providers in London we applied the transmission cost assumptions shown in Table 1d uniformly across all sites as an average cost to dig and install a fibre to a new site from an existing fibre network in nearby main streets.

The CAPisce cost model considers only the user plane RAN related costs. However, for the analysis of the cost of the end-to-end network two uplifts were applied. The first uplift is applied for the control plane and the core network and has a value of 10% based on industry experience. A second increase for the administrative costs of mobile service providers was also taken into account. Administrative costs include all retail costs (e.g. sales, marketing and billing) and organisational overheads such as buildings, information technology (IT), general management, vehicles, etc. To calculate the administrative costs we assumed an uplift of 30% on the RAN and core network costs. According to Vodafone Group data (of which the UK comprises a major part) administrative and retail costs make up 30% of the total cost of sales (Vodafone, 2017). We did not assess the cost for 5G network orchestrators or controllers and core network applications. The cost of spectrum was not considered in the calculation.

For macrocell antenna sites and their equipment we assume a 10 year lifecycle. For servers used at edge cloud sites we assume that these are COTS hardware and have a shorter replacement cycle of 4 years. Small cells replaced every 5 years.

OPEX values at the antenna sites and edge cloud sites include a component for site utilities (power costs). However, we do not explicitly calculate the power consumption of the different antenna site types nor vary the power cost per antenna site in line with this. A flat utilities OPEX is therefore assumed per antenna site. In the case of edge cloud sites, an OPEX cost per cabinet is included which includes a power cost estimate for a highly utilized cabinet of servers. Therefore, as the number of servers and cabinets needed on an edge cloud site grows to accommodate more demand, this OPEX element for the edge cloud sites will also grow.

Table 1. a) Main assumptions b) RAN cost elements, c) Relevant RAN unit costs; d) Site transmission costs.

a)

Item	MNO
Number of macrocell sites, start of 2020	134
Number of small cell sites, start of 2020	252
Number of edge cloud sites	6
Market penetration for eMBB to consumer portable devices	18%

b)

	Macrocell	Small cell	Edge cloud
CAPEX	Civil works and acquisition	Civil works and acquisition	Processing servers
	Antennas/feeder	Antennas/feeder	Cabinets
	RF front end and base band	RF front end and base band	--
	Labour	Labour	Labour
	Transport	Transport	Transport
OPEX	Rental	Rental	Site rental
	Rates and power	Rates and power	Cabinet rent and power
	Licensing and maintenance	Licensing and maintenance	Licensing and maintenance
	Transport	Transport	Transport
	Site visits and on-site maintenance		Site visits and on-site maintenance
			Operating overhead

c)

Item	£k
OPEX macrocell site C-RAN 2x2 MIMO 40 MHz	38 per annum
CAPEX macrocell site C-RAN 2x2 MIMO 40 MHz	97
CAPEX small cell site D-RAN 2x2 MIMO 20 MHz	12
OPEX edge cloud site with 15 servers*	54 per annum
CAPEX edge cloud site set up costs in 2019	150
CAPEX edge cloud site for 2 additional servers**	11.6

* A typical edge cloud site has 15 servers in 2020
** A typical edge cloud site adds 2 servers in 2020

d)

Type of connection	CAPEX per connection (£k)	OPEX per connection (£k per annum)
Dark Fibre (1 Gbps)	31.9	1.125
Dark Fibre (10 Gbps)	33	1.125
Dark Fibre (100 Gbps)	35.5	1.125
Ethernet Access Direct (EAD) 1 Managed (1 Gbps)	2.1	3.15

3.2 Cost Results

Fig. 5, 6 and 7 show the CAPEX, OPEX and total cost, respectively, observed for the network evolution required in the time period 2020 to 2030 to deliver the simulated mobile broadband service. The values shown in these graphs correspond to the legacy broadband-related equipment and the new 5G infrastructure. In Fig. 4 we see that traffic demand increases monotonically with time. However, the CAPEX evolution shown in Fig. 5 is non-monotonous because it is affected by demand, spectrum band support and quantity, MIMO order support, and end-of-life cycles. More specifically, CAPEX of macrocells fluctuates with two distinct peaks: a) in 2022 there is a peak of new sites because hotspots of demand require new macrocells; thus there is increased civil works, site acquisition and RF front end expenditure; and b) in 2028 there is a peak of end-of-life cycles with increased spending on RF front ends, antennas and feeders. The cost of the site transmission is included under the RAN elements.

The OPEX evolution described in Fig. 6 shows the OPEX components: RAN elements (macrocells, small cells and edge cloud sites), core network and administrative costs. The OPEX values include the components of the new 5G infrastructure and of the legacy infrastructure. In other words, all the RAN infrastructure is considered in the OPEX calculation. The OPEX values shown in Fig. 7 are much higher than the corresponding CAPEX values. The total cost (comprising RAN, core and administrative costs) for the network to support the simulated mobile broadband service over the period 2020-2030 is £153 million with £17 million in CAPEX and £136 million in OPEX.

Fig. 5. CAPEX components (baseline).

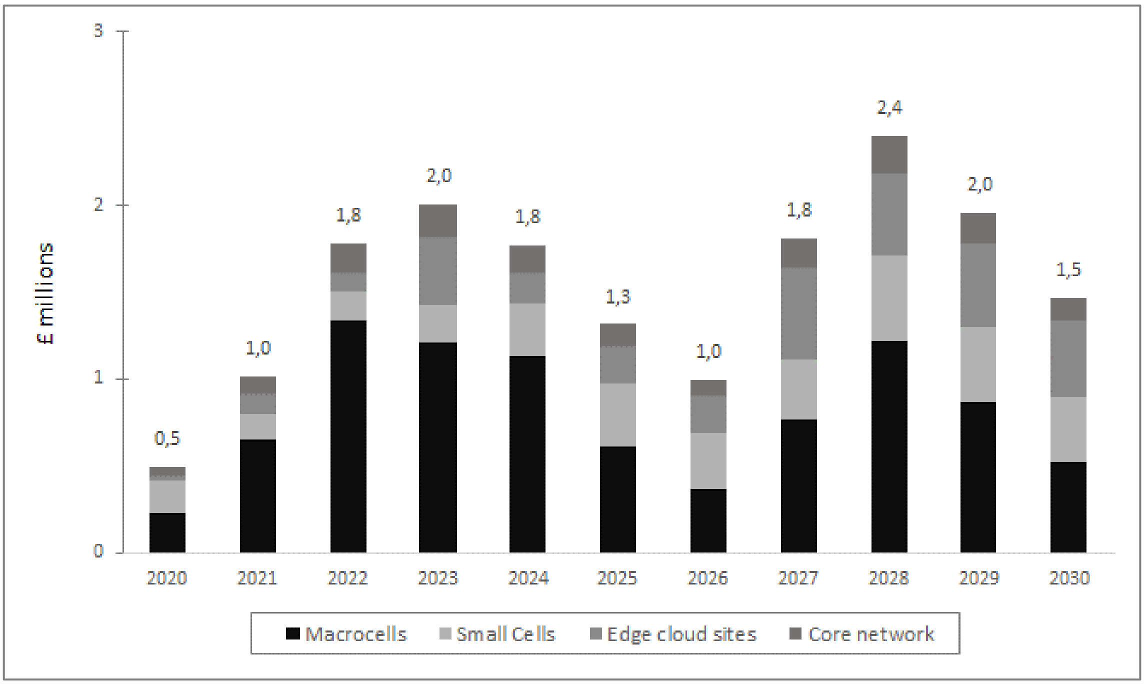


Fig. 6: OPEX components (baseline).

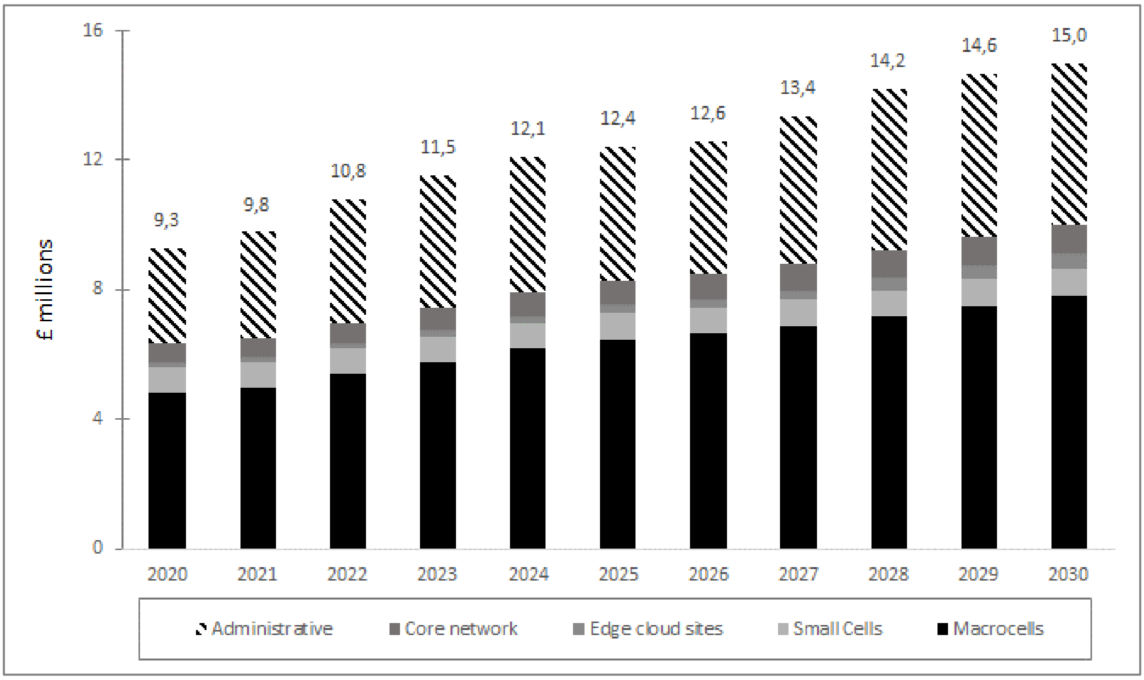
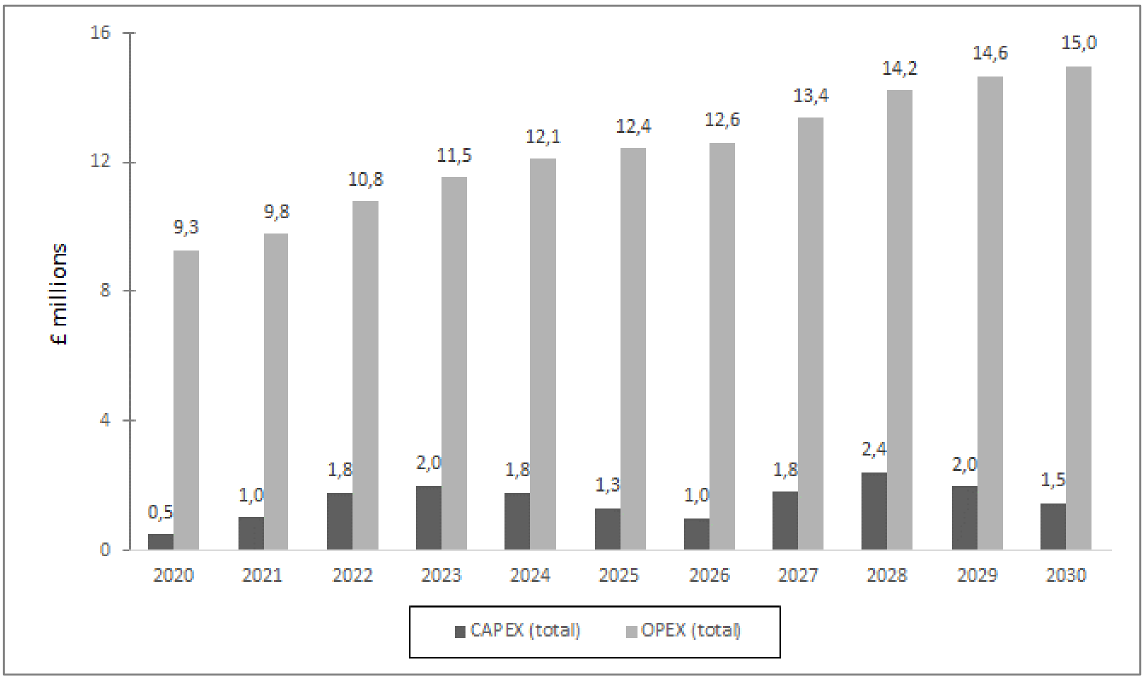


Fig. 7. CAPEX and OPEX (baseline).



4 Revenue calculation

4.1 Approach for the revenue calculation

This section sets out our analysis of 5G revenues as part of our business case analysis. The broadband services modelled are as follows:

1. eMBB –We consider a 5G network providing this service;
2. Legacy MBB – this is mobile broadband that subscribers consume today using LTE, Universal Mobile Telecommunications System (UMTS) and General Packet Radio Service (GPRS) services. We assume that legacy MBB subscribers will decline corresponding to the uptake of eMBB over time.

The business case analysis is for the central London area, hence we forecast revenues for this area. We also forecast revenues for the UK as a whole, to provide greater context for our results. Given the high population density and wealth of this area, a priori we would expect economies of density and higher take-up to make the business case more favourable here than elsewhere in the UK. However, this might not necessarily be the case, e.g. the real estate market could lead to exceptionally high site rental costs.

Predicting future revenue is inherently uncertain, particularly for new and innovative services. We were careful to draw on as much evidence as possible including publicly available market research and operator strategies for 5G. However, as there is little consensus in the available literature in this area, particularly for eMBB, we therefore developed low, baseline and high revenue estimates for the broadband service.

4.2 eMBB services

We distinguish between eMBB and legacy (i.e. current) MBB in terms of eMBB's higher throughput with minimum DL user throughputs of 10Mbit/s assumed. We expect that subscribers will consume greater amounts of data given increases in mobile broadband throughput. This could be through more intensive use of existing streaming and social media services, higher quality versions of existing services such as 4k video streaming and new services such as augmented reality (AR). We expect the latter two services to be key drivers of demand beyond legacy MBB. Although VR is included in some 5G use cases, it is likely to be used mostly indoors, hence it would be more effective to carry it over dedicated indoor networks than via outdoor macrocells and small cells. In contrast, AR services could be used equally outdoors or indoors. Hence, our definition of eMBB excluded VR.

4.3 Market segmentation

We segmented the market for eMBB into five groups and derived the number of potential users, penetration and average revenues in each:

- Consumers - Pre-pay;
- Consumers - Post-pay:
    - Early adopters;
    - Mainstream;
    - Laggards;
- Business (where organisations pay for the mobile services of individual users).

We model pre-pay and post-pay users due to their distinctiveness in willingness to pay. Table 2 shows our market segmentation. According to Ofcom, the proportion of pre-pay subscribers is around 40% though falling (Ofcom, 2016b). We segment post-pay users according to established principles from studies of technology diffusion, e.g. (Rogers, 1962). Early adopters, are typically intensive users and the least price sensitive. These users will be the most likely to take the type of unlimited data packages which MNOs have started to offer in recent years. Mainstream users are less intensive users and take up the service when it becomes more established; laggards are typically price sensitive and the least intensive users. We assume that both mainstream and laggards will purchase a service with a capped monthly data allowance. Over time, some mainstream users may move towards unlimited packages, depending on MNO tariff structures.

Table 2. Subscriber market segmentation.

Market segment	Proportion of total market
Pre-pay	34.1% (39.5% of non-business)
Early adopter	8.4% (16% of post-pay)
Mainstream	35.6% (68% of post-pay)
Laggard	8.4% (16% of post-pay)
Business	13.6%

4.4 Service penetration per segment

Table 3 shows our forecasts for service penetration and subscribers for our eMBB market segments. To simplify the analysis, we assumed that penetration was the same for central London as for the UK as a whole, though in reality it is likely to be faster in central London where economic activity is above the UK average.

Table 3. Central London eMBB subscribers by market segment.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Early Adopters	4,966 (11%)	9,554 (21%)	13,068 (29%)	16,406 (36%)	19,556 (42%)	22,981 (49%)	26,838 (57%)	31,336 (66%)	36,603 (77%)	42,736 (90%)	45,913 (96%)
Mainstream	959 (1%)	5,800 (3%)	21,437 (11%)	41,245 (21%)	56,398 (29%)	70,760 (36%)	84,047 (42%)	98,417 (49%)	114,961 (57%)	134,221 (66%)	156,778 (77%)
Laggards	0 (0%)	0 (0%)	229 (1%)	1,386 (3%)	5,122 (11%)	9,849 (21%)	13,419 (29%)	16,777 (36%)	19,931 (42%)	23,339 (49%)	27,261 (57%)
Pre-pay	0 (0%)	0 (0%)	936 (1%)	5,658 (3%)	20,904 (11%)	40,197 (21%)	54,769 (29%)	68,474 (36%)	81,347 (42%)	95,254 (49%)	111,262 (57%)
Business	4,208 (6%)	8,849 (12%)	14,679 (20%)	21,161 (28%)	26,604 (35%)	32,118 (42%)	37,778 (50%)	44,163 (58%)	51,587 (67%)	60,230 (78%)	67,106 (87%)

5G post-pay service penetration was based on the historical take-up of 4G; see (GSMA, 2015). We applied this to the mainstream market segment and then varied penetration in the other segments. The early adopter segment was assumed to be 2 years in advance of the mainstream and the laggard and pre-pay segments 2 years behind the mainstream segment. Business take-up was assumed to be the average of the early adopters and the mainstream.

We took the residential population of central London as the addressable market for eMBB. This is predicted to rise from 414,300 to 438,900 over the model period according to (Greater London Authority, 2017). An alternative would have been to take an average of the number of residents and non-resident daytime users (non-resident workers, tourists and other city visitors such as shoppers, medical visits, personal visits, etc.) over the course of the day – this is sometimes called the mobile active population. This approach may be more detailed, but it would have required assumptions on allocating the revenues of residents and incomers, which could have introduced inaccuracies. Hence we decided to adopt the more simplistic approach. The traffic analysis did take into account the residential and non-resident population since this directly affects the dimensioning of the network and this flowed through into the cost analysis as described earlier.

4.5 Average Revenue per User (ARPU)

Industry is divided on whether eMBB will lead to an increase in mobile broadband ARPU (strictly speaking, we have modelled users as the number of unique mobile subscriptions). On the one hand, Mobile ARPU has remained relatively constant despite the introduction of 4G (although the GSMA in (GSMA, 2017) suggests that increasing LTE penetration may be one of several factors leading to an increase in mobile revenues). On the other hand, some business surveys report that businesses are willing to pay more for higher speed services – 75% of business according to (Mobile Europe, 2017). Applications such as AR might also be seen as a step-change in value by consumers. This may feed through into traffic and consumer willingness to pay, however the scale of the impact is not clear. A counter-weight to this more optimistic view are the recent developments in mobile broadband pricing in Europe including: price wars fuelled by intense competition in some markets; and the generally static level of ARPU in the UK despite increases in total data usage.

We generated our baseline revenue forecast by estimating the minimum and maximum feasible ARPU and calculating the baseline as the average of these two low and high revenue forecasts. Table 4 shows the assumptions for ARPU in each market segment. We assume that Pre-pay ARPU was assumed to be constant across the three forecasts. For post-pay services we made the following assumptions. In the low case, we assumed that the average ARPU across all segments equalled ARPU today. The low estimate for the business segment was based on current business ARPU (Ofcom, 2016b). In the high case, we made a number of specific assumptions:

- The benefit for early adopters was similar to today's superfast broadband services and the ARPU reflected this;
- Mainstream and laggards would be willing to pay a premium for improved quality of experience (QoE) leading to a modest increase compared to the low case;
- Business ARPU was assumed to vary in the same way as for early adopters.

Table 4. Monthly ARPU for eMBB by market segment.

	5G Baseline
Pre-pay	£5
Early adopter	£27
Mainstream	£21.5
Laggard	£11
Business	£27

4.6 eMBB and legacy MBB revenues

Tables 5 and 6 report the results of our eMBB and legacy MBB revenue forecasts for central London and the UK, which are directly calculated by ARPU and service penetration figures. Population growth is also modelled which was forecast to be 5.9% over the period according the UK's Office of National Statistics (Office for National Statistics, 2015). The figures show the revenues for eMBB delivered over a true 5G network.

Table 5. eMBB revenue forecast, baseline scenario, UK (central London) – £ million.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Early Adopters	262 (2)	502 (3)	686 (4)	860 (5)	1,024 (6)	1,201 (7)	1,405 (9)	1,643 (10)	1,922 (12)	2,249 (14)	2,418 (15)
Mainstream	40 (0)	243 (1)	896 (6)	1,722 (11)	2,351 (15)	2,945 (18)	3,503 (22)	4,110 (25)	4,808 (30)	5,624 (35)	6,574 (40)
Laggards	0 (0)	0 (0)	5 (0)	30 (0)	109 (1)	210 (1)	286 (2)	358 (2)	426 (3)	500 (3)	585 (4)
Pre-pay	0 (0)	0 (0)	9 (0)	55 (0)	203 (1)	389 (2)	531 (3)	665 (4)	791 (5)	928 (6)	1,085 (7)
Business	222 (1)	465 (3)	771 (5)	1,109 (7)	1,393 (9)	1,679 (10)	1,978 (12)	2,316 (14)	2,709 (17)	3,169 (20)	3,534 (22)
Total eMBB	523 (3)	1,211 (7)	2,367 (15)	3,775 (23)	5,079 (31)	6,423 (40)	7,703 (48)	9,093 (56)	10,657 (66)	12,471 (77)	14,195 (87)

The cost model assumes that the network carries legacy MBB traffic in addition to eMBB. Table 6 reports eMBB and legacy MBB revenues together. As a cross-check, UK mobile retail (voice & data) revenues in 2017 were £15.6 billion, as reported by Ofcom (Ofcom, 2018).

Table 6. Legacy MBB and eMBB revenues, baseline scenario, UK and central London – £ billion.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Legacy MBB UK	14.78	14.12	13.16	12.01	10.73	9.38	8.24	7.12	5.97	4.74	3.54
eMBB UK	0.52	1.21	2.37	3.78	5.08	6.42	7.70	9.09	10.66	12.47	14.20
Total MBB UK	15.30	15.33	15.53	15.78	15.81	15.81	15.95	16.21	16.63	17.21	17.73
Legacy MBB central London	0.09	0.09	0.08	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.02
eMBB central London	0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
Total MBB central London	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11

5 Results of the business case

5.1 Baseline case

5.1.1 Approach for the business case calculation

The following sections set out the financial implications of our work, bringing together the cost and revenue modelling. The financial measures we calculated were: the business case net present value (NPV) of cash flows (CFs), which is the discounted cumulative cash flow (DCCF) (ECOSYS D9, 2005); the pay-back period and the return on investment (ROI) undiscounted. Where appropriate, we used a commercial discount rate for MNOs of 7% as used in (Ofcom, 2015).

The business case NPV is calculated according to the following formula:

$$\text{NPV} = -\ \text{CF}_0 + \sum_{i=1}^{n} \frac{CF_i}{(1+rate)^i}$$

where i is the time of the cash flow, n is the total time period studied, CF_i is the net cash flow at time i, and CF_0 is the capital outlay at the beginning of the investment at time t = 0.

The ROI is a high-level estimate and is calculated as follows:

$$ROI = \frac{(Total\ revenues - Total\ Costs)_{2020-2030}}{Total\ Costs_{2020-2030}}$$

5.1.2 The business case for broadband

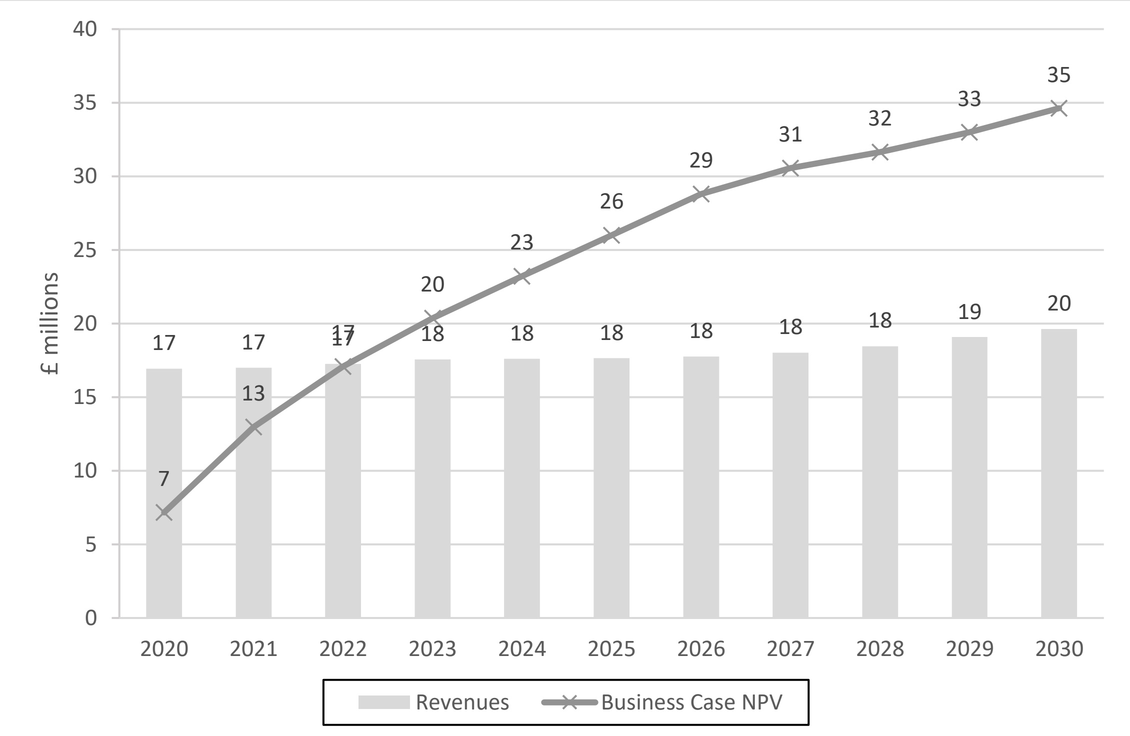
Table 7 reports the results for the baseline broadband scenario. This assumes one MNO with an 18% market share, consistent with current operator market shares in the UK. As noted above, MBB includes both eMBB revenues and revenues of legacy MBB subscribers who have yet to switch to eMBB since both these services are supported by the RAN. The table also shows the cumulative discounted cash flow (DCF), where “cash” in this case is the difference between total revenues and total costs (we make no allowance for taxes on profits in this simple analysis).

Table 7. Case 1: cost and revenue results combined, baseline scenario, central London operator Note: while the cost and revenue figures in the table below are not discounted by the operator cost of capital, the cumulative DCF reflects the discounted cost and revenue figures.

(£ millions)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Total cost	10	11	13	14	14	14	14	15	17	17	16	153
Legacy MBB revenues	16	16	15	13	12	10	9	8	7	5	4	115
eMBB revenues	1	1	3	4	6	7	9	10	12	14	16	82
Total revenues	17	17	17	18	18	18	18	18	18	19	20	197
Business Case NPV	7	13	17	20	23	26	29	31	32	33	35	N/A

Fig. 8 shows the evolution of the revenues and the cumulative DCF over time. The business case has a positive NPV of £35 million over the full 10 year period and the payback period is less than one year since the cash flow is positive in the first year of the period. The ROI is, at 29%, slightly higher than industry earnings before interest, tax, depreciation and amortization (EBITDA) margins which are typically between 20%-25% in the UK. The business case results are sensitive to the assumptions on MBB revenues and traffic growth, this is the reason why this topic is analysed in Section 5.2.

Fig. 8. MBB, baseline revenues and baseline cost scenario, central London operator.



5.2 Sensitivity Analysis

5.2.1 Effect of revenue variation and traffic growth

5.2.1.1 Scenarios

We examine the following cases, which are also described in Table 8, so as to include a sensitivity analysis of our results to changes in revenues and traffic growth:

- **Case 1**: Baseline traffic scenario with revenue sensitivity – MBB revenues increased and decreased by 15% and 30%. This tests the sensitivity of the business case under our baseline traffic and cost forecast to fluctuations in revenues and may illustrate the riskiness or robustness of the business case.

- **Case 2**: Baseline revenue forecast with high traffic scenario. This shows the impact of potentially higher traffic growth on the business case. Higher traffic demand feeds through into more capacity deployment and hence higher costs.
- **Case 3**: High traffic scenario with revenue sensitivity – MBB revenues increased and decreased by 15% and 30%. Similarly to case 2, this tests the sensitivity of the business case under our high traffic and cost forecast to fluctuations in revenues.

Table 8. Scenarios for the sensitivity analysis.

	Revenues: baseline	Revenues (modification of baseline)
Traffic: baseline	**Baseline Case** baseline traffic & baseline revenues	**Case 1:** baseline traffic & values to be applied to the baseline → Revenues: 15%, 30% higher, 15%, 30% lower
Traffic: high	**Case 2:** traffic high, baseline revenues	**Case 3:** traffic high & values to be applied to the baseline → Revenues: 15%, 30% higher, 15%, 30% lower

5.2.1.2 Results of the sensitivity analysis

Fig. 9 shows the traffic forecast employed to calculate the case of traffic "high", whereas Fig. 10 shows the evolution of CAPEX and OPEX for the baseline case and for the case of traffic "high". For the last year, year 2030, the traffic "high" is 274% higher than the baseline case. The traffic of cost "high" was prepared by assuming a flat growth of 30% CAGR from 2020 to 2030. As mentioned in Section 3.1, the baseline traffic volume was prepared by assuming a traffic volume with 21% CAGR in 2020 which declines to a 16% CAGR by 2030. In each case, the demand growth rate affects the number of new sites and upgrades in the network. For example, a higher traffic volume growth corresponds to more new macrocells sites and more small cells (230 macrocell sites and 510 small cells in 2030), compared to the baseline case (154 macrocell sites and 336 small cells in 2030). Moreover, the capacity provided by each macrocell site is in a few cases higher. As a result, the total cost is affected by the demand growth rate, even though the unit costs are equal between the two modelled cases. The total cost (comprising RAN, core network and administrative costs) in the high traffic case is £203 million, compared to £153 million for the baseline. This breaks down into £30 million (£17 million) CAPEX and £173 million (£136 million) OPEX for the high traffic (baseline) case.

Fig. 9. Traffic forecast: baseline case and case of traffic “high”.

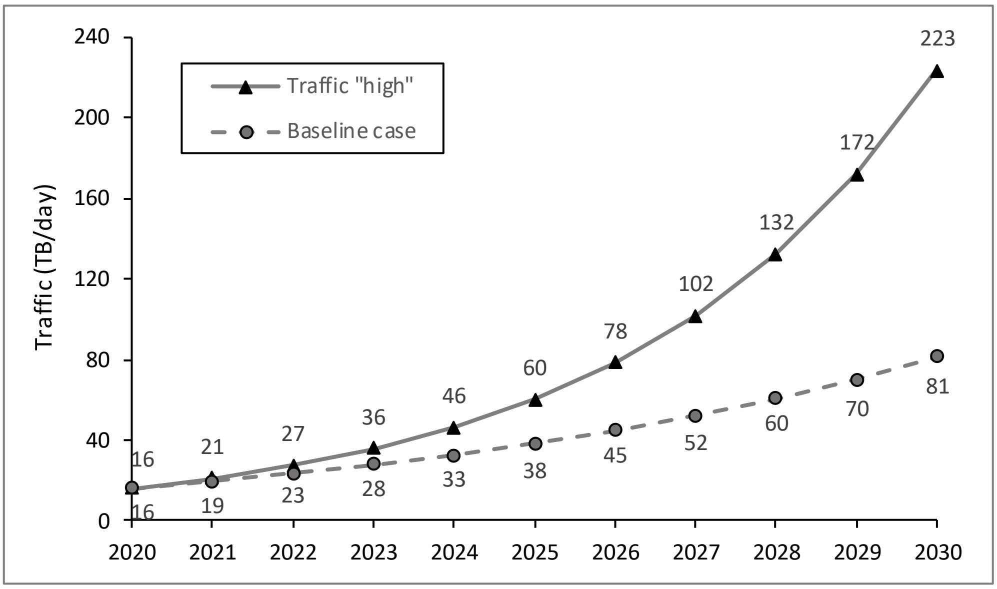


Fig. 10. Total cost (CAPEX and OPEX): baseline case and case of traffic “high”.

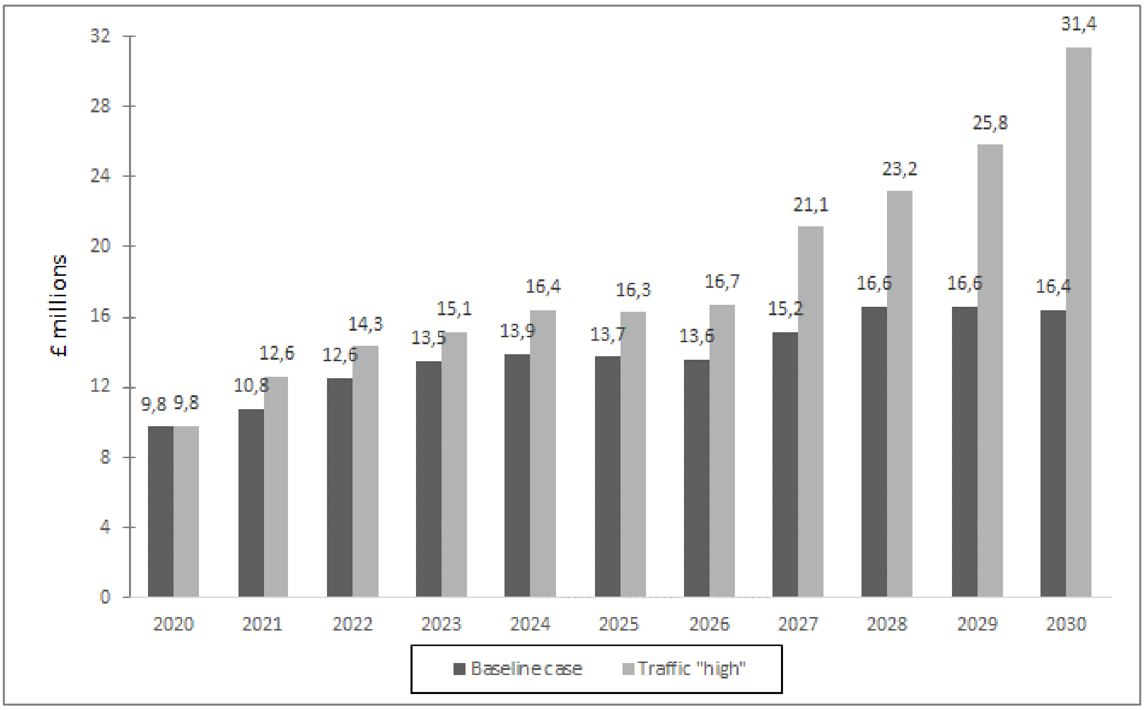


Fig. 11 shows the results of the financial results for case 1, where the baseline cost scenario is employed and the revenues are varied. The results of case 2 are depicted in Fig. 12, whereas Fig.

13 shows the results of case 3. Table 9 describes the outcome of the financial indicators related to all the scenarios studied.

Fig. 11. MBB business case NPV, baseline traffic scenario with varying revenue sensitivities, central London operator (case 1).

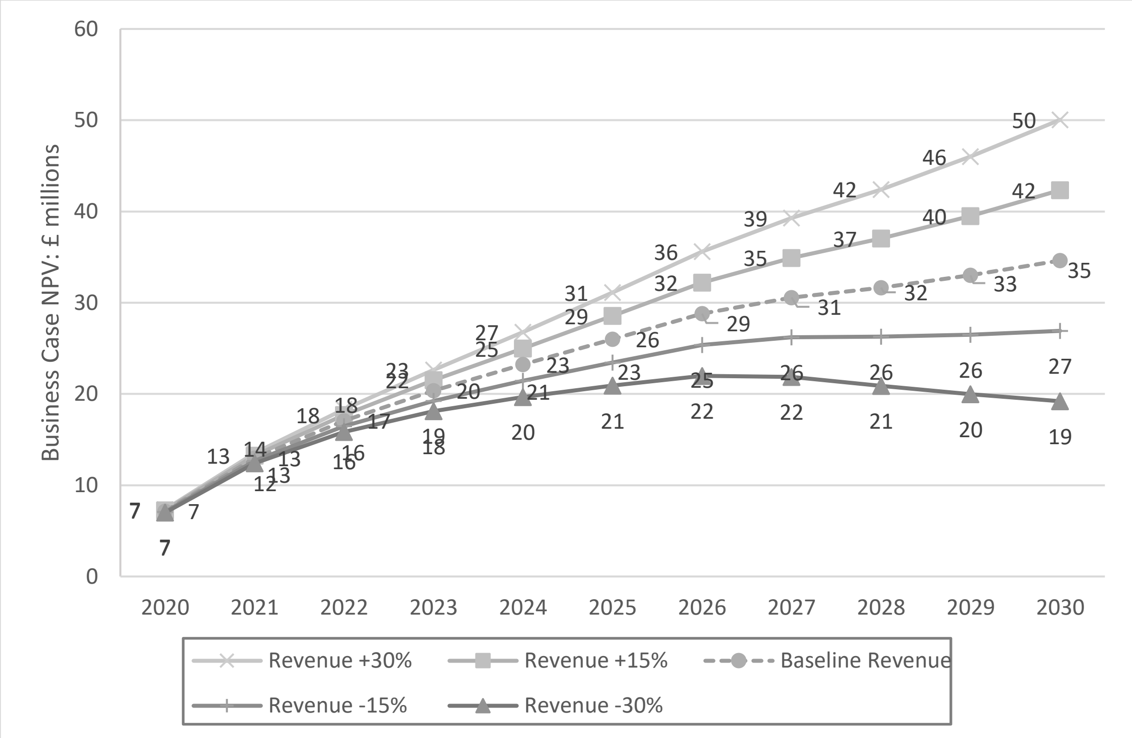


Fig. 12. MBB, baseline revenues and high traffic scenario, central London operator (case 2).

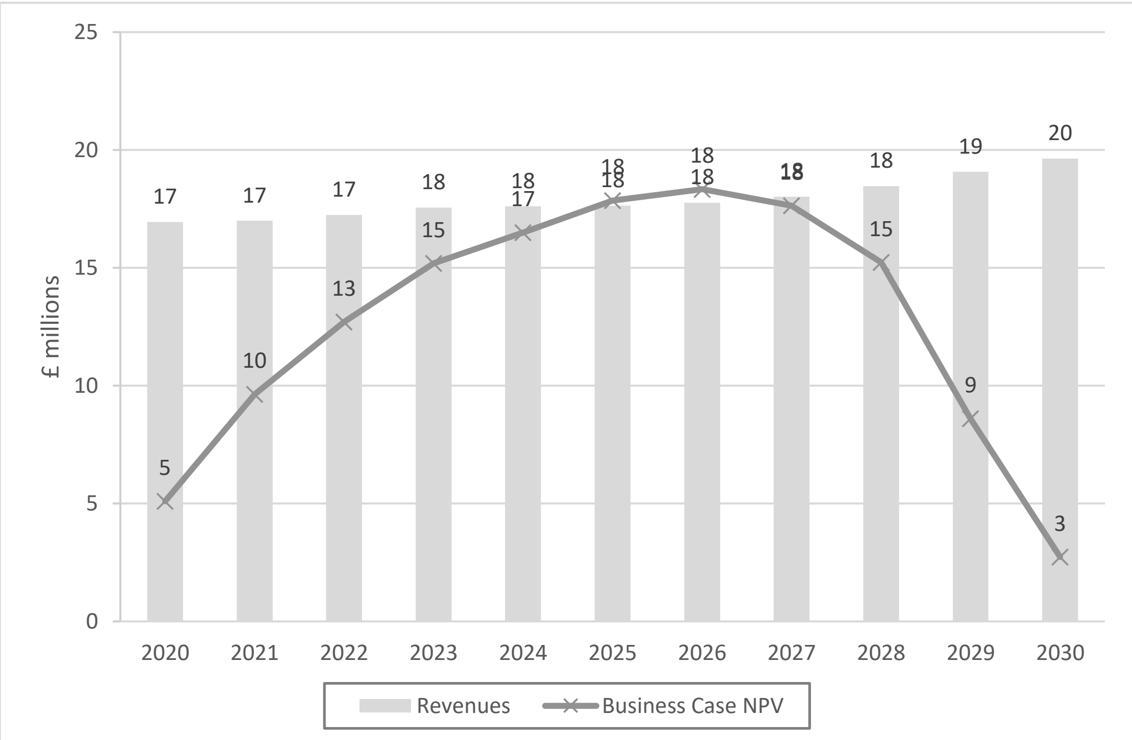


Fig. 13. MBB business case NPV, high traffic scenario with varying revenue sensitivities, central London operator (case 3).

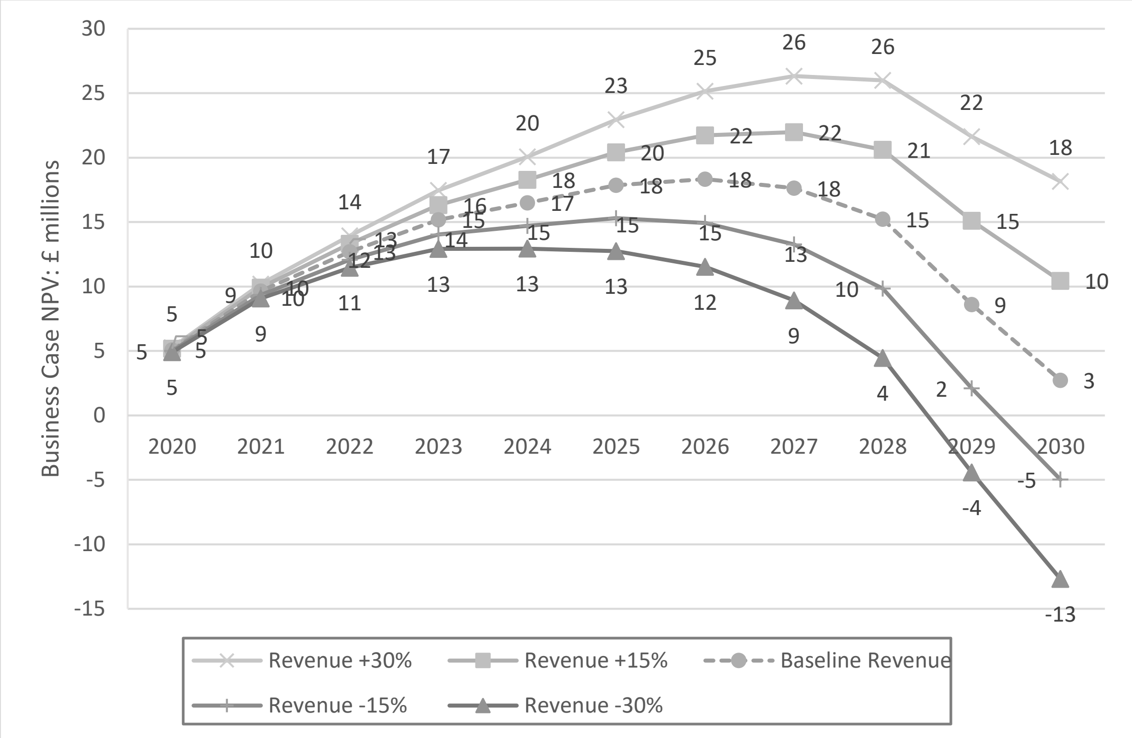


Table 9. Main economic indicators.

Scenario		Business case NPV: £ millions	ROI	Payback period	Evolution of NPV of business case
Baseline		35	29%	less than 1 year	upwards trend
Case 1: Traffic high, baseline revenues		3	-4%	less than 1 year	upwards trend until year 7, then downwards trend
Case 2: Baseline traffic & variable revenues	Revenues 15% higher	42	37%	less than 1 year	upwards trend
	Revenues 30% higher	50	45%	less than 1 year	upwards trend
	Revenues 15% lower	27	21%	less than 1 year	upwards trend
	Revenues 30% lower	19	13%	less than 1 year	upwards trend until year 7, then downwards trend
Case 3: Traffic high & variable revenues	Revenues 15% higher	10	2%	less than 1 year	upwards trend until year 8, then downwards trend
	Revenues 30% higher	18	8%	less than 1 year	upwards trend until year 8, then downwards trend
	Revenues 15% lower	-5	-10%	less than 1 year	upwards trend until year 6, then downwards trend
	Revenues 30% lower	-13	-16%	less than 1 year	upwards trend until year 5, then downwards trend

5.2.2 Effect of network sharing

5.2.2.1 Assumptions for network sharing

In this section we examine the case of infrastructure sharing between two operators. More specifically, we investigate the case of two existing site portfolios becoming a shared network for two MNOs, each with a typical eMBB market share of 18%, as in (5G NORMA D2.3, 2017). We assume that all passive network elements are shared, i.e. masts, antennas, feeders, fronthaul, backhaul. We further assume that sharing extends to all active elements, i.e. RRH, baseband processing, spectrum and core network, and to any new or upgraded sites. Each site in this shared infrastructure set is assumed to have access to a shared spectrum set or pool of the spectrum held by each MNO i.e. spectrum is shared as well as infrastructure. The cost results are described in Table 10.

The shared infrastructure sites have access to pooled spectrum from the parties sharing the site and hence are higher capacity than in dedicated sites with access only to spectrum from one party. The ability to deploy these higher capacity multi-tenant sites means that site densification can be done more efficiently than in dedicated networks with a reduction in the total number of antenna sites needed. This reduction in site count leads to savings in large cost components such as site rental. With the baseline traffic scenario such site densification is not required as much as in the high traffic scenario and hence the savings from sharing are less.

Table 10. Total costs with network sharing, values for the sum of the two operators.

Total Cost (CAPEX + OPEX): £ millions	Baseline	Traffic High
No network sharing	306	406
Network Sharing (2 operators)	269	350

The revenues in the two operators network sharing case are calculated as the sum of the revenues of an individual operator, i.e. twice the amount for one operator and equivalent to a 36% market share. We consider it reasonable to assume that the operators do not gain any additional market power through network sharing, which could increase their market share and/or revenues. Typically, regulators do assess network sharing agreements in order to avoid them leading to reductions in competitive intensity.

5.2.2.2 Results of network sharing

Table 11 describes the results of the network sharing case. The results show that network sharing significantly improves the business case for mobile broadband. In the baseline case, the NPV at £92 million is more than 2.5 times higher with network sharing than without. The return on investment is correspondingly higher too at 47% compared to 29%. The business case is still sensitive to the revenue assumptions, as shown in Case 2 in the table, however it is more positive across all the scenarios. A similar pattern is seen across the higher cost scenarios in Case 1 and Case 3. There rate of return is positive in all but one of the revenue sensitivities.

Table 11. Economic indicators for the network sharing case.

		Without network sharing		With network sharing (2 operators)	
Scenario		Business case NPV: £ millions	ROI	Business case NPV: £ millions	ROI
Baseline		35	29%	92	47%
Case 1: Traffic high, baseline revenues		3	-4%	42	13%
Case 2: Baseline traffic & variable revenues	Revenues 15% higher	42	37%	108	56%
	Revenues 30% higher	50	45%	123	65%
	Revenues 15% lower	27	21%	77	38%
	Revenues 30% lower	19	13%	61	28%
Case 3: Traffic high & variable revenues	Revenues 15% higher	10	2%	57	20%
	Revenues 30% higher	18	8%	72	27%
	Revenues 15% lower	-5	-10%	26	6%
	Revenues 30% lower	-13	-16%	11	-1%

5.3 Assessment of the results

5.3.1 Assessment of the results

The results of our modelling show that the business case for mobile broadband in the Central London study area with baseline revenues and costs is positive with an ROI of 29% and an NPV of £35 million. The payback period at less than one year is very short and the discounted cumulative cash flow continues on an upward trend throughout the period.

The sensitivity analysis shows that the strength of the business case does depend on the evolution of revenues and traffic (which is the principal driver of costs). Keeping the baseline costs (and traffic) but varying the revenues by +/- 15% and 30%, we find that the ROI remains positive in all scenarios, varying between 13% and 45%. The payback period is unchanged at less than 1 year, and the evolution of the cumulative DCF is an upward trend except for the most pessimistic revenue scenario of a 30% fall compared to baseline revenues.

When we apply our high cost (higher traffic) scenario, the results are different. In the baseline revenue, high cost scenario, the overall ROI is negative at -4% and the NPV is barely positive at £3 million. Reducing baseline revenues by 15% and 30% depresses the ROI further to a minimum of -16% and pushes NPV down to -£13 million in the worst case. In all the high cost (traffic) cases, the evolution of DCF changes from an initial upwards trend to a downward trend after between 5 and 8 years, depending on the scenario.

We conclude that the baseline business case for eMBB is positive with the degree of the return on investment depending on the extent to which eMBB can lead to an increase in ARPU. However, if traffic increases more quickly than we expect, driving higher costs because of the need to install more capacity, there is a significant risk that the business case turns negative.

Finally, our results have shown that network sharing has a significant and beneficial impact on the business case. In particular, the business case is more likely to be successful with network sharing than without, according to our results.

5.3.2 Limitations of the study

There are a number of aspects that could be improved in the future when preparing a business case for 5G.

Firstly, the study focuses on an area in central London which is a densely populated urban area. This is an area where the economic conditions are perhaps likely to be most favourable for a 5G virtualised network given the high concentration of potential users and the economies of density which reduce the unit costs of providing mobile services. As such, we do not have the basis to draw conclusions on the viability of the business case for other geotypes such as suburban or rural areas. However, we think that in less densely populated areas than central London, the business case is likely to be worse. Further research, particularly cost modelling and revenue forecasting in other geotypes, is required to address these areas.

Secondly, there is much interest in the potential multi-service capabilities of 5G networks. It would be useful to examine other 5G use cases, such as connected vehicle and smart city services, alongside mobile broadband to determine the impact of any economies of scope in the network costs and the additional revenues these use cases may bring.

Thirdly, there is considerable debate within the industry as to whether eMBB can drive a significant sustainable increase in ARPU or whether its impact will be similar to 4G where initial premiums for 4G services were soon competed away. It would also be useful to examine in more detail the impact of changed tariff structures such as possible moves towards unlimited data services and their impact on both revenues and traffic related costs.

Fourthly, we worked with several assumptions for the cost analysis. These assumptions were derived to the best of our knowledge for the central London area. Other areas might have different cost drivers, which could lead to higher costs.

Fifthly, the technical assumptions employed in the article were based on a cloudified and a distributed RAN deployment with a number of small cells and macrocells. For each MNO the decision of which type of RAN infrastructure and configuration that will be deployed and when might be different; in addition, also the spectrum availability can vary between different MNOs.

Finally, as highlighted in section 2.4, the model does not consider broadband traffic consumed inside buildings (indoor traffic) explicitly but focuses on broadband traffic consumed outdoors by handheld devices of pedestrians and passengers in vehicles. While the majority of mobile traffic is generated indoors much of this will be offloaded to Wi-Fi and other dedicated in-building solutions and hence has not been explicitly considered here.

6 Conclusions

In this article we have performed a 5G business case analysis for a mobile broadband service that is provided throughout a network deployed within 3 boroughs of central London, UK, over the period 2020-2030.

The results of the business case for the baseline case shows a ROI of 29% and the payback period is less than 1 year. Although the business case for the baseline case is positive, our sensitivity analysis shows that there are certain risks due to the uncertainty over revenues, traffic and cost growth. When performing the sensitivity analysis by keeping the same baseline costs and by reducing the revenues by 15% and 30%, the ROI drops to 21% and 13%, respectively. Moreover, if the traffic and the costs increase, and the revenues are reduced by 15% and 30%, the ROI drops to -10% and -16%, respectively. In these two last cases the cumulative DCF shows an upwards trend until the middle of the time period examined, but then there is a downwards trend. Network sharing, which reduces costs by 13.6% in the baseline, has a significant positive impact on the business case across the sensitivities we analysed. For example, the NPV in the baseline case (£92 million) is more than 2.5 times higher with network sharing than without.

Future research work should ideally include the calculation of a business case for other types of urban areas, as well as for suburban and rural areas. This will be a necessary step towards the construction of a regional or nationwide 5G business case. Currently planned future research work will include expanding the range of services considered beyond broadband to fit with specific use cases and integration of verticals into the 5G ecosystem. This further work will ideally add more detail to the network costs and challenges of delivering secure industrial slices. This work will also investigate further the higher value of these industrial services and how this might be translated into higher revenues per gigabyte of traffic delivered.

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