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# Towards 5G: Scenario-based assessment of the future supply and demand for mobile telecommunications infrastructure

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ABSTRACT

Moving from 4G LTE to 5G is an archetypal example of technological change. Mobile Network Operators (MNOs) who fail to adapt will likely lose market share. Hitherto, qualitative frameworks have been put forward to aid with business model adaptation for MNOs facing on the one hand increasing traffic growth, while on the other declining revenues. In this analysis, we provide a complementary scenario-based assessment of 5G infrastructure strategies in relation to mobile traffic growth. Developing and applying an open-source modelling framework, we quantify the uncertainty associated with future demand and supply for a hypothetical MNO, using Britain as a case study example. We find that over 90% of baseline data growth between 2016 and 2030 is driven by technological change, rather than demographics. To meet this demand, spectrum strategies require the least amount of capital expenditure and can meet baseline growth until approximately 2025, after which new spectrum bands will be required. Alternatively, small cell deployments provide significant capacity but at considerable cost, and hence are likely only in the densest locations, unless MNOs can boost revenues by capturing value from the Internet of Things (IoT), Smart Cities or other technological developments dependent on digital connectivity.

## 1. Introduction

The mobile telecommunications industry has a dynamic competitive environment due to widespread and sustained technological change (Curwen and Whalley, 2004; Han and Sohn, 2016). We experience generational upgrades on at least a decadal basis, requiring Mobile Network Operators (MNOs) and other market actors to have an understanding of future digital evolution. Even market leaders with significant advantages in the telecommunications industry can fall behind if they are unable to keep abreast of new developments and actively adapt existing market strategies for new conditions (Asimakopoulos and Whalley, 2017). Indeed, the digital ecosystem is experiencing significant disruption from new digital platforms and services (Ruutu et al., 2017; Wang et al., 2016), with substantial ramifications for MNOs as revenues have been either static or declining (Chen and Cheng, 2010), and these conditions exist alongside the increasing operational costs of serving ever increasing mobile data traffic. Hence, in wireless telecoms, MNOs must be aware of both opportunities and threats arising from technological change, particularly when moving from one generation to the next (du Preez and Pistorius, 2003; Salmenkaita and Salo, 2004).

Telecommunications are essential for modern economic activities, as well as for a fully functioning society. These technologies can enable economic growth through new content, services and applications (Hong, 2017; Krafft, 2010), while also enabling productivity improvements throughout the economy by lowering costs. The ability of Information Communication Technologies (ICT) to interchange data via telecommunications networks is essential for the economic development of the digital economy (Cheng et al., 2005; Kim, 2006; Wymbs, 2004), and the range of industrial sectors it comprises. New cross-sectoral advances have also emerged, such as the Internet of Things (IoT) and Smart Cities (Almobaideen et al., 2017; Bresciani et al., 2017; Hong et al., 2016; Yang et al., 2013), which rely on the availability of digital connectivity for smartphones, sensors and other communications devices. Hence the signal quality of mobile telecommunications infrastructure is an ever more important factor, requiring operators to focus on both network reliability and capacity expansion techniques to meet consumer and industrial requirements (Shieh et al., 2014). This is

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challenging however, given the weak revenue growth currently experienced, leaving only a modest appetite for infrastructure investment.

Scenario planning is a foresight tool that can be applied to understand how changes in the external environment may affect current or potential market strategies (Ramirez et al., 2015). On the one hand, this approach can be used to foster learning and the adaptive skills of an organisation (Favato and Vecchiato, 2016), while on the other, it supports high-level strategic decision-making (O'Brien and Meadows, 2013; Parker et al., 2015). Quantified approaches allow one to measure the impact of external drivers using systems modelling. Importantly, the choice of how much infrastructure is required, when, and where, is seen to be a problem of decision-making under uncertainty (Otto et al., 2016).

The aim of this paper is to quantify the uncertainty associated with the future demand for mobile telecommunications infrastructure, to test how different strategies perform over the long term. We focus specifically on capacity expansion via 5G mobile telecommunications infrastructure. In undertaking this task, the research questions which we endeavour to answer are as follows:

1. How will the combination of growing data usage and demographic change affect the demand for mobile telecommunications infrastructure?
2. How do different supply-side infrastructure options perform when tested against future demand scenarios?
3. What are the ramifications of the results, and how do they relate to the wider technological change literature, particularly in mobile telecommunications?

As the '5G' standard is still to be determined, the approach taken in this paper is to extrapolate LTE and LTE-Advanced characteristics, and to include those identified frequency bands that may be used for 5G rollout over the next decade, in relation to changing demand. Hence, a spectrum-based strategy includes integrating 700 and 3500 MHz on existing brownfield macrocellular sites, as these will be the newly available frequency bands to MNOs in Europe. Importantly, we also test the impact of increasing network densification using a small cell deployment strategy, as this is a key technological enabler for delivering expected 5G performance.

In the next section, a literature review will be undertaken in relation to the future demand for telecommunications services, as well as the current state-of-the-art of telecommunications infrastructure assessment. In Section 3 the methodology will be outlined, and the results reported in Section 4. The findings will be discussed in Section 5, and finally conclusions will be stated in Section 6.

## 2. Literature review

Although the full specification of '5G' is yet to be determined, it is likely that the technical requirements will include delivering peak rates of 20 Gbps per user in low mobility scenarios, user experienced data rates of 100 Mbps, radio latency of $< 1$ ms, significantly higher area traffic capacity (1000 times LTE), and a massive number of devices (ITU, 2015; Shafi et al., 2017). This will provide enhanced mobile broadband, massive machine type communications, and ultra-reliable low latency communications. While new generations of mobile technology can be dominated by marketing spin (Shin et al., 2011), there is consensus that network densification via smaller cells will be a key technique for 5G networks (Andrews et al., 2014). As the research questions outlined in this paper require a focus on technological forecasting, the relevant literature will now be reviewed, before the techno-economic literature on next generation mobile networks is evaluated.

### 2.1. Technological forecasting in telecommunications

Modelling and simulation methods are frequently combined with scenario planning approaches to test potential telecommunication strategies. As well as for strategic purposes, MNOs also often rely on demand forecasts methods to justify internally and externally the considerable investments required to move into new markets (see Fildes, 2002, 2003). This is often related to generational upgrades of technologies, where forecasts can help to understand, for example, how different factors affect the demand for future mobile wireless communications services (Frank, 2004). Commonly used methods include time-series econometric approaches (Lee, 1988), innovation diffusion modelling (Chu and Pan, 2008; Jun et al., 2002; Meade and Islam, 2006; Michalakelis et al., 2008; Venkatesan and Kumar, 2002) and technological forecasting (Meade and Islam, 2015). Systems dynamics approaches have also been applied to model the underlying dynamics of mobile telecommunications diffusion (Mir and Dangerfield, 2013).

Generational changes in mobile wireless technology also provide opportunities for new market niches (Nam et al., 2008), but this can often lead to failure (J. Park et al., 2015; S.R. Park et al., 2015). Shin et al. (2011) focus on the socio-technical dynamics of moving from 3G to 4G LTE telecommunications, and study how 4G strategies have been formed, shaped and enhanced. Importantly, the transition between different generations of mobile technologies requires executives to adapt to a dynamically evolving industrial landscape as technology and regulation both change.

Ghezzi et al. (2015) highlight the rapid transformation taking place in the telecommunications industry due to technological change and develop a framework to support MNOs operating in highly competitive markets. Using structured interviews with top- and middle-managers from four Italian MNOs, the authors identify the key drivers of disruptive change and the implications for their current business models. Increasing data traffic and decreasing voice revenues are the key drivers of disruptive change. Indeed, the emergence of Voice-over-IP (VoIP) services is one key driver of decreasing voice-related revenues, as users substitute paid voice services via an MNO for free VoIP access over the Internet (e.g. via Skype), leading the infrastructure owner to lose revenue (Kwak and Lee, 2011). MNOs have addressed this by bundling voice and SMS with data (Stork et al., 2017).

The analysis of digital adoption and the diffusion forecasting of mobile telephony has received significant attention in the technological change literature (Islam et al., 2002; Islam and Meade, 2015; James, 2012; Kim et al., 2010; Kyriakidou et al., 2013; Mayer et al., 2015; J. Park et al., 2015; S.R. Park et al., 2015; Pick and Nishida, 2015; Sadowski, 2017; Sultanov et al., 2016; Vicente and Gil-de-Bernabé, 2010), but relatively little focus has been placed on how this may affect mobile traffic growth, operator cost and competitiveness. However, in the rapidly growing ICT market, the forecasting of new technologies is a difficult yet necessary endeavour for operators and not something that should be purely left for the engineering domain as it has important commercial strategy ramifications.

In one such study, Lee et al. (2016) forecast mobile broadband traffic demand in Korea, using a device-based approach and a three-round Delphi expert elicitation process. Scenario analysis was applied to reflect uncertainty in the future dynamics of the sector, with 'optimistic', 'neutral' and 'pessimistic' scenarios being developed. Unsurprisingly, the conclusion was that mobile traffic will continue to increase, but the authors quantify by how much, and Korea is expected to see an increase to approximately 286 Petabytes per month by 2020, which is six times $>$ 2012. This is approximately 6 GB of monthly mobile traffic per user.

Velickovic et al. (2016) develop and apply a forecasting model for the deployment of fixed Fibre-To-The-Home (FTTH) telecommunication infrastructure, where demand forecasting is used to enable the dimensioning of necessary network resources. This is essential for operators to understand which investments are required, spatially and temporarily, to meet evolving demand. The network economics of telecommunications networks make it extremely challenging to service low demand areas, as there are inevitably large fixed capital costs in