European
Commission

Study on Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum

FINAL REPORT

A study prepared for the European Commission DG Communications Networks, Content & Technology

Digital Agenda for Europe

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Project number: 2013.5370

Contract number: 30-CE-0530064/00-25

SMART 2012/0015

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ISBN 978-92-79-30575-7

DOI: 10.2759/19531

Abstract

How is traffic off-loading evolving over time, both in terms of technical and of market developments, and how does this evolution influence the need for spectrum? It is widely recognized that traffic on the macro cellular network is growing rapidly, largely as a result of impressive take-up of smartphones and tablets. The surprising and little recognized reality is that, according to credible data captured from a range of sources, the visible growth in macro cellular mobile network traffic appears to be only the tip of a much larger iceberg. The volume of traffic that is already being off-loaded, chiefly to Wi-Fi in the home, already exceeds that of the mobile network, and can be expected to grow even faster as well. This is largely a result of the considerable effort that equipment vendors and standards bodies have invested in developing both Wi-Fi and cellular standards to improve interworking between the two and to optimise use of the available spectrum. Traffic off-load generates surprisingly large socio-economic benefits by virtue of the cost that MNOs have saved, or can be expected to save, by building a smaller network thanks to data traffic off-load. Relatively little action is needed at European level; however, a few interventions should be considered in order to ensure that the momentum is maintained. Among these are (1) seeking to make spectrum from 5150 MHz to 5925 MHz available globally for Wi Fi; (2) continue seeking to make 2.6 GHz and 3.5 GHz fully available for mobile use; (3) consulting on future licensing options for 3.5 GHz and other potential new licensed mobile frequency bands; and (4) various measures to reduce administrative burden on the deployment of public off-load services and networks.

Contents

Tables

Figures

Recommendations

Executive Summary:
Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum

How is traffic off-loading evolving over time, both in terms of technical and of market developments, and how does this evolution influence the need for spectrum?

Spectrum demand is being driven both by current consumer demand for data and by European policy goals. The user demand for mobile data is growing at explosive rates – one respected source[1] claims a *Compound Annual Growth Rate (CAGR)* of 66% for the period 2012-2017! At the same time, European policy in the form of Digital Agenda for Europe (DAE) calls for full availability of basic broadband to all Europeans in 2013, and full availability of 30 Mbps broadband to all Europeans in 2020. Wireless is likely to play a significant role in achieving these DAE objectives. Off-loading of data from the macro cellular network onto shorter-range alternatives such as Wi-Fi, picocells or femtocells can (and already does) provide much greater capacity at a lower cost and potentially and presently offers a more flexible alternative. Wireless off-load is especially relevant to the 30 Mbps objective, since deployment of "small cell" architectures could provide a cost effective means to deliver high data capacity in areas where alternative wired access platforms are not available, provided that adequate backhaul capacity is available.

These off-load solutions potentially provide relief in many dimensions. They do not necessarily depend on licensed spectrum. To the extent that they are shorter range, they permit much greater spectrum re-use over a given geographic area than does the macro cellular network alone and hence much greater capacity for a given amount of radio spectrum. And they potentially help "bridge" the time period until additional macro network spectrum can be cleared from incumbent use.

This study seeks to identify the opportunities that off-load technology now presents; to estimate any additional demands for spectrum that might be needed to facilitate data traffic off-load; to estimate costs and benefits of doing so at European level; and to make relevant recommendations for any policy interventions that are found to be warranted at European level.

What is meant by "data traffic off-loading"?

The Commission provided an unusually detailed definition in the Terms of Reference: "For the purpose of this Study, 'data traffic off-loading' should be defined as routing wireless data that could be served by macro cellular networks (UMTS, LTE or WiMAX) over alternative access network technologies that use local coverage (shorter transmission ranges) and operate in frequencies that may or may not be exclusively

1 Cisco VNI Mobile Forecast (2013).

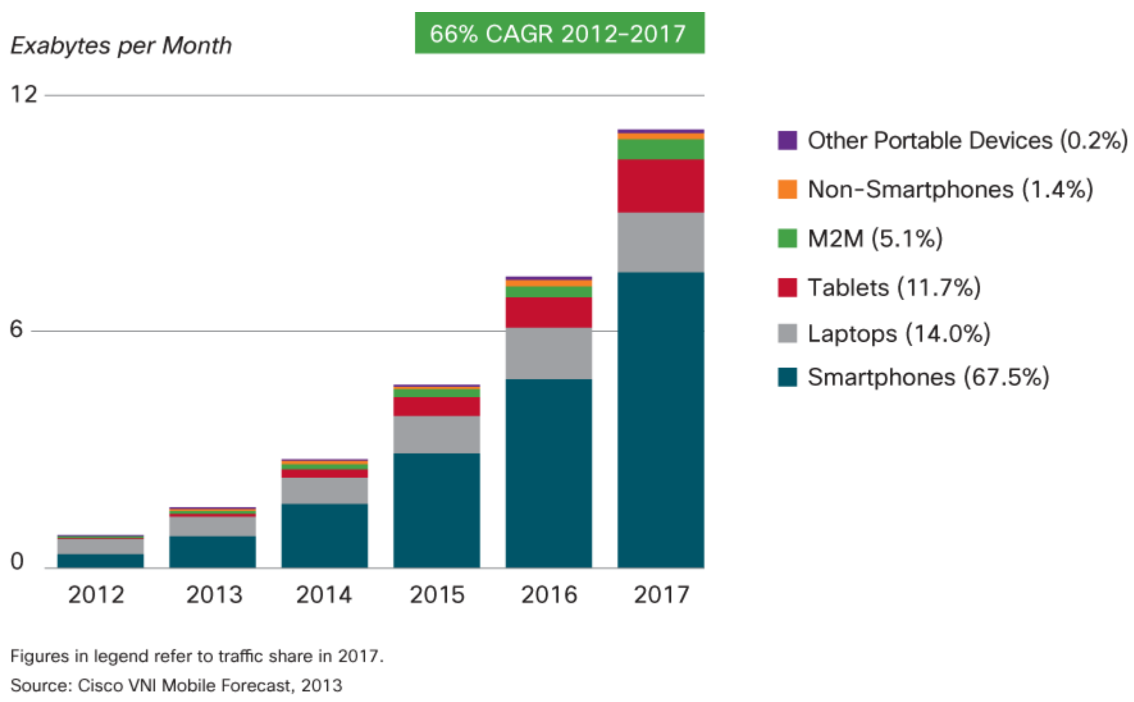
accessible by the network operator. Alternative access to wireless broadband is typically based on "small cells" such as Wi-Fi hotspots or the so-called femto- or picocells of cellular networks and could be provided as integral part of a managed cellular network by an MNO or based on user-owned infrastructures, such as self-organising Wi-Fi networks, e.g. run by a Wireless Broadband Operator (WBO)."

In practice, it was necessary to further refine the definition. Key distinguishing characteristics of off-load, as distinct from a mere re-grooming of the network of the *Mobile Network Operator (MNO)*, are (1) that some aspect, either spectrum or backhaul, is *not under the MNO's control*; and (2) that, in the nature of the end user device, it is reasonable to assume that the traffic *would have been sent over the macro cellular network if it had not in fact been off-loaded*.

Rapid growth in the use of traffic off-load

It is widely recognized that traffic on the macro cellular network is growing rapidly, largely as a result of impressive take-up of smartphones and tablets.

Figure 1: Predicted growth of mobile data (2012-2017)

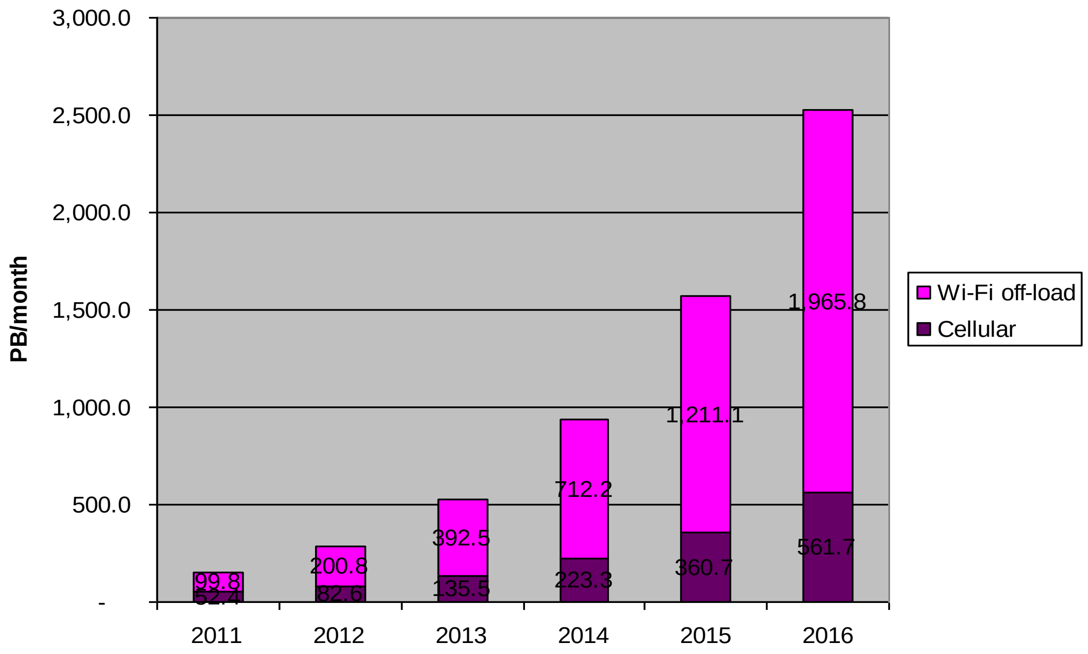


Source: Cisco Mobile VNI (2013).[2]

2 Cisco Systems, Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017, 6 February 2013.

The surprising and little recognized reality is that, according to credible data captured from a range of sources, the visible growth in macro cellular mobile network traffic appears to be only the tip of a much larger iceberg. The volume of traffic that is already being off-loaded, chiefly to Wi-Fi in the home, already exceeds that of the mobile network, and can be expected to grow even faster as well.

Figure 2: Observed or predicted mobile data off-load



Source: Cisco VNI (2012) and Informa/Mobidia data, WIK calculations

Evolution of the technology

In recent years, equipment vendors and standards bodies have invested considerable effort in developing both Wi-Fi and cellular standards to improve interworking between the two and to optimise use of the available spectrum. Whilst most legacy Wi-Fi equipment is based on the 802.11g standard with a maximum bit rate of 54 Mbps and operating exclusively in the 2.4 GHz band, more recent devices use the 802.11n variant which uses both 2.4 GHz and 5 GHz and incorporates additional enhancements such as MIMO and wider (40 MHz) RF channels to extend the available bit rate to hundreds of Mbps. The latest 802.11ac standard will enable even higher bit rates by deploying even wider channels (80 MHz or 160 MHz).

Interworking standards have been developed by both the Wi-Fi and cellular industries and are now becoming available commercially, with the potential to simplify greatly the ease of roaming between the two network domains. Of particular importance is Wi-Fi

Alliance certified PasspointTM (sometimes referred to as HotSpot 2.0) and the 3GPP's Access Network Discovery and Selection Function (ANDSF). The former is intended to simplify the authentication process for accessing Wi-Fi networks, for example by allowing SIM-based authentication for mobile devices, whilst the latter provides mobile network operators with a greater degree of control over which networks their subscribers' devices connect to (whether Wi-Fi or cellular), with automatic discovery and connection to the preferred network. Our view is that these developments will largely overcome a key barrier to greater mobile traffic offload to Wi-Fi, namely the historic complexity of the connection and authentication process.

On the cellular side, small cell technology has evolved to enable low cost "plug and play" devices to be deployed in operators' licensed spectrum without the need for the complex planning that is required for macro networks. Femtocells (typically deployed in homes and enterprises) and metrocells (typically deployed in outdoor or public locations) can co-exist with macro cellular networks either using the same frequencies or in dedicated bands, resulting in significant increases in network capacity and spectrum efficiency.

Evolution of the market

The Wi-Fi market as a whole is very mature in Europe, with over 70% of households already having a Wi-Fi access point in some Member States. Wi-Fi capability has also become increasingly a standard feature on smart phones, and in consequence off-load to Wi-Fi is now also well established. Currently, the great majority of this off-load is onto private (mainly home) Wi-Fi connections, with only a few per cent being off-loaded to public Wi-Fi hotspots. We expect this situation to change over the next few years, partly as a result of the technology improvements highlighted above and partly due to the greater availability of Wi-Fi connections in public locations, particularly outdoors. In Europe, the greatest progress in this area appears to have been made in the UK, where there are now at least five operators providing Wi-Fi metropolitan area networks, mainly in city centres and often in conjunction with local municipalities.

Another key development relates to community based public Wi-Fi access, which has been pioneered by the Spanish company FON in partnership with a number of national telcos such as BT, DT and Belgacom. This approach typically involves the use of specially adapted access points which enable participating subscribers to the partner network operator to access other subscribers' access points. For example, BT's partnership with FON in the UK provides participating BT Broadband subscribers with access to over four million BT FON hotspots in the UK as well as other FON partner hotspots elsewhere it the world. A number of Wi-Fi roaming aggregators have also emerged (examples include iPass and Boingo) who specialise in facilitating national and international roaming between Wi-Fi hotspot operators, thus making public Wi-Fi access more convenient and affordable for many users.

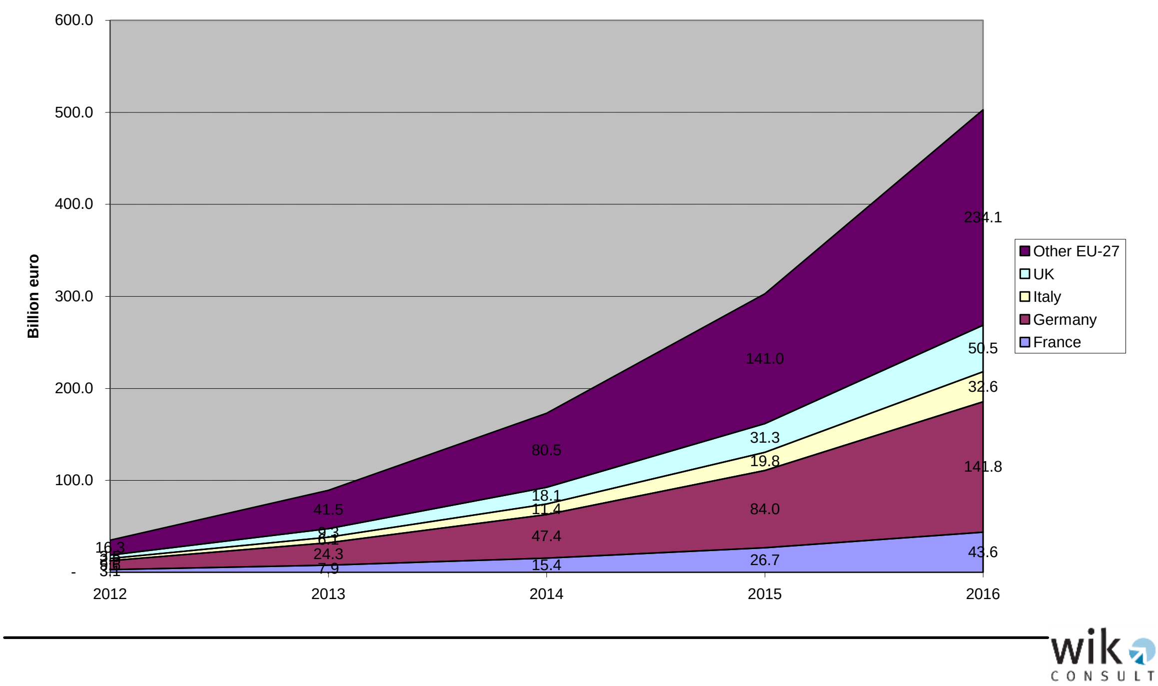
One strong message that has emerged from our stakeholder discussions is that Wi-Fi and licensed small cells are very much complementary to one another rather than substitutes. This is reflected in the growing market interest in “hetnets” that combine both cellular and Wi-Fi access in the same base station hardware, maximising the use of available spectrum and the devices that can be served whilst minimising costs by using common backhaul and other site infrastructure.

Socio-economic benefits of off-load

The largest and most readily quantified socio-economic benefit of traffic off-load is the cost that MNOs have saved, or can be expected to save, by virtue of being able to build a smaller network thanks to data traffic off-load. The annualised cost savings (primarily attributable to off-load to private Wi-Fi in the home or at work) are surprisingly large. Given that European mobile markets are reasonably competitive, a portion of these savings would be competed away and passed on to consumers.

We estimate the savings in network cost already generated in 2012 for the EU-27 to be 35 billion euro, and the projected savings in 2016 to be 200 billion euro; however, this rough estimate should be understood to represent a generous upper bound. In reality, consumers would choose instead to do somewhat less with their mobile devices, or to use fixed network devices and interfaces instead of mobile. In these cases as well, however, consumers clearly benefit from traffic off-load.

Figure 3: Cumulative savings in network cost due to off-load (€ Bn)



Source: Multiple sources, WIK calculations

Recommendations

For the most part, traffic off-load is a somewhat unanticipated success story for Europe and the world. The network cost reductions provided by traffic off-load can be expected to generate improved price/performance of mobile broadband for consumers. This can be expected to lead in turn to consumer welfare benefits, and to increased adoption and usage of mobile broadband.

Relatively little action is needed at European level; however, a few interventions should be considered in order to ensure that the momentum is maintained.

- Seek to make spectrum from 5150 MHz to 5925 MHz available globally for Wi-Fi.
- Continue seeking to make 2.6 GHz and 3.5 GHz fully available for mobile use.
- Consult on future licensing options for 3.5 GHz and other potential new licensed mobile frequency bands.
- Raise awareness of the value of dual radio hotspots.
- The need for back-haul for traffic off-load provides yet another reason to press ahead with DAE broadband goals.
- Ensure effective and consistent imposition and enforcement of remedies on firms that have SMP in regard to leased lines and equivalents.
- Consider further studies on administrative impediments to mobile and off-load deployment.

1 Introduction

This is the Final Report for the WIK-Consult / Aegis team for the project "Study on Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum", SMART 2012/0015, Ref. Ares(2012)729624 - 19/06/2012.

1.1 Traffic off-load

Spectrum demand is being driven both by current consumer demand for data and by European policy goals. The user demand for mobile data is growing at explosive rates – one respected source[3] claims a *Compound Annual Growth Rate (CAGR)* of 66% for the period 2012-2017! At the same time, European policy in the form of Digital Agenda for Europe (DAE) calls for full availability of basic broadband to all Europeans in 2013, and full availability of 30 Mbps broadband to all Europeans in 2020. Wireless is likely to play a significant role in achieving these DAE objectives. In the years since the DAE was published, it has become increasingly clear that wireless solutions will be required as a complement to fixed networks in order to achieve DAE goals at an affordable price.

Wireless off-load is especially relevant to the 30 Mbps objective, provided that adequate backhaul capacity is available. Off-loading of data from the macro cellular network onto shorter-range alternatives such as Wi-Fi, picocells or femtocells can (and already does) provide much greater capacity at a lower cost than does the macro cellular network.

These off-load solutions potentially provide relief in many dimensions. They do not necessarily depend on licensed spectrum. To the extent that they are shorter range, they permit much greater spectrum re-use over a given geographic area than does the macro cellular network alone and hence much greater capacity for a given amount of radio spectrum. And they potentially help "bridge" the time period until additional macro network spectrum can be cleared from incumbent use.

We have been asked to identify the opportunities that off-load technology now presents; to estimate any additional demands for spectrum that might be needed to facilitate data traffic off-load; to estimate costs and benefits of doing so at European level; and to make relevant recommendations for any policy interventions that are found to be warranted at European level.

1.2 A rapidly evolving view of a rapidly evolving environment

Just in the few months since the project was launched, new data has emerged which casts the entire data off-load discussion in a significantly different light. Taken as a

3 Cisco VNI Mobile Forecast (2013).

whole, the data off-load ecosystem turns out to be much larger, richer, and more complex than expected.

As we explain later in this section, the various data sources that we studied implied radically different and mutually inconsistent views as to the level of traffic off-load that is already taking place, and that is likely to place. Assessments and forecasts are in the process of being rapidly adjusted upwards as new data comes to light, which means that 2013 forecasts often differ substantially from forecasts just a year earlier. As a result, we have intensively reviewed the main available data sources, and interacted heavily with the analysts, in order to determine which data could be trusted and which could not. Based on this assessment, we have provided our own assessment and forecasts of mobile data traffic off-load, drawing on a combination of data sources (see especially Sections 4 and 7.2). We believe that we have arrived at forecasts that are plausible, and internally consistent to a reasonable degree, but we do not claim that they are perfect.

The traffic off-load space, and the understanding of it, are evolving rapidly in several dimensions.

First, multiple sources suggest that *the magnitude of data off-load already taking place is far greater than had previously been assumed*. In fact, in February 2013 the Cisco VNI (which we consider to be in most respects the most comprehensive, most robust, and best validated source of traffic projections for IP data) adjusted its estimate upward by a factor of two or more: however, we believe that the new estimates of off-load may still be much too low for major European countries, including France, Germany, Italy and the UK. As recently as June 2012, the Cisco VNI had identified data off-load using Wi-Fi and licensed small cells to represent 11% of mobile traffic in 2011, with an expected rise to 22% in 2016.[4] The new Cisco Mobile VNI of February 2013, using a different methodology to estimate data off-load, found 33% of mobile traffic to be off-loaded in 2012, rising to 46% in 2017.[5] This upward revision would bring the Cisco estimate more nearly in line with a 2011 estimate by Rupert Wood of Analysys Mason,

4 Cisco VNI (2012).

5 The Cisco VNI team explains as follows: “Offload is estimated based on the following factors: the percentage of handsets that are dual-mode, the percentage of handset users with an offload environment at home or work, the percentage of time spent in an offload-capable environment, the relative frequency of high bandwidth media in offload environments compared to ‘on the go’ mobile usage. The offload estimates have increased this year for the following reasons. (1) We raised our estimate for the percentage of smartphones that are dual-mode. In the past, we used a third-party analyst source for this metric, but we replaced this third-party source with our own estimates this year and we believe the newer estimates more accurately reflect dual-mode penetration of smartphones. (2) We lowered our estimate for mobile users without access to Wi-Fi in certain countries going forward. Tiered pricing and data caps have made it less likely that users will abandon their fixed connections and use only mobile. If more users retain their fixed connections, the mobile offload will be higher.”

who projected in 2011 that roughly 35% of mobile traffic would be off-loaded in 2012 and 58% in 2016.[6] Nonetheless, we think that these estimates may still be too low.

Second, and as a closely related matter, multiple sources indicate that *as much as 80-90% of Android smart phone and tablet mobile traffic is already being off-loaded to private Wi-Fi, e.g. within the end-user's home*. Particularly noteworthy is a new study by Informa and Mobidia that finds that at least two-thirds of mobile data for Android phones is already being off-loaded to "self-provisioned" Wi-Fi, which equates roughly to private Wi-Fi.[7] These data are consistent with those from a Cisco handset application, the Cisco Data Meter (see Section 4).

Third, the same Informa analysis found *only 2% of otherwise mobile traffic from Android smart phones to be transmitted over managed (i.e. public) Wi-Fi hotspots*, although this fraction varied greatly from one country to the next. In terms of traffic, then, private Wi-Fi off-load traffic appears to be thirty or forty times as great at present as public Wi-Fi traffic.

Based on our current assessment, drawing on all of these sources and others, we now believe that a majority of traffic that would otherwise be present on the macro cellular traffic is already being off-loaded, primarily to Wi-Fi in the home. This fraction will likely increase over time as smartphones play an increasing role, and personal computers play a declining role, in total mobile traffic. Our detailed projections appear in Sections 4 and 7.2.assessment and forecast of mobile data traffic and associated off-load are reflected in our assessment of societal benefits.

1.3 What is meant by "data traffic off-loading"?

Before commencing, it is necessary to be clear on exactly what is, and is not, within the scope of the study. This is a more complicated question than one might at first suppose, because the boundary between the wireless network and the fixed network is less crisp than it used to be.

The Commission provided an unusually detailed definition in the Terms of Reference, suggesting that the Commission itself recognised the challenges of identifying clearly the boundaries of the study. Per the Terms of Reference: "For the purpose of this Study, 'data traffic off-loading' should be defined as routing wireless data that could be served by macro cellular networks (UMTS, LTE or WiMAX) over alternative access network technologies that use local coverage (shorter transmission ranges) and operate in frequencies that may or may not be exclusively accessible by the network operator.

6 Rupert Wood, "Demand trends: growth is not straightforward", Analysys Mason workshop on Regulatory and policy challenges of next-generation access, 16 November 2011.

7 Informa, "Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience: A global analysis of smartphone usage trends across cellular and private and public Wi-Fi networks", February 2013.

Alternative access to wireless broadband is typically based on "small cells" such as Wi-Fi hotspots or the so-called femto- or picocells of cellular networks and could be provided as integral part of a managed cellular network by an MNO or based on user-owned infrastructures, such as self-organising Wi-Fi networks, e.g. run by a Wireless Broadband Operator (WBO)."

Implicit in the term "off-load" is the assumption that, in the absence of traffic off-load, the traffic in question would have been transmitted over the macro cellular network. This necessarily requires us to make assumptions about what *would have happened* in the counterfactual scenario where off-load is absent.[8]

The use of Wi-Fi in the home is widespread, but it does not necessarily off-load data from the "macro cellular network". A key question is, would the traffic carried by Wi-Fi otherwise have been carried by the macro cellular network? We chose to make a rough distinction based on the capabilities of the end user's device, following generally an approach similar to that of the Cisco VNI. If the end user's device has two interfaces, Wi-Fi and mobile, for instance, then it is reasonable to assume that their traffic would go to the mobile network in the absence of Wi-Fi.[9] This is the case for many smart phones and tablets.

Conversely, even though personal computers can be configured to use the macro cellular network by means of, for instance, a dongle, we do not think that it is meaningful to speak of *data off-load* in the context of a personal computer. In the absence of Wi-Fi, a personal computer would be much more likely to connect directly to the fixed network than to the macro cellular network.[10] Conversely, smart phones (and many tablets) typically do not have a physical attachment to the fixed network (e.g. an Ethernet connector); thus, in the absence of Wi-Fi, a mobile connection might be the only option.

Traffic from personal computers represents a large (albeit declining) proportion of total mobile traffic today, and personal computers play a large role in the use of residential Wi-Fi. The classification of personal computer traffic consequently has a significant influence on our assessment of socio-economic benefits, but has no influence on our assessment of spectrum requirements.

Indeed, as more and more technological solutions emerge, it is becoming increasingly difficult to identify what does, and does not, constitute data traffic off-load. In this study, we assume that off-load from a cellular-capable device occurs when (1) a wireless access technology with local coverage and shorter transmission ranges are used, and (2) the Mobile Network Operator (MNO) does not have control over either (2a) the

8 The need to develop sensible and defensible assumptions is a fundamental challenge in any analysis that involves counterfactuals. See Stephen L. Morgan and Christopher Winship, *Counterfactuals and Causal Inference*, Cambridge University Press, 2007.

9 The traffic might still, of course, be off-loaded to a femtocell or picocell.

10 In the VNI, Cisco also excludes laptop traffic from their estimate of off-load.

spectrum that is used to access the mobile device, or (2b) the back-haul from the customer premises to the base station or network.[11]

This implies that data traffic off-loading can be said to take place:

- Whenever data is transmitted over Wi-Fi, because the MNO does not exclusively control the spectrum that is used; or
- Whenever the backhaul connection from the customer premises to the base station or network is not controlled by the MNO, no matter what wireless access technology is used (including femtocells); but
- Not when, for instance, LTE cells (no matter how small) with backhaul integral to the mobile network are used.

Not all communication takes place within the home. One must clearly distinguish among services that are *fixed*, *nomadic*, or *mobile*. A *nomadic* service moves over time, but is relatively stationary while in use. Providing service to a traveller in his or her hotel room is a significantly different proposition from providing service to a user walking down the street. First, the hotel room user is likely to already have a business relationship, and payment arrangements, in place with the hotel; second, there is usually no need for complicated hand-offs among networks in the middle of a conversation or interaction.

The implications of these various forms of off-load to the fixed and wireless networks (including both fixed and mobile wireless) for spectrum management are complex. Where traffic is off-loaded onto the fixed network, for instance, it is still necessary to consider the possible need for additional licence exempt spectrum (or possibly for licensed spectrum in the case of femtocells or picocells) for traffic distribution in the home or local context. Moreover, a shift from the macro cellular network to traffic off-load potentially enables the use of higher frequency spectrum (e.g. at 5 GHz) instead of the scarce and expensive frequency bands below 1 GHz that are ideal for coverage with the macro cellular network.

Finally, we note that our focus here is on wireless (primarily mobile) data, not on the use of mobile traffic off-load in support of circuit-switched voice. In any case, as we explain in Section 1.4, mobile voice represents a rapidly declining fraction of the totality of mobile traffic.

1.4 Demand for mobile traffic is growing rapidly

As we explain in this section (and others) of this Report, mobile data traffic (and wireless traffic generally) is growing rapidly, and is expected to continue to do so for many years. It is this traffic growth that is putting considerable pressure on mobile data

11 Some interviewees considered the distinction based on backhaul to be meaningless. For cells in shopping malls or stadia, the MNO often controls the cell, irrespective of who provides the backhaul.

networks (i.e. macro cellular networks), and creating an impetus for (1) more spectrum to be made available, either on an exclusive or a shared basis; (2) migration to more efficient technology such as LTE and eventually LTE-Advanced; and (3) off-load of traffic from the macro cellular network to the fixed network and/or to more local wireless distribution.

Data traffic off-load potentially ameliorates the need for additional spectrum for the macrocellular network, or enables customer demands to be satisified prior to additional spectrum and better technology becoming available. It also potentially serves to provide an infrastructure-based competitive alternative to the macro cellular network.[12]

Voice still represents the majority of the *revenue* of most mobile networks; however, mobile data traffic is experiencing explosive growth, and now represents the majority of *traffic* in most mobile networks. The rate of mobile data traffic growth is declining year on year, but is nonetheless extraordinarily high, and can be expected to remain high for many years to come.

One respected source, the Cisco *Visual Networking Index (VNI),* projects a Compound Annual Growth Rate of 66% for mobile data over the years 2012-2017 (see Figure 1-1). These data correspond to traffic over the macro cellular network, net of any off-load to the fixed network that is predicted to take place via Wi-Fi or licensed small cells.[13] Predictions are always uncertain, but the Cisco assessments are professionally done and are at least plausible.

Also clear from Figure 1-1 is that the growth is driven not only by the use of smartphones, but also by the increasing use of other mobile devices including tablets, laptops and netbooks (e.g. with dongles), and to some extent by home gateways. This has the further implication that not all wireless traffic is limited to a small screen format.

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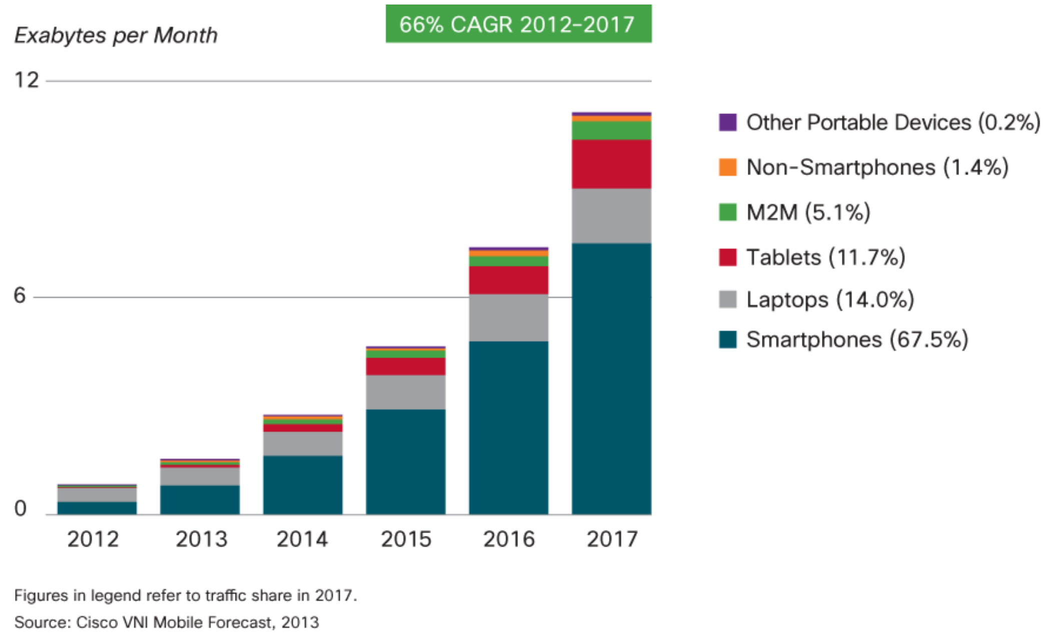
12 The benefits of facilities-based competition are explicitly recognised in the European Regulatory Framework. In Article 8 of the Framework Directive, among the duties of NRAs are "… safeguarding competition to the benefit of consumers and *promoting, where appropriate, infrastructure-based competition* (emphasis added); … promoting efficient investment and innovation in new and enhanced infrastructures …"

13 "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017", February 2013, page 11. "Much mobile data activity takes place within the user's home. For users with fixed broadband and Wi-Fi access points at home, or for users served by operator-owned femtocells and picocells, a sizable proportion of traffic generated by mobile and portable devices is off-loaded from the mobile network onto the fixed network."

Figure 1-1: Predicted growth of mobile data (2012-2017)

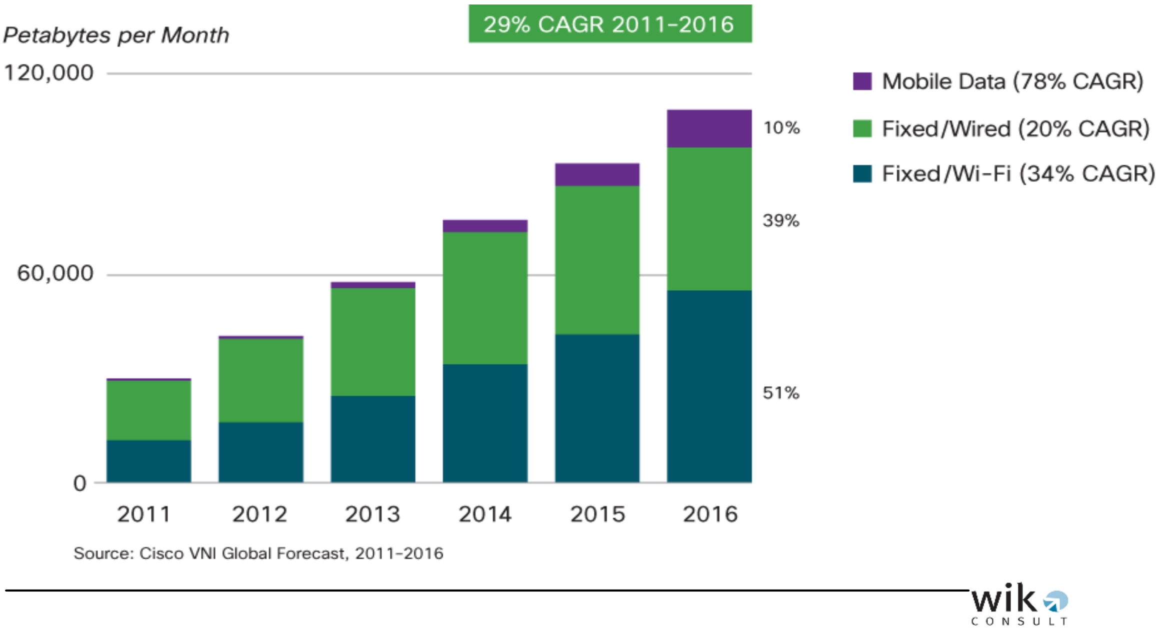


Source: Cisco Mobile VNI (2013).[14]

We would additionally point out that it is increasingly common that the physical access to end-user device is wireless, even when the underlying network is fixed. The fixed and wireless networks are growing together in complicated ways. We have long taken it for granted that local distribution of fixed network DSL traffic within the home would often take place by means of Wi-Fi, but the increasing tendency in some Member States to replace the fixed access with wireless, together with data off-load itself, is causing the distinction between the fixed network and the mobile network to blur altogether. This is visible in Figure 1-2, which provides predicted growth of fixed network traffic delivered over Wi-Fi connections, fixed network traffic delivered over wired connections, and mobile data. Fixed network traffic delivered over wired connections is growing more slowly than the other two categories, albeit from a significantly higher base.

14 Cisco Systems, Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017, 6 February 2013.

Figure 1-2: Fixed wired, fixed Wi-Fi, and mobile data projections (2011-2016)



Source: Cisco VNI (2012).[15]

The increasing complexity and sophistication of end-user devices plays a crucial role in all of these trends. The end-user device can typically choose, or can be configured to choose, among fixed (wired) access, Wi-Fi access, and mobile access. Even where the Network Operators make clearly distinct offerings, the use of those offerings by end-user devices tends to be increasingly sophisticated.

The same Cisco analysis suggests that mobile data traffic off-load is likely to play a significant role in meeting the growing demand for mobile data. Indeed, they predict an increasing portion of mobile traffic to be off-loaded onto the fixed network via Wi-Fi or licensed small cells, increasing from 33% in 2012 to 46% of all mobile traffic in 2016. Cisco estimates that in the absence of mobile data off-loading, the compound annual growth rate (CAGR) of mobile traffic (i.e. the CAGR of the combined cellular traffic and off-loaded traffic from 2012 to 2017 would have been 74% instead of 66%. We believe, however, that this substantially underestimates the data off-loading that is already taking place, at least in Europe.

15 Note that the data in this figure reflect Cisco VNI June 2012 estimates, which differ in a number of respects from their revised estimates in the VNI Mobile Forecast of February 2013.

1.5 Traffic off-load of fixed wireless traffic is minimal compared to mobile off-load

Fixed wireless is clearly within the scope of our study, but we have little to say about it because traffic off-load in fixed wireless networks is tiny in comparison with traffic off-load in mobile wireless networks. Although there area a significant number of licensed WiMAX networks in the EU, virtually all of these operating in the 3.5 GHz band,[16] the role of the technogy is declining as networks and equipment vendors increasingly look towards LTE as the preferred technology in this band. For example, the Clearwire network in Belgium is already planning to migrate to LTE, and in the UK there is already an operational LTE network in the 3.5 GHz band. In 2009, the projected global WiMAX subscriber base for 2012 was approximately 70 million, of which 4% were projected to be in Western Europe.[17] Two years later, the 2012 estimate had been downgraded to just 28.6 million.[18] Although more recent data is not available, it seems likely that this downward trend in expectations is continuing, and that there are probably no more than a million WiMAX subscribers in Europe

Traffic off-load from WiMAX networks is therefore likely to be insignificant compared to that from other 3G and 4G mobile networks. The presence of existing WiMAX networks also has implications for the future use of the 3.5 GHz band, which could be particuarly attractive for small cell deployments using LTE technology. As WiMAX declines, there may also be greater interest in using existing 3.5 GHz licences to support backhaul of traffic for small cell networks. In some ways, the emergence of LTE as an option in this band may create new opportunities for existing licensees to raise their profiles, either by operating their own LTE access networks or by providing an alternative backhaul network for other Wi-Fi or LTE small cell providers.

The table below summarises the current status of WiMAX and other licensed networks in the 3.5 GHz bands, based on data from the ECO[19] and the 2012 spectrum inventory study conducted on behalf of the European Commission by WIK, Aegis, Plum Consulting and IDATE.[20]

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16 Wherever we refer to the 3.5 GHz band in this report, we mean to refer to the range from 3400-3800 MHz. This is consistent with usage that is common, but not universal, in the field.

17 “Reaching sustained growth in the WiMAX market – a survey of WiMAX operators, with a subscriber forecast for 2009–2014”, Senza Fili Consulting, released 2010.

18 Maravedis market statistics for 4G, March 2011, available at http://archive.constantcontact.com/fs096/1103610692385/archive/1105004296897.html.

19 ECO Report 3, “The licensing of mobile bands in CEPT”, April 2013.

20 J. Scott Marcus, John Burns, Frédéric Pujol and Phillipa Marks: “Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency”, report on behalf of the European Commission, September 2012.

Table 1: Current status of 3400 – 3800 MHz band[21] in Europe

Country	3400-3600 MHz	3600-3800 MHz
Austria	65 regional licences (technology unknown), expiry 2019	Not yet licensed
Belgium	3 regional licences, expiry 2019-2021. Clearwire currently deploys WiMAX for FWA but plans to migrate to LTE. ZapFi has a licence in Bruges which provides backhaul for its local Wi-Fi network	
Czech Republic	Several hundred local licences (technology and expiry date unknown)	Licences planned
Denmark	One FWA licence (Telenor, currently WiMAX), expires 2020	One FWA licence (TDC, technology unknown), expires 2024
Estonia	Two regional WiMAX licences, renewed annually	Two national WiMAX licences, renewed annually
Finland	44 regional WiMAX licences, expiry 2015-2016	
France	5 regional licences	
Germany	3 national WiMAX licences, expiry 2021, three regional WiMAX licence, two expiring in 2022 and one indefinite	Various regional WiMAX licences, expiry 2022
Greece	3 national WiMAX licences, expiry 2015-2016	Not yet licensed
Ireland	Large number of local fixed wireless networks (WiMAX and LTE), expiry 2017	Large number of local fixed wireless networks (WiMAX and LTE), expiry 2017
Italy	61 local BWA networks (technology unknown), expiry 2023	
Latvia	3 national BWA licences, expiry 2018-2021	2 national and 4 regional BWA licences, expiry 2014-2025
Lithuania	3 national WiMAX licences, expiry 2022	1 national and 1 regional WiMAX licences, expiry 2027
Luxembourg	No licences	No licences
Malta	2 national WiMAX licences, expiry 2020	
Netherlands	1 WiFi licence, used to provide Wi-Fi backhaul in Scheveningen, South Holland and Zeeland, expiry 2015	
Poland	Various regional FWA licences (technology and expiry unknown)	3 national FWA licences, expiry 2019. Various regional FWA licences (technology and expiry unknown)
Portugal	1 regional WiMAX licence, expires 2025	2 national licences, expiry 2025
Romania	5 national licences	1 national licence
Slovak Republic	3 national WiMAX licences, expiry 2015-2025	
Slovenia	4 regional WiMAX licences, expiry unknown	
Spain	3 national WiMAX licences, expiry 2020	Currently used by fixed links

21 Again, wherever we refer to the 3.5 GHz band in this report, we mean it to refer to the entire range from 3400-3800 MHz. This is consistent with usage that is common, but not universal, in the field.

Country	3400-3600 MHz	3600-3800 MHz
Sweden	2 national WIMAX licences, expiry 2017 and several regional licences, expiry 2022	1 national licence and c. 800 community based local licences, expiry 2022
UK	1 national licence (LTE technology), expires 2019	1 national licence, indefinite duration

1.6 European policy calls for widespread broadband and NGA deployment

European policy promotes deployment and adoptions of broadband. The Europe 2020 strategy, and its flagship initiative Digital Agenda for Europe (DAE), seek to:

- by 2013, bring basic broadband to all Europeans;
- by 2020, to ensure that all Europeans have access to much higher Internet speeds of above 30 Mbps, and
- by 2020, to ensure that 50% or more of European households subscribe to Internet connections above 100 Mbps.[22]

The rationale for promoting widespread deployment and adoption of broadband, including ultra-fast (30 Mbps or more) broadband, seems clear enough. Widespread availability of broadband is widely viewed as an important contributor to European economic well-being, and to European competitiveness with other regions including Asia and the United States. One study after another, in Europe and around the world, has shown a range of net benefits for society as a result of the take-up of broadband.

It is widely acknowledged, however, that meeting these DAE goals will be extremely challenging. With that in mind, wireless solutions clearly have a role to play in at least the first two of the DAE goals, if not all three. Data traffic off-load can play an important role in improving the cost-effectiveness of wireless solutions. Wireless data traffic is observed to be growing rapidly, creating an impetus for availability for more spectrum and more efficient technology. Data traffic off-load potentially ameliorates the need for additional spectrum for the macrocellular network, or enables customer demands to be satisified prior to additional spectrum and better technology becoming available. It also potentially serves to provide an infrastructure-based competitive alternative to the macro cellular network.[23]

22 DAE, page 19.

23 The benefits of facilities-based competition are explicitly recognised in the European Regulatory Framework. In Article 8 of the Framework Directive, among the duties of NRAs are "… safeguarding competition to the benefit of consumers and *promoting, where appropriate, infrastructure-based competition* (emphasis added); … promoting efficient investment and innovation in new and enhanced infrastructures …"

1.7 The structure of this report

Within this report, Section 2 explains the many technical factors that are shaping the traffic off-load environment, while Section 3 explains the back-haul environment, a key enabler for traffic off-load. Section 4 presents our estimate of the current and future magnitude of off-load traffic available. Section 5 presents off-load scenarios in the home, at work, and as a public offering. Section 6 presents our views on spectrum requirements. Section 7 provides an assessment of socio-economic benefits. Section 8 explains the (limited) role that off-load plays in meeting DAE objectives, while Section 9 provides our findings and our recommendations going forward.

Supporting tables, figures and analysis appear in an Annex to this report.

2 The evolving technology of mobile, Wi-Fi, and traffic off-load

In this section, we consider overall technology trends, compare cellular and Wi-Fi in terms of technology, coverage and capacity capabilities, and availability of spectrum, review emerging approaches to user authentication, and assess interoperability between the cellular and Wi-Fi environments.

2.1 Introduction

Technology evolution and increased spectrum availability over the next few years will play a significant role in providing the required capacity to meet mobile data traffic growth, but such is the pace of traffic growth that additional strategies such as data off-load are likely to also be required. The majority of mobile data terminals such as smart phones and tablets are Wi-Fi enabled, making Wi-Fi an obvious choice for providing additional capactiy where traffic demand is high. Indeed, Wi-Fi is already widely used to provide public access to broadband services at traffic hotspots, such as airports, railway stations, hotels, bars and coffee shops.

Many of these connections are operated on an individual basis; however, increasingly fixed and mobile network operators are rolling out their own public Wi-Fi networks which can be accessed by subscribers as part of their data bundle and in some cases provide automated switching between the cellular and Wi-Fi neteworks. At some particularly traffic-intensive locations (typically the central business districts of major cities), dense “mesh” networks have been configured to provide contiguous Wi-Fi coverage that can be a viable alternative to a cellular mobile data network in those locations.

More recently, many mobile networks in Europe have acquired additional spectrum in the 2.6 GHz band which is ideally suited for operation of small cells based on cellular rather than Wi-Fi technology[24]. These small cells can be deployed alongside conventional macro cells operating in lower frequency bands to provide a massive increase in mobile network capacity whilst allowing the mobile network to retain full control over the subscriber connection and benefit from the improved qualtiy of service available from exclusive licensed spectrum.

It is currently unclear what the relative impact of licensed and licence-exempt small cell technologies will be over the longer term, since the former is in its infancy; however, there appears to be a broad consensus in the industry currently that the two will largely complement rather than compete with each other. This is supported by our discussions with network operators, service providers and equipment vendors and also reflects the findings of other recent studies. For example, a recent study by Senza Filli Consulting

24 See section 2.6 for a description of licensed small cell technologies and architectures.

highlighted the potential cost efficiencies for mobile networks resulting from deployment of hybrid 4G / Wi-Fi small cells (see also Section 2.6).[25]

In the following sections, we review the status of cellular and Wi-Fi technologies, with a particular focus on their role in suppporting traffic offload from traditional large cell (macro) cellular networks.

2.2 Licensed small cell technology

Cellular technology has evolved considerably since it was first introduced over thirty years ago, particularly in terms of its ability to handle data traffic. The latest LTE Advanced standard, commonly referred to 4th generation (4G), uses multi-carrier orthogonal frequency division multiplex (OFDM) technology, which improves performance over adverse radio paths and enables greater average throughput per base station. The standard also allows for wide radio frequency channels (up to 20 MHz for individual channels, or even greater if channel aggregation technology is deployed[26]), allowing very high peak bit rates (potentially hundreds of Mbps) to be achieved.

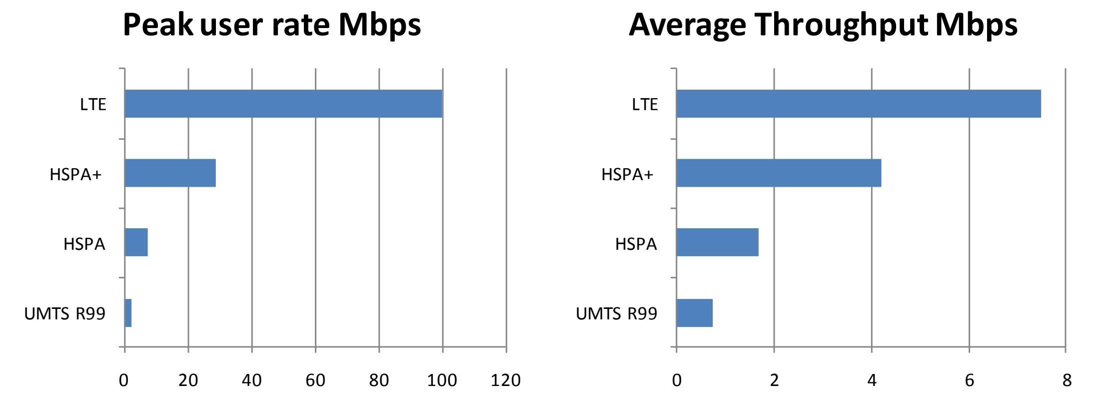
In a macro cellular network, the typical user bit rates experienced are likely to be substantially lower than this, due to contention between multiple users and the variability of the radio signal. This is because there is a relatively large number of users served by each cell, many of whom may be close to the cell edge where the signal is weaker and the available bit rate much lower.

Figure 2-1 shows how the peak available bit rate and the average cell throughput per 5 MHz carrier in a typical macro network has improved since the first 3G services were launched.

25 Monica Paolini, “Carrier Wi-Fi® for mobile operators: A TCO model assessing the cost benefits of Wi-Fi and cellular small-cell joint deployments”, Senza Fili, on behalf of the Wi-Fi Alliance, May 2013.

26 Up to 5 carriers can be aggregated under the latest LTE standards, i.e. a potential aggregate bandwidth of up to 100 MHz.

Figure 2-1: Comparison of peak bit rates and average cell throughput for 3G and 4G technology



Source: Aegis

To increase network throughput and users' quality of service, networks are increasingly looking towards implementing small cell configurations. Small cells are essentially cellular network base stations that serve areas substantially smaller than conventional cellular "macro" cells. According the Small Cell Forum, which is an industry body representing most of the major global network operators and vendors, small cells typically have a range from ten to several hundred metres, compared with a typical mobile macro cell that would range several hundred metres to tens of kilometres. Femtocells, picocells, microcells and metrocells all represent different types of small cell onto which traffic may be offloaded from the macro network.

The distinction between these different cell types is somewhat blurred, however in broad terms they can be summarised as shown in Table 2.

Table 2: Different types of cells

Type of Cell	Typical range	Typical Environment	Backhaul
Macrocell	2 – 30 km	Outdoor, wide area	Operator controlled
Microcell	200 m – 2 km	Outdoor, wide area	Operator controlled
Metrocell	Up to 200 m	Outdoor, localised or targeted coverage	Operator or third party controlled
Picocell	Up to 200 m	Indoor public locations	Mostly operator controlled
Femtocell	Up to 20 m	Indoor residential of business premises	End user of third party controlled

It can be seen that apart from the cell size, another important differentiator in the case of femtocells and metrocells is that the backhaul is less likely to be provided directly by the network operator. Indeed, when considering traffic off-load, this is probably a more significant factor in differentiating between traffic that is or is not off-loaded, in the sense that traffic carried over macro, micro and pico cells is retained entirely under the network operator's control from end to end, whereas traffic carried over metro and femto cells is more likely to rely on an external backhaul link to connect to the core mobile network. Hence the latter largely meets our definition of offload traffic in section 1.3 as “whenever the backhaul connection from the customer premises to the base station or network is not controlled by the MNO”.

2.2.1 Femtocells

A femtocell is essentially a cellular base station that provides coverage comparable to (or in some cases slightly greater than) that of a Wi-Fi Access Point and typically uses an existing fixed broadband connection as backhaul (again in a similar way to Wi-Fi). Examples of femtocell deployments include the “Sure Signal” device that is currently being marketed in the UK by Vodafone, and AT&T's “3G Microcell” product in the US. Femtocells can be deployed in both consumer (residential) and enterprise (business) environments. Femtocells operate at very low transmit powers, radiating less than 100 mW (i.e. less than a standard Wi-Fi access point) and more typically operating at powers well below 0.02 watts.

The spectrum efficiency of a femtocell (and hence the capacity that can be supported in a given amount of spectrum) is likely to be greater than that of a macro cell, especially where femtocells are deployed indoors or provide selective coverage at specific traffic hotspots. This is because there is less likelihood of overlapping coverage between two femtocells (although it should be noted that in high density femtocell networks, this may not always be the case). There is also a greater probability that the user will be located close to the femtocell base station and hence enjoy a higher data rate, rather than being towards the edge of a macrocell where the data rate may be an order of magnitude or more lower. A more detailed discussion of femtocell spectrum efficiency is presented in section 6.3.

One current key limitation of femtocells compared to Wi-Fi is that devices are generally operator-specific, so to provide access to all users at any location multiple femtocell base stations would be needed. It is not immediately obvious how a multi-operator femtocell could be provided, other than by deployment of multiple small cell devices (one for each operator), much as they do today on shared masts.[27] One option may be to set aside a small portion of spectrum (such as the currently unlicensed TDD spectrum in the 2 GHz 3G band) for self-co-ordinating femtocell base stations that could

27 This is, for instance, the case in the Virgin Media network described in Section 5.3.5.3.

provide roaming onto any of the licensed networks, but this would require both regulatory agreement and co-operation between the operators.

Licensed femtocells are able to operate at higher power levels than licence exempt Wi-Fi access points, providing extended coverage and better performance in challenging RF environments.[28] Conversely, Wi-Fi provides substantially higher throughput under optimal conditions than the current generation of femtocells[29] and is therefore likely to be better suited to traffic hotspots where the instantaneous volume of traffic is very high but users are generally stationary at any given time (i.e. nomadic usage).

Femtocells can be deployed in an operator's existing macro network spectrum (and indeed this is the case for most existing femtocell deployments), but this largely depends on there being a degree of attenuation between the macrocell and femtocell signals. In current deployments, where femtocells are mainly deployed in areas with poor or non-existing macro 3G coverage, this is generally the case; however, it would not necessarily be the case in an urban environment where femtocells were being used to provide enhanced capacity at traffic hotspots. In such a scenario, inter-cell interference between the femtocells and the macro network would be likely to reduce the performance and capacity of both, and it is likely that a separate frequency would be required.

Compared to Wi-Fi, femtocell deployment in licensed bands is currently very much a niche application, typically being used to compensate for coverage deficiencies on operators' macro networks; however, a number of concurrent factors suggest that this is likely to change over the next few years, potentially leading to much more widespread femtocell deployment. Factors likely to stimulate interest in femtocell deployment include:

- Availability of spectrum in the 2.6 GHz band which is ideally suited for small cell deployments.
- Increasing availability of LTE enabled devices capable of operating in the 2.6 GHz band.
- Growing demand for mobile data traffic.
- The need to improve indoor coverage of mobile networks (particularly for data access where the quality of the connection has an important bearing on the network resources that are required to support a connection).

However, growth in femtocell deployment is likely to depend on the degree of cooperation between networks, since users are unlikely to want to deploy multiple

28 Note however that most femtocells typically operate at lower power levels to minimise interference with each other and into the macro network.

29 This may not be the case in the future if higher capacity LTE devices are made available.

femtocells on their premises to support different operators. Fortunately, sharing of base station sites already widely takes place for macro cellular networks, so it is reasonable to assume that such cooperation would extend into the small cell environment. For example, in Sweden two joint ventures for 3G networks already exist (SUNAB owned by Telia and Tele2, and 3GIS owned by Telenor and 3), and there appears to be even closer co-operation in the 4G market, where Tele2 and Telenor have formed a new joint venture “Net4mobility” for deployment of a joint LTE network in the 2.6 GHz band.

Femtocells can support a variety of approaches to user access. Residential femtocells have commonly been designed with a closed-access model. This restricts their use to the owner and a nominated list of mobile numbers held in a white-list. This avoids potential abuse by uninvited or unknown users in the area, who may unwittingly use the full capacity of the femtocell and prevent access from the owner. A more sophisticated hybrid option gives priority access to the whitelist, but still allows open access to anyone for the remaining capacity.

In other cases, mostly in enterprise or outdoor environments, femtocells can be configured to provide open or semi-open access. The choice of approach depends on the service being offered; however, in all cases only registered users of the relevant mobile network may gain access, and the full authentication and security mechanisms typically used in mobile networks are applied.

2.2.2 Metrocells

Metrocells are in technological terms similar to femtocells, but are intended for deployment in public areas where traffic demand is particularly high. An open access approach is generally applied, enabling any subscriber to the metrocell network operator to gain access. One of the first deployments of LTE metrocells was by Telefonica prior to the 2012 World Mobile Conference in Barcelona. This involved the rollout of eleven metrocells in the Fira convention grounds, in addition to other traffic hot spots in the city such as the Camp Nou football stadium, the Diagonal 00 tower and the Ayre and Arts hotels. Telefonica subsequently deployed a high density 3G metrocell network comprising 1,500 small cells at the 2012 London Olympics. Metrocell deployments are increasingly based on dual mode technology, where both Wi-Fi and cellular connectivity can be provided by the same access point (see Section 2.6).

Although the term “metrocell” implies urban deployment, the same concept can also be used to extend mobile coverage to more remote areas. In the UK, for example, Vodafone has undertaken a number of trials of rural metrocells to provide coverage to remote villages. The metrocells are typically installed at outdoor locations, and have a typical range of 100 metres. The company has subsequently invited local communities to propose themselves for the scheme. The incremental cost of a rural metrocell is substantially lower than that of a large scale cell tower. The equipment deployed is essentially the same as Vodafone's indoor femtocells, but in a more robust housing because of the unsupervised outdoor location. Dedicated wireline broadband is used to ensure good backhaul connectivity. Some configuration of the neighbouring macro cell parameters was used to facilitate handover into the femtocell where possible. The success of the scheme to date has allowed Vodafone UK to expand it to a wider range of communities.

2.2.3 Radio Access Network (RAN) Sharing

One of the current limitations of licensed small cells is that the devices are operator-specific. This can limit their appeal, particularly in residential or business environments where users may subscribe to multiple networks. In public locations, it may be practical for each operator to deploy its own small cell base station, but this leads to additional costs and may make site access more complex.

RAN sharing involves the sharing of some or all of the radio access network infrastructure, and is already widely in place in macro cellular networks; however, such sharing is generally limited to passive infrastructure, such as transmission towers or power supply equipment. More recently, there have been initiatives to share backhaul infrastructure between operators, but sharing does not usually extend to the access radio equipment or spectrum.

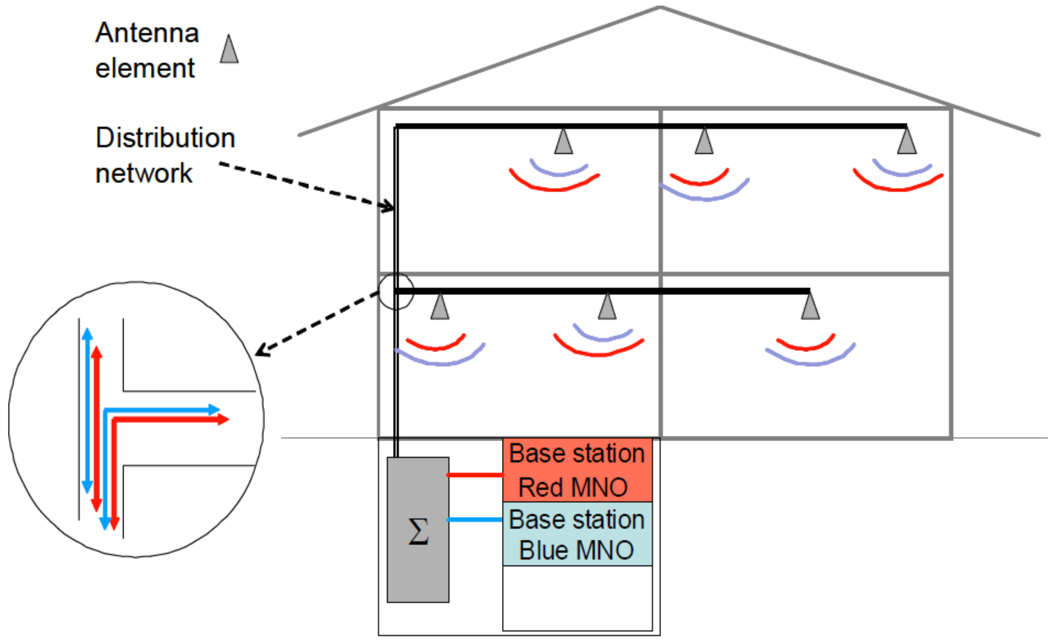
RAN sharing is likely to be particularly attractive for high density networks of small-cell base stations, for which site acquisition and backhaul installation are especially challenging. Work is under way in the 3GPP standards forum to develop the necessary standards to allow full sharing of RAN infrastructure between multiple networks, which would avoid the need for multiple base station equipment. A study in 2009 suggested that operators could benefit from cost savings of as much as 40% by adopting such active RAN sharing techniques, compared to existing passive sharing arrangements.[30]

2.2.4 Distributed Antenna Systems (DAS)

In larger premises, distributed antenna systems (DAS) may provide a more attractive solution than individual femtocell deployments for enhancing indoor coverage and capacity to support off-load. Distributed antenna systems can operate independently of the network operator or access technology. The antennas typically connect back to operator base stations, which can be co-located e.g. in the basement of the building being served.

30 See http://www.cellular-news.com/story/36831.php.

Figure 2-2: Example of a mobile distributed antenna system[31]



The approach to funding such enhancements varies. In premises where the quality of coverage is perceived as important to the owner's core business (e.g. hotels, shopping malls, and some business premises), the premises owner may decide to install and pay for such a system. More often, some form of cost sharing between the premises owner and one or more network operators is involved.

Whilst there are some similarities between DAS and managed enterprise Wi-Fi systems, it should be noted that the latter provide can provide significantly greater capacity gains than DAS. It is also arguable whether DAS constitute off-load in the true sense, since the base stations that the distributed antennas connect back to are operated by the mobile networks who would generally also be responsible for the backhaul for those base stations.

2.3 Regulatory issues relating to licensed small cells

The small cell forum has identified a number of regulatory issues pertaining to licensed small cell deployment. These include the need for appropriate base licensing arrangements and the approach taken to maintain records of base station parameters. A number of regulatory authorities have moved to support and clarify the regulatory

31 Source: Markendahl, Jan; Nilson, Mats (2010): Business models for deployment and operation of femtocell networks: Are new cooperation strategies needed for mobile operators?, 21st European Regional ITS Conference, Copenhagen 2010, http://hdl.handle.net/10419/44340.

position of small cells. For example, in June 2009, the UK regulator Ofcom clarified its approach to femtocell regulation by confirming that regulations on the provision of emergency call location and national roaming access to emergency calls applied equally to femtocell users as to macro cell users. Ofcom also proposed to vary the existing operator 3G licences to remove the requirement to keep records of the location and technical details of femtocell equipment, recognising that this may be impractical for widespread deployment of femtocells.

At a European level, the Radio Spectrum Committee (RSC) in 2008 endorsed the initial position of the Commission Services that, in view of the control which operators can exert over femtocells as part of their existing network, femtocells could operate under the existing spectrum licensing regimes of EU member states and there was no current need for the RSC to take action.[32]

2.4 Current status of Wi-Fi technology and its capabilities

Most legacy Wi-Fi equipment is based on the 802.11g standard, which has a maximum bit rate of 54 Mbps and operates exclusively in the 2.4 GHz band, though some devices also conform to the 802.11a standard, which enables access to the much wider 5 GHz band. More recent devices use the 802.11n variant which is also dual band and incorporates additional enhancements such as MIMO and the use of wider (40 MHz) channels, extending the theoretical over-the-air bit rate to as high as 600 Mbps. Further enhancements are embodied in the recently released 802.11ac standard, for example additional “channel bonding”, whereby multiple RF channels can be deployed simultaneously to extend the theoretical over-the-air bit rate to well over 1 Gbps.

After the lengthy gestation period of the 802.11n standard, the emergence of the latest 802.11ac standard has been remarkably quick. The main features of 802.11ac are:

- 80 MHz and 160 MHz channels, which means that 802.11ac is suitable only for the 5 GHz frequency band. This compares with the 40 MHz channels supported by 802.11n.
- 256-QAM modulation compared to the 64-QAM of 802.11n.
- 8 MIMO spatial streams compared to the 4 of 802.11n.

Broadcom was one of the first suppliers to implement 802.11ac in the form of its so-called 5G chipset. This has been taken up by Netgear and Belkin amongst others who have just released residential routers to the market which it is claimed will support 1750 Mbps. This is based on the simultaneous use of the 2.4 GHz and 5 GHz bands:

32 “Regulatory Aspects of Femtocells”. RSCOM(08)40, European Commission, 2008.

- 5 GHz supporting 1300 Mbps in an 80 MHz channel bandwidth using 256-QAM and 3x3 MIMO (802.11ac).
- 2.4 GHz supporting 450 Mbps in a 40 MHz channel bandwidth using 64-QAM and 3x3 MIMO (802.11n).

Even higher data rates are promised by the 802.11ad standard which is based on the WiGig Alliance specification. This standard uses the 57 – 66 GHz frequency band for very high bit rate short range communications. The frequency band is divided into four 2.16 GHz wide channels each of which supports transmission speeds of up to 7 Gbps using OFDM. A lower power consumption single carrier option supports speeds up to 4.6 Gbps. This technology is likely to be effective over short ranges (a few tens of metres) where there are few or no physical obstructions, but is unlikely to be suitable for covering entire buildings.

Note that all the bit rates referred to are theoretical maximum over-the-air rates that include signalling and control overheads, optimal signal conditions and exclusive access to the radio channel. Actual usable bit rates (often referred to as “throughput”) in practice may be substantially lower, especially at busy locations with a large number of users or where the user is some distance from the access point.

By way of example, Table 3 compares the theoretical maximum over-the-air bit rates for typical equipment with typical usable data rates, based on measurements carried out on a range of vendors’ equipment.

Table 3: Comparison of headline over-the-air bit rates with typical measured useful bit rates[33]

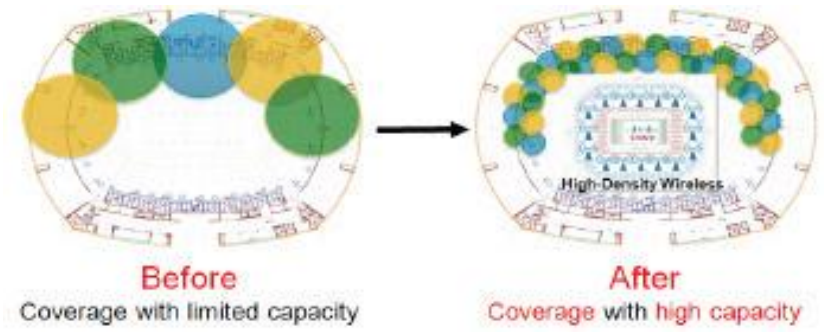
No. of 802.11n MIMO streams	Headline over the air bitrate		Best measured throughput	
	20 MHz	40 MHz	20 MHz	40 MHz
1	65 Mbps	150 Mbps	30-40 Mbps (46-61%)	50-60 Mbps (33-40%)
2	130 Mbps	300 Mbps	60-70 Mbps (46-54%	70-80 Mbps (23-27%)
3	217 Mbps	450 Mbps	75-85 Mbps (35-39%)	90-100 Mbps (20-22%)

It can be seen that the typical achievable throughput rates are at best just over half the nominal headline over the air rate, and that the percentage of the headline rate diminishes considerably further for wider RF channels and multiple MIMO streams. This probably reflects the limitations of MIMO in terms of its ability to achieve completely orthogonal transmission paths for the separate beams, together with a greater likelihood of interference being present in a wider bandwidth channel.

33 See Small Net Builder (www. smallnetbuilder.com/wireless/wireless-basics/31083-smallnetbuilders-wireless-faq-the-essentials).

Although most Wi-Fi deployments (especially in the home) use single access points, large enterprise or public access networks may use multiple access points equipped with smart antenna technology and advanced traffic management protocols to maximise capacity across the network. Such systems are typically deployed in situations where very high volumes of traffic are anticipated, such as sports stadia or transport hubs. By using densely packed access points and intensive frequency re-use, a very high data capacity can be achieved, as illustrated in Figure 2-3.

Figure 2-3: Illustration of Cisco's "Connected Stadium" high density Wi-Fi solution



Source: Cisco

2.5 Coverage and capacity considerations

One of the key differences between conventional macro cellular networks and Wi-Fi is that the former can deploy much higher power levels and are consequently able to provide much greater coverage from each base station compared to a typical Wi-Fi access point. This reflects the different status of the spectrum – cellular networks operate in licensed spectrum where the operator has control over the interference environment, whereas Wi-Fi operates in collective use bands where individual users have no little or no control over interference levels. Wi-Fi coverage is further constrained by its current limitation to bands above 2 GHz, whereas most cellular networks have access to frequencies below 1 GHz which have much more favourable coverage characteristics. The difference in terms of the infrastructure required to provide continuous coverage is significant, as illustrated in Figure 2-4.

Figure 2-4: Estimated number of 3G cell sites and Wi-Fi Access points required to cover the City of London, based on typical cell sizes and access point ranges

Source: Aegis

Whereas the central business district of London can be covered by as few as 12 conventional macro cells (even in the relatively high frequency 2 GHz band), over 450 Wi-Fi access points would be required to provide contiguous outdoor coverage over the same area. Of course, the much denser Wi-Fi network would have a correspondingly larger network capacity making the small cell approach more attractive in areas where traffic density is particularly high.

2.6 Dual Mode Small Cell systems

Given the current uncertainty about the future of the small cell market, there is growing interest in the deployment of systems that can accommodate both Wi-Fi and femtocells in the same hardware. One of the pioneers of such a “heterogeneous network” (or “hetnet”) approach is Ruckus, who have already shipped a large number of dual mode access point to operators such as Telefonica and Virgin Media. Another key player in this area is Ericsson, who recently acquired Wi-Fi hotspot specialist BelAir to advance its own hetnet strategy.

The objective of dual mode hetnet technology is to enable operators to manage Wi-Fi access points as if they were any other mobile network cell, and to tightly integrate small cells into their network hierarchies without the risk of interfering with each other or the operator’s existing macro network. Dual mode access points also enable the same backhaul and network management to be applied to both Wi-Fi and licensed small cell connections. As a result, cellular operators are able to install small cell infrastructure and to initially use Wi-Fi to provide additional capacity where needed, supplementing this with licensed small cells when additional spectrum has been acquired. Fixed network operators such as Virgin Media and COLT have also identified hetnets as an opportunity to provide a managed small cell service that enables them to provide Wi-Fi directly to end users whilst simultaneously offering a wholesale platform for cellular operators who have spectrum for licensed small cells but do not have the necessary infrastructure and backhaul in place.

The small cell forum has highlighted a number of key benefits that arise from complementary licensed small cell / Wi-Fi deployment, including:

- Leveraging the increasing range of support in mobile devices for various combinations of 3G, 4G and Wi-Fi
- Operator-managed services with enhanced Quality of Service and differentiated capabilities over multiple simultaneous radio bearers
- Better device battery life and
- Ability to use the full range of radio spectrum – both licensed and unlicensed - at a given location.

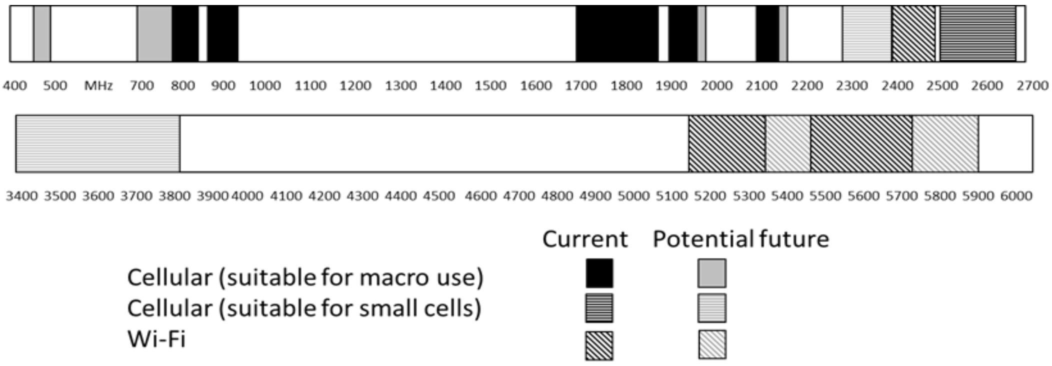
A new study by Senza Fili finds that dual mode deployment offers significant cost savings in comparison with deployment of 3G or 4G cells alone.[34]

2.7 Comparing cellular and Wi-Fi spectrum availability

Figure 2-5 shows the harmonised European frequency bands currently available for cellular and Wi-Fi deployment along with some examples of potential future candidate bands for such services. In addition to the bands shown the 1.4 GHz band (1452-1492 MHz) has also recently been mooted as potential additional mobile broadband spectrum.

34 Monica Paolini, “Carrier Wi-Fi® for mobile operators: A TCO model assessing the cost benefits of Wi-Fi and cellular small-cell joint deployments”, Senza Fili, on behalf of the Wi-Fi Alliance, May 2013.

Figure 2-5: Frequency bands for cellular and Wi-Fi in Europe



Source: Aegis

In total, there is currently 2 x 270 MHz of paired spectrum available for cellular deployment in the bands between 800 MHz and 2.6 GHz. An additional 85 MHz of unpaired spectrum is also available along with up to 400 MHz of spectrum in the 3400 - 3800 MHz band, although part of the latter is likely to be constrained by the need to protect existing satellite services. By comparison, there is a total of 538.5 MHz currently available for Wi-Fi.

Feedback from wireless network operators indicates that licensed and licence-exempt spectrum are seen more as complements to one another rather than substitutes. Whilst licence exempt spectrum can provide advantages at specific locations, the lack of control over who else has access to the spectrum means it is not generally regarded as a direct alternative to licensed spectrum where quality of service is important.

2.8 Authentication and interoperability between cellular and Wi-Fi networks

One of the biggest impediments to traffic off-load to date has been the difficulty for users to transition between cellular and Wi-Fi networks. Until recently, it was generally necessary for users to log in manually to a public Wi-Fi hotspot in order to use the service. In some cases, this would require the entry of a WPA-2 key in the same way as a user's home or office connection – once entered, this would provide automatic connection in the future as long as the password does not change.

In other cases, the hotspot would provide an "open" connection whereby the client device would connect automatically once the SSID is recognised, but the user would then be required to log in via a web browser. End-users would tend to find this approach counter-productive, in that by connecting automatically the cellular data connection is disabled, but the Wi-Fi connection will not convey data until the browser log-in is complete. As a result, background data functionality (e.g. for synchronising e-mails) is lost, possibly prompting some users to disable Wi-Fi in order to maintain background connectivity.

More recently, technical improvements to the authentication process have been developed to overcome this problem and provide a more seamless network connection. These include:

- **MAC authentication:** This provides automatic authentication of pre-registered devices based on their unique MAC address. It is now commonly used by the larger public Wi-Fi networks. Typically, the user is required to download an app to their device and to carry out a one-time registration, which registers the device MAC address on the network. Thereafter, the device will automatically connect to any of that network's access points.

- **Passpoint^{TM}:** The Wi-Fi Alliance certified Passpoint^{TM} programme (part of the Hotspot 2.0 initiative) takes automatic authentication a stage further by adding features such as SIM-based authentication for Wi-Fi networks. Additional security is also provided, equivalent to the WPA-2 protocols used on enterprise Wi-Fi networks. SIM-based authentication lends itself to roaming agreements between mobile network operators and Wi-Fi service providers. A number of such roaming agreements are already in place. For example, AT&T cellular subscribers from the US can now automatically roam on the The Cloud network in the UK. AT&T also has roaming agreements in France, the Netherlands and Spain.

  Passpoint^{TM} also caters for other types of authentication, including trusted root certificates or the use of username and password credentials. Passpoint^{TM} is also sometimes referred to as Hotspot 2.0 or Next Generation Hotspot.

- **IEEE 802.11u:** Another potentially important element of next-generation hotspots, 802.11u facilitates the discovery of accessible networks where these were not previously known to a client device. When a device detects the presence of one or more hotspots that indicate support for the IEEE 802.11u protocol, the device queries each access point and in return receives a set of credentials (e.g. whether the hotspot is free or paid for and in the latter case whether a relevant roaming agreement is in place) that can be used to decide whether to connect to a particular access point. If more than one accessible access point is detected, the mobile device uses operator policy to determine which Wi-Fi network to join.

A number of companies (sometimes referred to as Wi-Fi aggregators) are currently offering roaming across multiple Wi-Fi networks. Examples include iPass and Boingo. Both companies provide managed Wi-Fi access to a wide range of international partners' hot spot access points, using secure authentication to pre-registered devices. A more detailed examination of the role of Wi-Fi aggregators in supporting mobile data traffic offload is presented in section 5.3.7

The Third Generation Partnership Project (3GPP), which co-ordinates development of cellular mobile standards at a global level has also developed specific standards to facilitate interworking between 3G mobile networks and Wi-Fi networks. Two key standards are TS 24.327, which defines the mechanism for automatic handover between cellular and Wi-Fi networks, and TS 24.234, which defines the protocols for Wi-Fi devices to connect to cellular operators' core networks. Another important development is the Access Network Discovery and Selection Function (ANDSF) standard, which is intended to extend a degree of control by mobile operators over which access network a device will preferentially attach to (this could either be the mobile network or one or more preferred Wi-Fi networks). Operators and equipment vendors are actively working on additional proprietary solutions to provide seamless switching between cellular and Wi-Fi networks. For example, Huawei has just announced trials of an integrated cellular and Wi-Fi platform in China, in which the mobile network assists in identifying and selecting the best Wi-Fi signal, thus enabling subscribers to connect to Wi-Fi without having to input their user name and password.[35]

The automated authentication enhancements referred to in this section relate to *public* Wi-Fi networks. Users will still be able to control whether to connect to a private Wi-Fi network at home or at work by manually selecting the local Wi-Fi network as they do today. It is conceivable that future automated authentication software might limit consumer choice over which public network a device connects to by, for example, preventing connection to Wi-Fi networks that are not approved by the mobile network operator; however, we would expect that the device vendors who provide the connection manager software would resist any move to restrict the choice of network access for specific devices.

35 www.huawei.com/en/about-huawei/newsroom/press-release/hw-146103-mlabgsmwcdmaWi-Fi.htm.

3 Backhaul Requirements for Mobile Data Off-load

Off-loading of mobile data to Wi-Fi or licensed small cells requires access to a suitable backhaul connection to route the data back to the core mobile network. Indeed one of the distinguishing features of each of the traffic off-load scenarios considered in this report (see Section 5) is that, unlike macro cellular networks, the backhaul network is often not under the direct control of the mobile operator. Where Wi-Fi is used for off-load or a licensed small cell network is operated by a third party network (as proposed by Virgin Media in the UK, for example, see Section 5.3.5.3) the physical backhaul link is external to the mobile operator's network. Indeed, we have identified the lack of MNO control of the back-haul as one of several defining characteristics of data traffic off-loading (see Section 1.3).

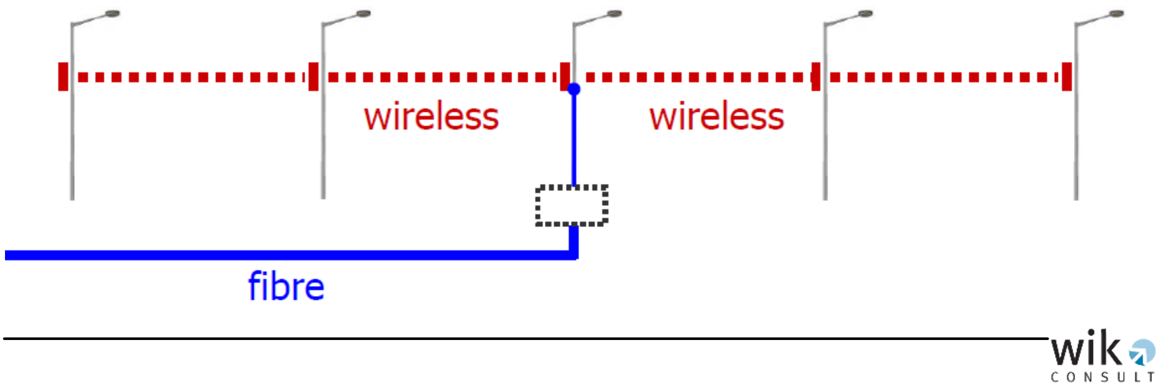
A key requirement for off-loading of mobile data traffic to small cell networks (whether using licensed femtocells or licence exempt Wi-Fi) is having access to sufficient backhaul capacity. In home and office environments, backhaul is generally provided via the existing fixed broadband connection. In home environments, this is most likely to be a cable or DSL connection, whereas in a business environment fibre access may be available. Backhauling via an existing cable or DSL connection is likely to have implications for the carriage of third party traffic (e.g. through roaming or remote access arrangements), since this could impinge on the capacity to carry the subscriber's own broadband traffic. In practice, where such backhaul facilities are used to carry third party traffic, the network can be configured to give priority to the subscriber's own traffic.

Backhaul to public small cell networks, such as Wi-Fi hotspots or metrocells can be provided in a number of ways. Most small hotspots are served by DSL or cable connections, which may either be the existing broadband connection to the premises or one or more dedicated DSL lines for the public Wi-Fi access. The latter tends to be more common where managed Wi-Fi services are provided (i.e. the hotspot is managed by a specialist wireless Internet service provider rather than directly by the owner of the premises).

The capacity provided by current DSL connections varies depending on location and whether the DSL line is dedicated or shared. A dedicated DSL connection might typically provide approximately 12 Mbps (though much higher speeds may be available in some locations where fibre to the cabinet has been deployed). In high traffic locations, multiple DSL connections may be used; for example, a separate DSL connection is sometimes provided to connect co-located 5 GHz and 2.4 GHz access points.

For larger installations where multiple access points are required, a dedicated fibre connection may be used. Fibre is also used to provide the core backhaul to outdoor MANs, with each fibre connection typically providing access to a number of meshed Wi-Fi access points or small femtocells. The meshing is most commonly achieved using wireless links, which may be either in the licence exempt Wi-Fi band itself (5 GHz), the "light licensed" 5.8 GHz band, or in a licensed point to point link band. In the future, it is likely that light licensed or licence exempt frequencies in the millimetre wave region (60 GHz and above) will be used for this purpose. There may also be a role for WiMAX or other point-to-point technologies operating in the 3.5 GHz band in supporting Wi-Fi backhaul.

Figure 3-1: Example of meshed small cell WMAN



Source: Virgin Media

3.1 Use of existing broadband for back-haul

By far the most common form of back-haul today for private Wi-Fi data off-load, and also for some forms of co-operative public Wi-Fi off-load (see below), is by means of the user's own broadband connection.

Many consumers are on flat rate plans for their fixed broadband connections, and their Wi-Fi routers are already in place; consequently, they would tend to perceive zero incremental cost for implementing private Wi-Fi off-load from the home. There are strong incentives to off-load in this way, and negligible cost.

Where a consumer chooses to open up his or her private Wi-Fi access point to third parties for co-operative off-load use, the consumer could in principle experience a performance loss due to contention with traffic from external users; however, some of the services emerging today (notably FON) mitigate this effect by prioritising the consumer's traffic ahead of that of external users (see Section 5.3.6).

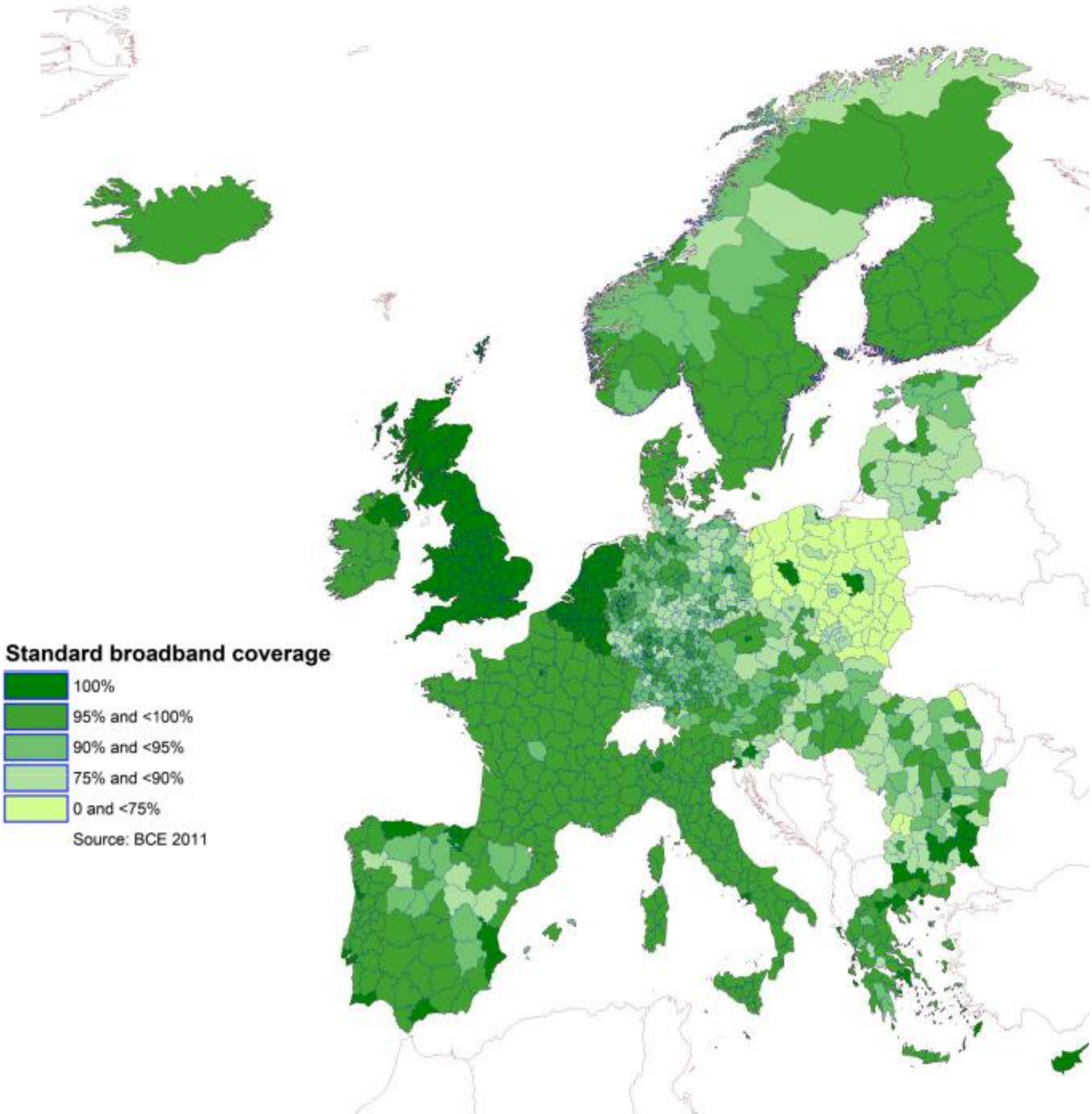
For this form of back-haul to be relevant, the consumer has to have broadband service available, generally for the fixed network. That is an imminent Digital Agenda for Europe (DAE) goal, but it may not be 100% fulfilled.

In order to achieve the second DAE objective (30 Mbps broadband for all), the consumer's back-haul obviously limits throughput, and in particular limits the burst capacity available. For co-operative data off-load solutions, third party users will obviously not have burst capacity greater than that of the underlying back-haul. Consequently, limitations in the deployment and adoption of ultra-fast (primarily fixed) broadband at the back-haul could have an important influence on the ability of these data off-load services to meet DAE objectives.

Basic broadband coverage as of 2011, and ultra-fast broadband coverage, are as depicted in Figure 3-2 and Figure 3-3, respectively.[36] Rural areas still pose challenges, particularly in some of the newer Member States in the east. Gaps in basic (under 30 Mbps) broadband are especially noteworthy in Bulgaria, Poland, and perhaps somewhat surprisingly in Germany.

36 Point Topic (2012), "Broadband Coverage in 2011".

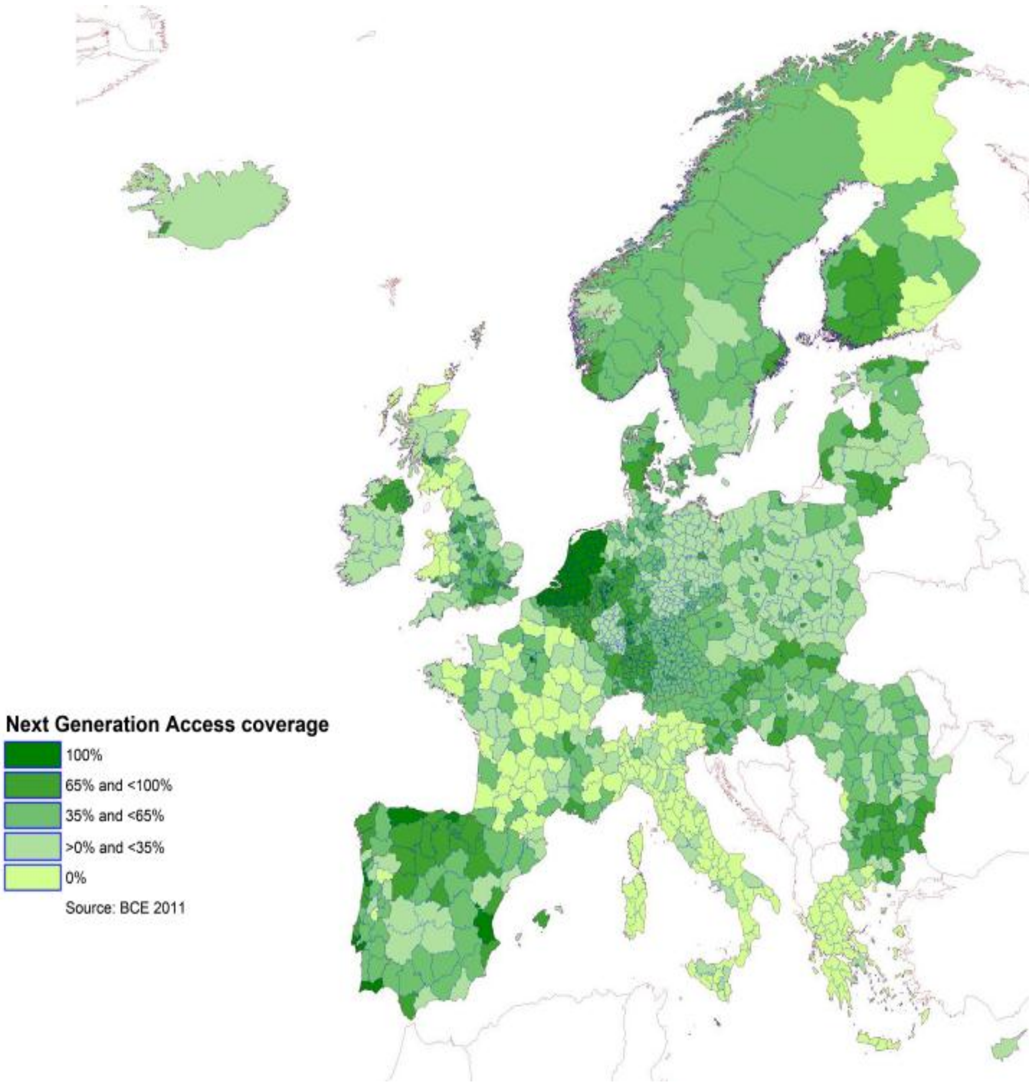
Figure 3-2: Basic broadband coverage in 2011



Source: Point Topic (2012)

For ultra-fast broadband coverage, the Netherlands, Malta and Belgium have nearly full NGA coverage today (largely due to extensive cable deployment). Some of the newer Member States have done surprisingly well, presumably because they have raced to deploy fibre-based ultra-fast broadband to address historical coverage gaps in the copper network. Conversely, some advanced western European Member States had surprisingly little ultra-fast broadband coverage.

Figure 3-3: Ultra-fast broadband coverage in 2011



Source: Point Topic (2012)

3.2 Fibre backhaul

Larger Wi-Fi networks such as the WMANs operating in the UK (see Section 5.3.5) tend to use fibre where available as the main backhaul medium, supplemented by short range radio links (see section 3.4 below). Where the networks are operated by established fixed operators such as Virgin or BT, the companies generally use their own fibre infrastructure. In other cases, dark fibre capacity may be leased from other providers. For example, The Cloud's outdoor network in the City of London is served by a mix of BSkyB's own fibre and dark fibre capacity leased from COLT.

Where access to fibre backhaul is expensive or unavailable, off-load operators are obliged to find other alternatives. This was, for instance, cited as an issue by O2 in the UK, who in consequence make extensive use of lower cost alternatives such as ADSL+.

3.3 Importance of having access to backhaul capacity

The availability and cost of backhaul capacity is likely to have a significant impact on the extent to which traffic can be off-loaded from mobile networks in the future, particularly in public environments. In the home and work scenarios backhaul is generally provided by the existing broadband connection, as we have seen, and one might expect the cost of any additional capacity required to support off-load (e.g. by upgrading to a higher tier broadband service) would be borne by the user. However, where a network is providing public access to residential or business hotspots (e.g. through FON or a similar arrangement) there may be an incentive for the network to upgrade the broadband capacity at its own expense to support any additional traffic generated.

In some public hot spot locations and particularly for WMANs, backhaul connectivity may not always be readily available and it will be necessary for a service provider either to install its own backhaul network or to call on the services of a third party provider. Established fixed or mobile operators have an advantage in this regard as they generally have existing fibre or microwave networks that can be used to provide backhaul capacity. Short range wireless links can be used to connect individual access points or small cell base stations to the nearest fibre point.

In urban areas there is often a choice of provider for fibre backhaul, but availability may be more limited in suburban or rural areas (though we would expect this situation to improve as the as the DAE rollout progresses). In more remote locations, satellite backhaul links may be used to support small cell deployments. For example, Informa recently assessed the business case for deploying rural small cells combined with satellite backhaul to extend rural mobile broadband coverage in the UK, as an alternative to expanding the macro cellular network. The analysis concluded that despite having high OPEX requirements, satellite backhaul provides payback in two years and other financial metrics are also very positive.[37]

3.4 Role of Wireless Technology in providing small cell backhaul

Whilst a fibre connection to the core network is likely to be required in many cases, particularly for larger hotspot or WMAN deployments, it will generally not be practical nor economic to run fibre directly to individual access points or small cell base stations. Instead, it is likely that wireless technology will be used to connect individual sites back

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37 See “Satellite backhaul for rural small cells”, Informa Telcoms and Media 2012.

to a fibre hub. An example of such an approach used by Virgin Media in the UK was shown in Figure 3-1.

In some cases, licensed microwave links could be used to provide these wireless links; however, microwave links require a clear line of sight, and can incur high commissioning and licence fee costs. An alternative approach that is being used by a number of operators is to use Wi-Fi technology itself to provide the wireless backhaul. For example, Ruckus has developed point to point and point to multipoint Wi-Fi systems that are intended to provide backhaul for both Wi-Fi and licensed small cell networks. The technology uses adaptive directional antennas with smart meshing and predictive channel management to optimise throughput and reliability. Costs are substantially lower than with conventional licensed microwave equipment. Whilst this is clearly an attractive option for service providers, it is likely to create additional demand for Wi-Fi spectrum to support both the access and backhaul elements.

Another effective short range backhaul solution where a line-of-sight path does exist between access points or base stations is to use mm-wave links operating in frequency bands above 50 GHz. The abundance of spectrum in this range (19 GHz in total) means gigabit capacities can easily be accommodated and the compact antennas are ideal for linking dense networks of small cells such as those deployed on lamp-posts and other street furniture. The Wireless Gigabit (Wi-Gig) alliance is developing global standards under the IEEE 802.11ad umbrella for licence exempt links in the 57 – 66 GHz band, which will operate in a similar manner to existing Wi-Fi technology and provide connectivity over distances of hundreds of metres. Licensed links may be operated in the 70 / 80 GHz bands, comprising 2x10 GHz in total and catering for longer distances of up to a few km. Typically a “light licensing” or registration regime operates in these bands rather than the stricter and more expensive licences issued in microwave fixed link bands.

Where a line of sight path does not exist, spectrum below 5 GHz is likely to be needed and the existing 3.5 GHz band could fulfil a useful role in providing small cell backhaul.

4 The volume of data traffic potentially available for off-load

In this chapter, we discuss, the traffic potentially available for off-load (and some newly identified challenges in estimating it), together with the factors influencing the level of off-load. Traffic off-load is far more widespread than we would have assumed at the outset of the study, as we explain in Section 4.1. Our estimates of the volume appear in Section 4.2.

4.1 Surprisingly rapid adoption of off-load

Our expectation at the outset of the study, based in part on estimates of the level of traffic off-load from sources such as the Cisco VNI (2012), was that take-up of traffic off-load by consumers would prove to be small relative to the total volume of mobile traffic, largely due to possible inconvenience of enabling off-load. As we explain in this chapter, the data sources that we have studied seem to demonstrate instead that consumer use of traffic off-load is extremely widespread.

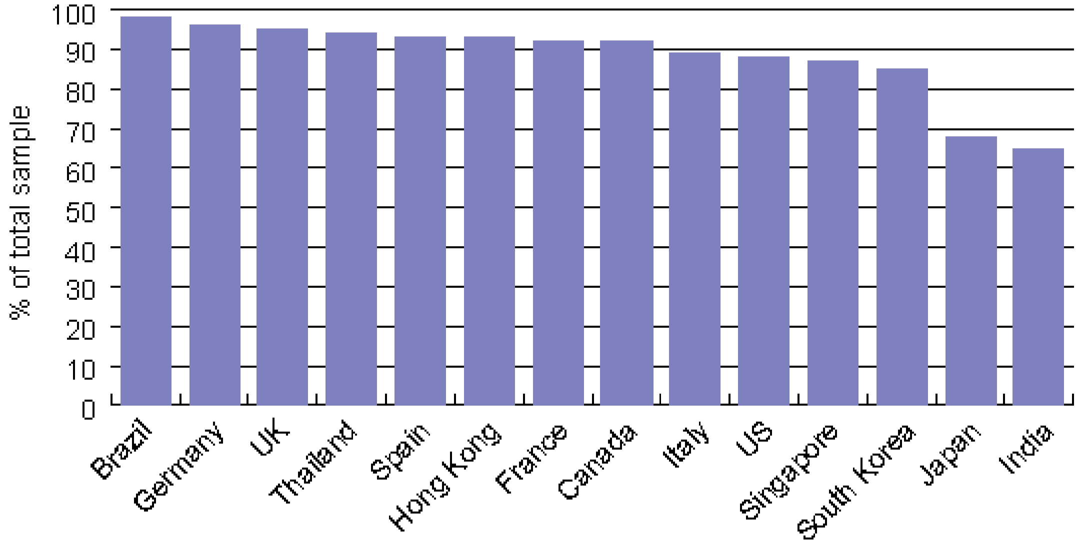
For the end-user, traffic off-load may require minor reconfiguration of the end-user device. For a device in the home, the user must be aware of the option of using a Wi-Fi router that often is already installed, and needs to configure the end-user device (e.g. smartphone) to recognise the router (which may involve setting an SSID, a password, whatever). Multiple sources suggest that most European consumers who have smart phones, under the strong incentives of capacity limitations, data caps, and tiered pricing plans, have already surmounted this hurdle, as we explain shortly.

When a user is moving or travelling, even if an off-load capability is available, its use depends not only on the ability of the device to recognise and use the capability, but also on a commercial arrangement with the provider. The most familiar example is nomadic use of Wi-Fi in one’s hotel room. Many users are now experienced with configuring their laptop computers to find the hotel’s Wi-Fi service, and with entering a user id and password so as to ensure that payment proceeds properly.

As noted in Section 2.8, technological and market solutions have emerged. Techniques such as MAC authentication and Passpoint™ can greatly simplify authentication and hand-over for public data off-load services.

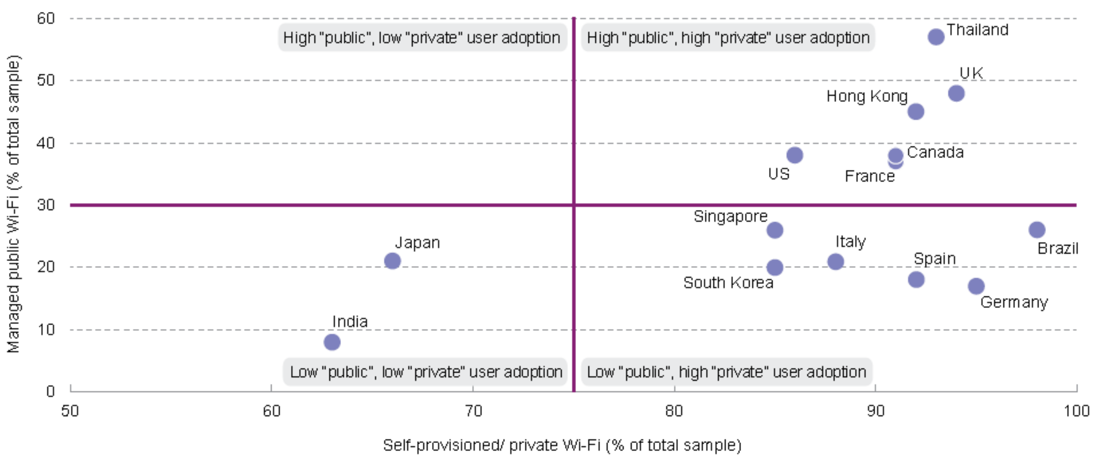
Apparently, users are getting past these impediments, at least for private (e.g. home) Wi-Fi use, and we feel that they are likely to get past them for public Wi-Fi use as well. In the case of Android smart phones, a recent study by Informa and Mobidia found that the use of Wi-Fi exceeded 90% in developed European countries.

Figure 4-1: Percentage of Android phone users who use Wi-Fi (January 2013)



The same Informa / Mobidia study found a significant number of Android smart phone users who had connected at least once during the month of January 2013 to a public Wi-Fi service; however, while the numbers varied greatly from one country to the next, in no case were public (managed) Wi-Fi connections as widely prevalent as private (self-provisioned) Wi-Fi connections. In any case, it appears that users are able to get past the user convenience impediments.

Figure 4-2: Managed vs. self-provisioned Wi-Fi adoption by country (January 2013)



One might have anticipated that these user convenience issues would be analogous to those that pertain to international mobile roaming. Work-arounds to high mobile roaming costs have been available for a decade, but the tendency has been for only highly motivated and highly knowledgeable consumers to avail themselves of them. Work-arounds to expensive mobile roaming have tended to be a niche solution, not a mass market solution.

Based on usage data such as that depicted in Figure 4-1 and Figure 4-2, however, traffic off-load solutions seem to be following a quite different trajectory than that of international mobile roaming solutions. The technical solutions seem to be sufficient, and consumers are motivated to use them.

4.2 Estimating the magnitude of traffic off-load

The starting point for this part of the work is an estimation of the volume of data traffic that would be mobile in the absence of any off-load. In network design and analysis, one typically starts with an estimate of the *offered load* that would be present in the absence of constraints.

The Cisco Mobile VNI data represents, in our view, a good estimate of mobile data traffic *net* of off-load; however, we have less confidence in their estimates of the amount of mobile data off-load, which neither the fixed nor the mobile operators can directly measure. Our approach has therefore been to “triangulate” among multiple data sources in order to obtain a clearer picture of the level of off-load already taking place.

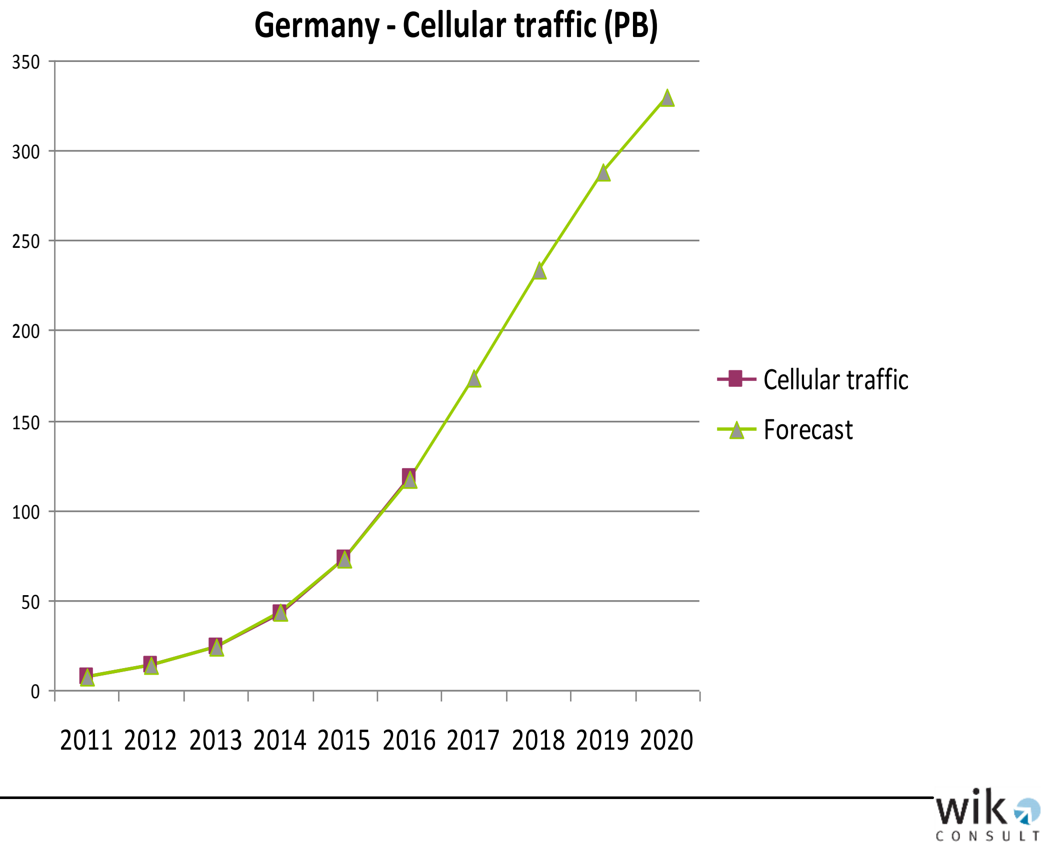
Our analysis reflects groupings of the “Big Five” Member States: Germany, France, the UK, Spain, and Italy. Data at Member State level does not appear in Cisco’s publications, but data on these Member States can be extracted from their online database. The Annex to this report contains figures that depict the results for Germany, Spain, the UK, and Italy.[38]

Our time window for this study runs until 2020 and beyond, while Cisco data covers the period to 2016 or 2017. We have therefore extrapolated the Cisco data forward using a so-called “logistic curve”. This is a standard technique in forecasting technology take-up. The logistic curve recognises that year over year growth does not remain constant in percentage terms, but tends to decline as products and services reach maturity and markets approach saturation. This has visibly been the case with Internet fixed traffic,[39] and appears to be the case for mobile Internet data as well. A projection to 2020 of total mobile traffic for Germany, for example, appears in Figure 4-3.

38 Note that the data used was viewed in March and April 2013, and did not yet reflect the revisions of February, 2013.

39 See for instance J. Scott Marcus and Dieter Elixmann: "Re-thinking the Digital Agenda for Europe (DAE): A richer choice of technologies", report on behalf of Liberty Global, September 2012, available at: http://www.lgi.com/PDF/public-policy/LGI-report-Re-thinking-the-Digital-Agenda-for-Europe.pdf.

Figure 4-3: Cisco VNI estimates for mobile Internet traffic in Germany projected forward to 2020



Source: Cisco VNI (2012) data, WIK calculations

Our assessment of spectrum needs later in the report reflects logistics curve extrapolations of this type to 2025 for France, Germany, Italy, Spain and the UK.

The Cisco VNI includes a rough estimate of the degree of data traffic off-load; however, their estimate of data traffic off-load does not suffice for our purposes. First, they provide only a global estimate, while we require country-specific estimates that clearly cannot be assumed to be the same; second, their estimate seems to be implausibly low, at least in regard to some of the more advanced European Member States.[40] We have therefore developed our own Member State-specific estimates.

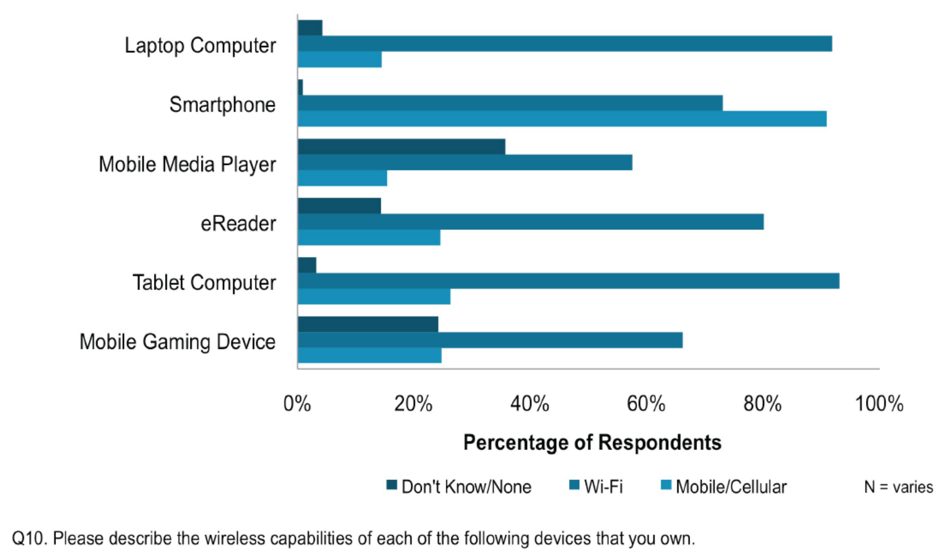
The level of off-load that is possible clearly depends on many factors, some of which are in rapid flux just now, including:

40 Given the lower presence of Wi-Fi hotspots in some other regions of the world, and the lower penetration of the fixed network in developing countries, the estimate may possibly be correct for the world as a whole.

- The nature of the end-user's device, and in particular the combination of network connections it supports (Wi-Fi, the mobile network, and/or the fixed network);
- Where the user is, and whether he or she is moving or stationary at the time (i.e. mobile versus nomadic use);
- Whether the user is in a location where Wi-Fi or a small cell is available; and
- The willingness and ability of the end-user to utilise off-load.

By 2012, the vast majority of smartphones had Wi-Fi capability (see Figure 4-4). For smartphones shipping today, Wi-Fi capability is nearly universal. For tablets, laptops, and a range of other devices, Wi-Fi connection to the Internet is more common than a direct mobile connection.

Figure 4-4: Device network connectivity (owned device)

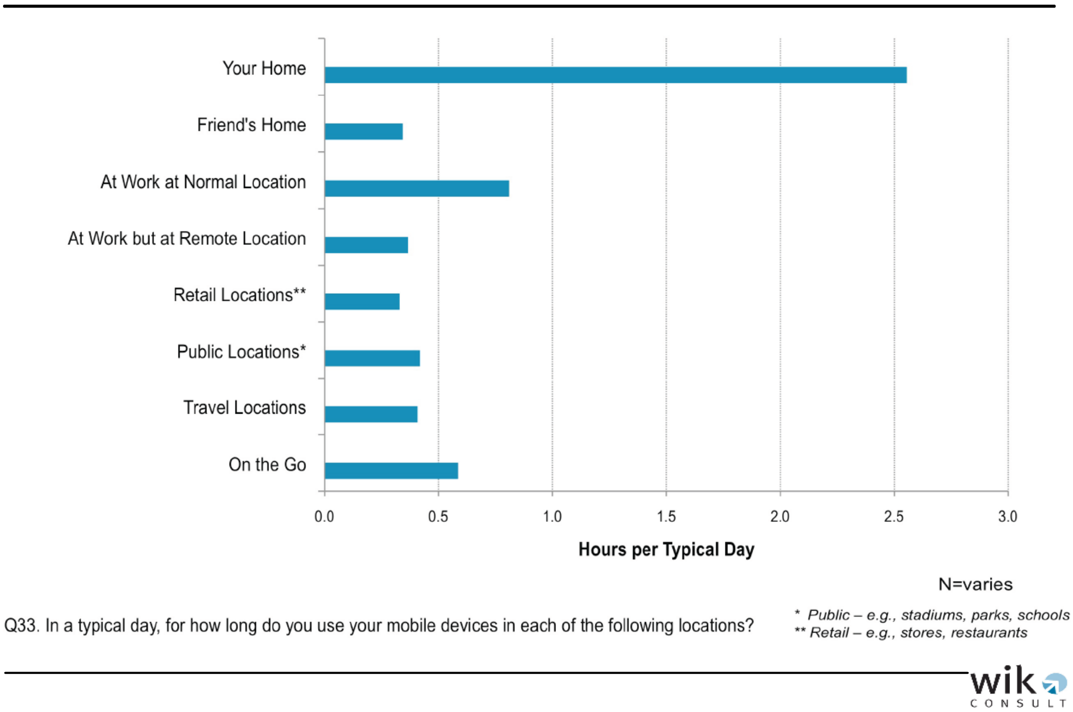


Source: Cisco IBSG (2012)[41]

Survey data suggest, perhaps counter-intuitively, that most smartphone use occurs at home. Relatively little smartphone data usage is truly mobile. Consumers report using their mobile devices some 2.5 hours per day at home, versus a mere 0.5 hours per day while on the go (see Figure 4-5). This implies that the opportunity for mobile data off-load to Wi-Fi is large. As we saw in Section 4.1, European consumers are availing themselves of these opportunities.

41 Cisco Internet Business Systems Group (2012), Stuart Taylor and Andy Young, The New World of SP Wi-Fi: Cisco IBSG Research Uncovers What U.S. Consumers Want from Wi-Fi and Mobile.

Figure 4-5: Average daily device usage by location



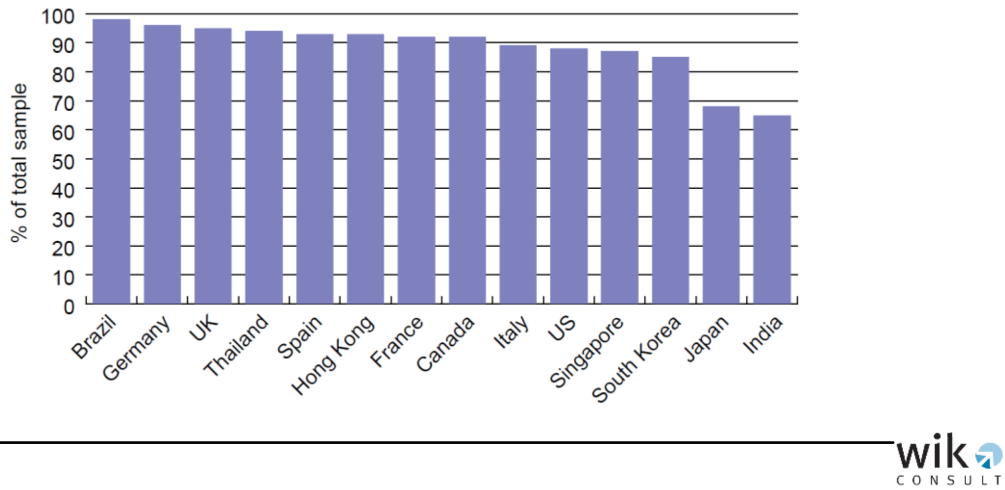
Source: Cisco IBSG (2012)[42]

Mobidia data collected from Android smartphone users demonstrate that users are increasingly comfortable with the use of Wi-Fi off-load.[43]

42 Cisco Internet Business Systems Group (2012), Stuart Taylor and Andy Young, The New World of SP Wi-Fi: Cisco IBSG Research Uncovers What U.S. Consumers Want from Wi-Fi and Mobile.

43 The use of femtocells/picocells is presumably even more transparent to the end-user, but experience is still small compared with that of Wi-Fi.

Figure 4-6: Penetration of Wi-Fi adoption of users, by country (2013)



Source: Informa/Mobidia (2013)[44]

It is also worth noting that the use that consumers make of Wi-Fi off-load is different from their normal mobile use of the same smartphones. This presumably reflects both (1) the greater speed of Wi-Fi, and (2) price sensitivity to mobile data plans that are tiered or have usage caps. Mobidia data show that YouTube and downloads are far more common at home than when using the macro cellular network.

Table 4: Top five smartphone applications by absolute traffic volumes (MB) as of January 2012 in the UK

Rank	Cellular	Wi-Fi	Roaming
1	Browsing	Browsing	Browsing
2	Facebook app	YouTube	Facebook app
3	Tethering	Video and audio streaming	Google Maps
4	YouTube	Downloads	E-mail
5	Downloads	iPlayer	Tethering

Source: Informa/Mobidia (2012)[45]

The increased use of bandwidth-hungry applications on private Wi-Fi (presumably especially at home) rather than over the cellular network means that the Wi-Fi off-load

44 Informa (2013), "Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience: A global analysis of smartphone usage trends across cellular and private and public Wi-Fi networks".

45 Informa (2012), "Understanding today's smartphone user: Demystifying data usage trends on cellular & Wi-Fi networks".

plays a substantially greater role, in terms of the per cent of total smartphone traffic, than the number of users alone would suggest.

The prevalence of Wi-Fi at home is thus a critical driver of Wi-Fi off-load, and leading Europe countries are among the global leaders by this measure. The UK, France and Germany have among the highest household penetration of Wi-Fi in the world.

Table 5: Wi-Fi penetration of households: 17 selected countries in 2011

Wi-Fi Household Penetration %	2011
South Korea	80.3%
United Kingdom	73.3%
Germany	71.7%
France	71.6%
Japan	68.4%
Canada	67.8%
Italy	61.8%
USA	61.0%
Spain	57.1%
Australia	53.8%
Czech Republic	31.6%
Mexico	31.5%
Poland	28.0%
Russia	22.9%
China	21.8%
Brazil	20.4%
India	2.5%

Source: Strategy Analytics Connected Home Devices service, April 2012[46]

One dramatic new result by Informa, together with Mobidia, shows data off-load as already comprising the majority of potentially mobile traffic,[47] albeit substantial differences exist from one country to the next.

The data need to be interpreted with caution, however, first because they are available only for Android smart phone users (who are not representative of all mobile users, as we explain shortly), and second because it may well be that the users who chose to install the Mobidia application, and chose to make their statistics available to Mobidia, may have different characteristics than those of mobile users in general. It might well be

46 At http://www.strategyanalytics.com/default.aspx?mod=pressreleaseviewer&a0=5193.

47 Informa, "Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience: A global analysis of smartphone usage trends across cellular and private and public Wi-Fi networks", February 2013.

that they are more sophisticated, or that they are heavier users of data, or that they are heavier users of data off-load.[48]

At the same time, the sample size is large, which provides some comfort, and Mobidia claims that their service provider customers have validated some of their results using deep packet inspection (DPI) and other tools. As we explain shortly, the Mobidia data are also consistent with data from a Cisco handset-based application. All things considered, we believe that the Mobidia / Informa data are important, and open a useful new window into Wi-Fi based mobile data off-load.

The data are undeniably striking (see Figure 4-7). First, it is clear that self-provisioned Wi-Fi represents more than three quarters of all Android smart phone traffic in France, Germany, and the UK (slightly less in Italy); and second, managed and presumably public Wi-Fi traffic does not significantly exceed 2% anywhere today except Thailand.

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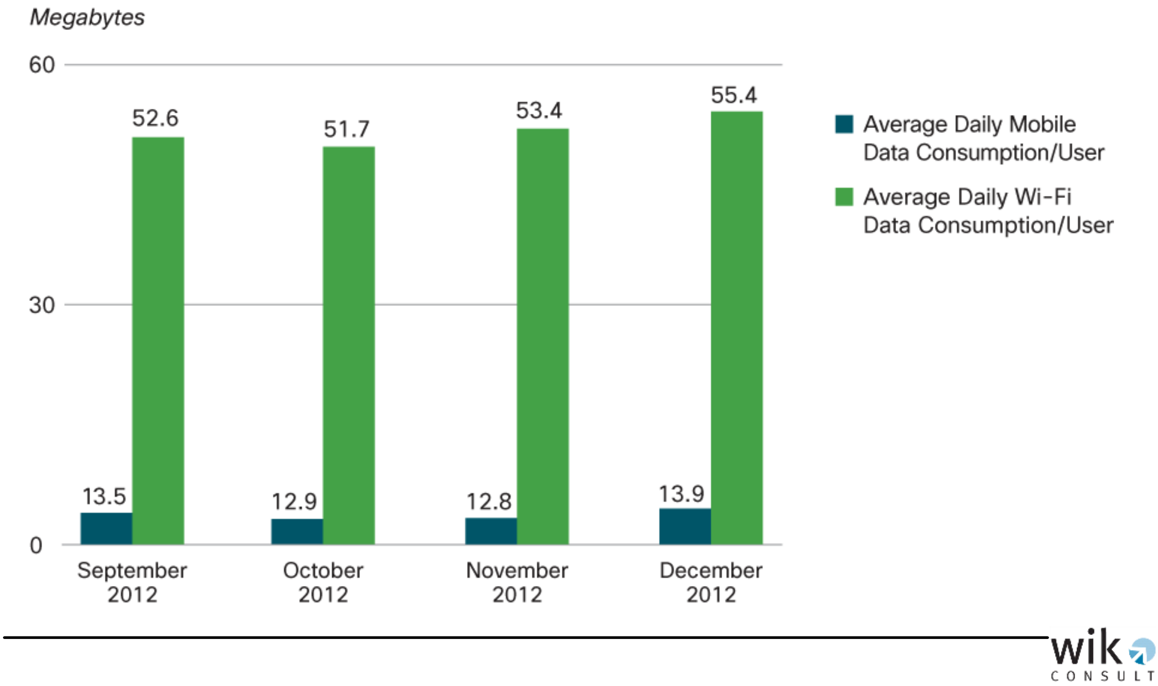
48 The study itself notes this: “The data is based solely upon active users of Mobidia’s My Data Manager application. As more than 600,000 users globally have downloaded the application and more than 30% of active users have agreed to share data with Mobidia on a strictly opt-in and anonymous basis, the sample represents a statistically significant and growing class of users that are data-usage-sensitive and savvy enough to use a dedicated application to monitor their daily data usage. This class of users does not necessarily represent today’s entire mass-market smartphone user base, but Informa believes this is a significant and growing proportion of the overall smartphone population. The sample collected refers only to smartphone users on the Android platform and does not include an analysis of users of other smartphone platforms, the users of which could display usage behaviour that varies from those outlined in this report. Finally, the data refers to smartphone data usage during the month of January 2012 only and may therefore display some level of seasonal bias."

Figure 4-7: Fraction of Android smart phone originated traffic sent over cellular, private Wi-Fi, and public Wi-Fi networks[49]

The high percentage of data off-load that is already taking place is, in our view, stunning and not altogether expected. It is, however, entirely consistent with data from a Cisco handset-based application, the Cisco Data Meter (see Figure 4-8). Cisco Data Meter statistics show Wi-Fi off-load data traffic to be roughly four times as great as conventional mobile data traffic.

49 Their measurements of public versus private Wi-Fi are based on whether an IP proxy redirect is used. Self-provisioned Wi-Fi is assumed to be private, Managed Wi-Fi is assumed to be public.

Figure 4-8: Average daily mobile and Wi-Fi data consumption

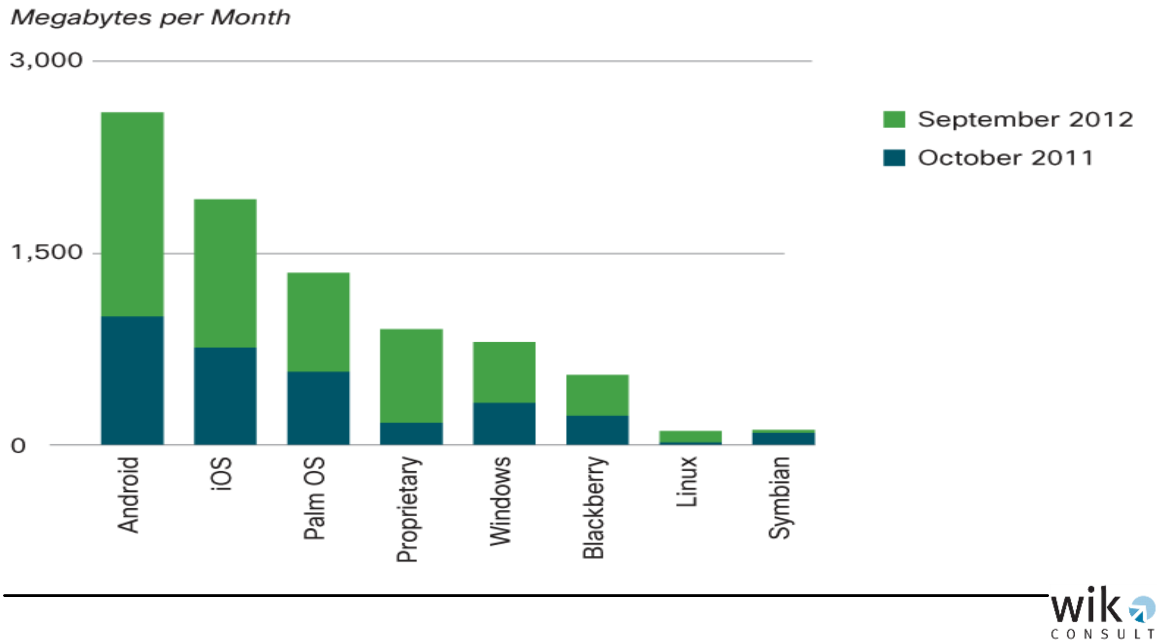


Source: Cisco Data Meter, September-December 2012

That the Mobidia data relates only to Android smart phones might imply that it is not fully representative of all mobile uses and users. Users of laptops and tablets have different characteristics from those of smart phones and not-so-smart phones, which are also different from those of machine-to-machine (M2M) communication. A separate analysis quoted in Cisco's Mobile VNI for 2013 shows that, even among smart phone users, Android users have different characteristics.[50]

50 To understand the relative magnitude of traffic from these devices, consider Figure 4-10.

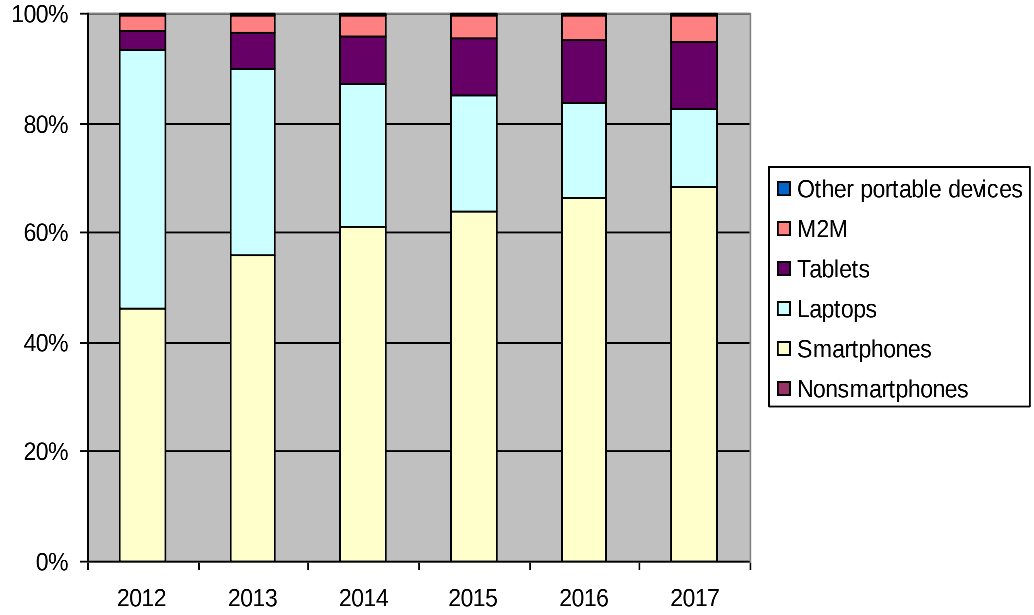
Figure 4-9: Megabytes per month by operating system



Source: Cisco Mobile VNI (2013)

To put these figures in perspective, we note that the great majority of mobile data traffic today comes from smartphones, personal computers, and to a lesser degree tablets; however, the proportion attributable to smart phones is growing rapidly, while the proportion attributable to personal computers is declining. Moreover, Android and iOS represent a large fraction of the installed base of smartphones, and must therefore represent (based also on Figure 4-9) the preponderance of smartphone traffic.

Figure 4-10: Per cent of mobile traffic attributable to different device types



Source: Cisco Mobile VNI (2013), WIK calculations

As we noted in Section 1.2, these brand new data have obliged us to re-think our understanding of data off-load. The data off-load eco-system appears to be larger, richer, and more complex than we initially thought.

In predicting the amount of Wi-Fi data off-load taking place today, both to private Wi-Fi (e.g. in the home) and to service provider Wi-Fi, our analysis has led us to trust some data sources more than others. That is reflected in our analysis. We have based our estimates on a combination of sources that we considered to be sufficiently reliable.

- **Mobile data traffic 2011-2016:** We believe that the MNOs know the traffic that is on their networks, and that the Cisco VNI (based in part on figures that ultimately derive from multiple sources including MNO data) is reasonably reliable. We think that the MNOs know far less about traffic that is off-loaded to Wi-Fi. In this report, we have extrapolated these data forward using logistics curves ("s" curves).

- **Fraction of mobile traffic contributed by different device types:** We have chosen to use the Cisco VNI estimates, and to ignore possible differences from one country to the next (about which we presently have no data).

- **Fraction of traffic being off-loaded to private versus service provider Wi-Fi:** We base our estimates on the Mobidia/Informa data, which appear to be the best available. The fraction of time spent at home, fraction of homes served by Wi-Fi, and many other variables are already reflected in these data.

In projecting the potential for off-load traffic, we have also made a number of key simplifying assumptions, including:

- We assume that off-load is relevant only to smartphones and tablets. A personal computer may or may not have a dongle for the cellular network, but we do not think that it is meaningful to speak of "mobile data off-load" for a personal computer. Personal computers have always had the ability to use the fixed network, and have routinely done so.

- We have chosen to model the *offered load*. To a network designer, the offered load is the traffic that would be present in the absence of constraints (e.g. limitations of spectrum or of backhaul capacity). This is an important simplifying assumption that enables us to avoid mixing the potential off-load traffic with the potential policy interventions that address possible capacity shortfalls. We assume that these constraints have only minimal impact at current levels of mobile data off-load, i.e. offered load is not substantially different from the actual, measurable off-load traffic in 2011 and 2012.

- For analogous reasons, we disregard for now the interaction that capacity constraints might have with the total volume of traffic transmitted. For example, if traffic available for mobile data off-load were to exceed Wi-Fi off-load capacity, consumers would likely choose to use the network less rather than to consume expensive mobile bandwidth. These considerations come into the analysis, and indeed become important, later on when we consider potential policy interventions (e.g. allocation of additional licensed or licence exempt spectrum).

- We tacitly assume that the percentage of traffic off-loaded per user will remain at current levels. In the absence of capacity constraints, it might in fact have some tendency to increase over time. The off-load per user is presumably driven by multiple additional factors, including (1) the mix of devices employed by end-users, (2) the availability of hotspots and metrocells for public off-load, and (3) the price at which conventional services and off-load are offered. The mix of devices is already reflected in our estimates, and in the underlying Cisco data; any increase in the number of hotspots and metrocells is difficult to predict, and is not reflected. The fraction of traffic off-loaded to public services today is small, but presumably will grow as a proportion of the total over time.

- The elasticity response to price for Wi-Fi off-load is presumably limited by the fact that a large fraction of Wi-Fi off-load is already free (e.g. done at home); however, relative prices of small cell services versus services on the macro cellular network could influence both the balance of usage of macro cellular and small cell services, and the total volume of traffic (see also Section 8.2).[51] Estimating the magnitude of these effects would require some estimate of the evolution of mobile data prices and public off-load prices going forward perhaps ten or twelve years, as well as the price elasticity of demand on the part of consumers, all of which is in our view impractical. In ignoring this factor, our estimate might possibly be low.

- These estimates reflect Wi-Fi off-load, but do not include small cell off-load. As noted elsewhere, those volumes are small today, but are likely to grow over time. Again, our estimate might possibly be low.

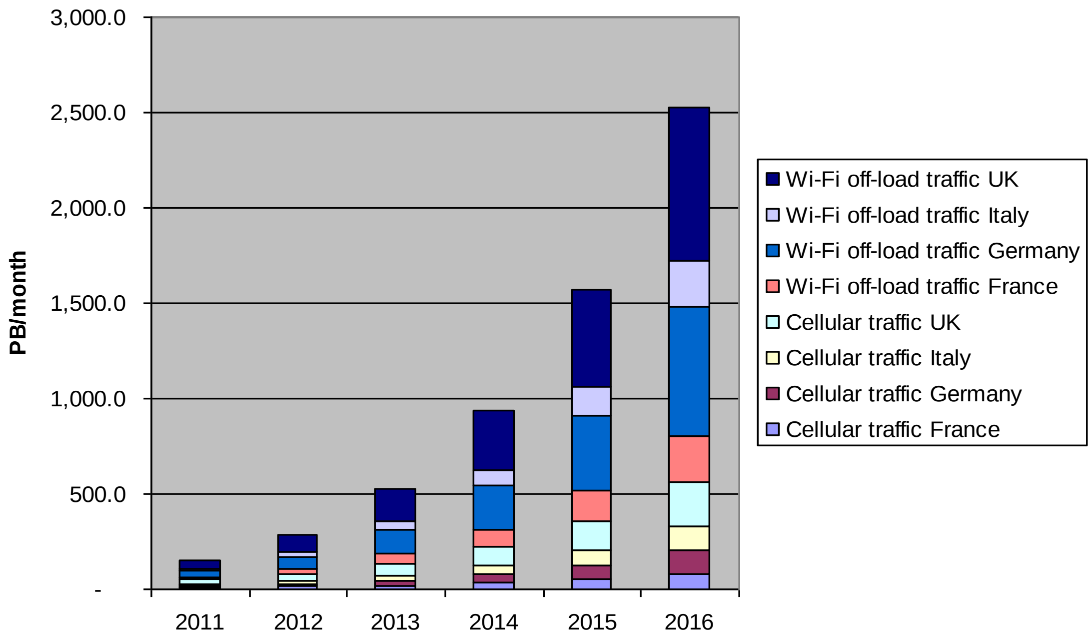
Taking all of these factors together, our rough estimates of the level of off-load for 2011-2016, which seem to us to be unexpectedly high, could be viewed as being conservative (i.e. more likely to be too low than to be too high).

Our overall estimates appear in Figure 4-11 (see also Table 13). Detailed estimates for France, Germany, Italy, and the UK appear in Section 6 of the Annex to this report. In all cases, *the off-load traffic substantially exceeds the traffic present on the cellular network*. This becomes even more pronounced over time as the traffic from personal computers declines as a percentage of total traffic, given that we assume that personal computer traffic in the absence of Wi-Fi would otherwise have been sent over the fixed network and not the mobile.

The different Member States contribute in varying degrees to these totals based on several variables, notably including (1) the level of existing or estimated mobile traffic (net of any off-load), and (2) observed tendency to off-load, which obviously reflects for instance the availability of Wi-Fi in the home and the willingness of consumers to avail themselves of off-load.

51 Demand elasticity effects along these lines probably also play a role in the claims by Telefonica/O2 that traffic increased substantially once they deployed an outdoor Wi-Fi metropolitan area network in central London which requires only a once-off registration after which connection is automatic.

Figure 4-11: Contribution of selected Member States to observed or predicted data off-load



Source: WIK

These parameters interact in complicated ways. The UK has higher mobile data traffic per capita than the other countries listed here, for instance, but the percentage of traffic off-loaded from Android smartphones and tablets is higher in Germany than in the UK. It is possible that a higher price per MB in Germany explains both differences.

5 Data traffic off-loading scenarios and business models

In this chapter, we consider typical scenarios where off-load of mobile traffic is likely to take place and the implications for the overall level of wireless data traffic. This informs our analyses of spectrum demand and socioeconomic benefits, which are presented in Chapters 6 and 7 respectively. We also consider the role that Wi-Fi aggregation services and managed small cell networks may play in supporting traffic off-load and the linkage between data traffic off-load and backhaul infrastructure.

In principle, data off-load from macro cellular to small cell networks can take place anywhere where access to a small cell network or Wi-Fi access point is available. In practice, there are three primary scenarios where off-load is most likely to take place, namely:

- In the home environment, where traffic is off-loaded to the user's home broadband connection via a residential Wi-Fi access point or femtocells;
- In the work environment, where traffic is off-loaded to the user's work broadband connection via a local Wi-Fi access point or femtocells; and
- In a public environment, where traffic is off-loaded to a Wi-Fi hotspot, femtocell or metrocell network.

The approach taken to traffic off-loading will differ in these three scenarios, with different implications for the volume of traffic off-loaded and the spectrum resource required to support traffic off-load. In each case, traffic may be off-loaded either onto Wi-Fi access points operating in licence exempt spectrum or onto small cells that use cellular mobile technology such as HSPA or LTE. Currently, the latter are required to operate on frequencies licensed to one or more mobile network operators; however, this is essentially a regulatory rather than a technological constraint in that currently all HSPA and LTE spectrum is licensed to individual operators.

The main advantage of licensed small cells from a mobile network operator's perspective is the ability to have greater control over the quality of service provided to the end-user, since the spectrum is exclusively under the control of the operator. Since the device remains connected to the mobile network, the network operator also has a greater opportunity to provide additional services, such as targeted advertising based upon the user's location. The main benefit of Wi-Fi is that it can provide additional capacity (and in some cases coverage) at negligible cost to the network operator. For fixed network operators or other wireless broadband providers, public Wi-Fi services provide an opportunity to enhance brand loyalty (by providing free or preferential access to their own subscribers) and to extend the reach of their service beyond their existing subscriber base.

Whilst in principle femtocells or metrocells using cellular technology could be deployed by parties other than mobile network operators, this is likely to be substantially more costly and complex than deploying Wi-Fi, since additional core cellular network functionality (e.g. Home / Visitor Location Registers) would be required. In consequence, there appears to be little interest in licensed small cells beyond those to whom licensed mobile spectrum is already assigned. It is interesting to note that BT, which recently acquired spectrum in the 2.6 GHz band at auction but are not currently a mobile network operator, is seeking a mobile network partner to enable it to deploy 4G small cells using this spectrum, in parallel with its existing Wi-Fi portfolio.[52]

Virtually all mobile traffic off-loading currently is onto Wi-Fi networks. This is a reflection of the relative maturity of the two technologies – Wi-Fi has been in common usage for over a decade, and billions of access points are now deployed worldwide. Cellular small cell technology by comparison is still in its infancy, though there are signs that the market is starting to expand rapidly as equipment costs fall and more licensed cellular spectrum becomes available.

A 2012 report by Strategy Analytics reported that the UK had the second highest domestic Wi-Fi penetration in the world at 73.3% of households, and that several other EU countries had penetration levels over 50%, although penetration is somewhat lower in some Eastern European countries (see Table 5, which appears in Section 4). By comparison, the largest provider of residential cellular femtocells in the UK, Vodafone, reports the number of installations as being in the "hundreds of thousands"[53], compared to a mobile subscriber base of over 20 million (see Table 5, which as noted appears in Section 4).

Informa estimates the total number of femtocell deployments globally today to be approximately 11 million[54] – by comparison, 439 million households worldwide were reported to have installed home Wi-Fi networks in 2011.[55] The percentage growth rate for femtocells is much higher than that of Wi-Fi, with Informa projecting the number to grow to 92 million units in 2016 (an eight-fold increase in four years), whereas Strategy Analytic's projection for Wi-Fi installations is approaching 800 million by 2016 (an annual growth rate of approximately 12.5 %, albeit on a far larger base). As with many statistics about the off-load marketplace, these statistics are shifting rapidly.

In the following sections, we describe how off-loading would typically work in each of the three scenarios identified and the implications of using Wi-Fi or licensed small cells for such off-loading.

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52 "BT seeks mobile partner in 4G push", Financial Times, 24 April 2013.
53 Source: Vodafone news release, 2 November 2011.
54 Informa (2013), "Small Cell Market Status", December 2013. See also Small Cell Forum, "Public access small cell market to hit US$16 billion in 2016", at http://www.smallcellforum.org/newsstory-public-access-small-cell-market-to-hit-us-16-billion-in-2016.
55 Strategy Analytics (2012), "Broadband and Wi-Fi Households: Global Forecast 2012".

5.1 Off-loading in the home environment

As noted above, mobile traffic off-load in residential environments is currently almost entirely to Wi-Fi, reflecting the high penetration of home Wi-Fi routers in many countries. Even where femtocells have been deployed, this has generally been to overcome deficiencies in coverage of the macro network rather than to boost data capacity. Indeed, the two largest providers of femtocells worldwide (AT&T in the US and Vodafone in the UK) both currently treat data carried via femtocells in the same way as data carried over the macro network for charging purposes, despite there being substantially lower data transport costs. Hence, even where a subscriber has a home femtocell, it is still often necessary to switch to Wi-Fi to avoid breaching any monthly data caps applied by the network.

Given the high penetration of residential Wi-Fi in many EU countries, it seems unlikely that there will be a strong case for widespread deployment of femtocells in homes other than where required to improve coverage. It is relatively straightforward for users to connect mobile devices to their home Wi-Fi connection. Once this has been done, the devices are able to switch seamlessly between the home Wi-Fi and mobile networks (in general the latter continues to be used for voice and SMS communication). Furthermore, the projected level of mobile data traffic, whilst growing rapidly, is likely to remain relatively small compared to fixed Internet traffic and other local in-home wireless traffic, as we discuss in the following section.

5.1.1 Wireless traffic projections in the home environment

Wireless data traffic in residential environments principally comprises four elements, namely:

- Fixed internet traffic, connected via the domestic fixed broadband connection
- Local broadband data traffic. e.g. for in-home distribution of audio-visual content
- Off-loaded mobile data traffic, backhauled via the domestic fixed broadband connection
- Local narrowband data traffic, e.g. for home automation, alarm systems, etc.

The first three of these are likely to use Wi-Fi technology operating in either the 2.4 GHz or (increasingly in the future) the 5 GHz band. Some of the fourth category uses non-Wi-Fi technology but operates predominantly in the 2.4 GHz Wi-Fi band or in other, dedicated bands such as 868 MHz.

In the following sections we discuss the likely impact of these four traffic elements on the overall level of wireless data traffic in the home.

5.1.1.1 Fixed internet traffic

Currently, the dominant source of Wi-Fi traffic in most homes is fixed Internet data; however, estimates vary as to the actual level of Internet traffic carried over the fixed networks. Probably the most oft-quoted source of such estimates is the Cisco VNI. The table below shows the estimated average and busy hour internet traffic for all of Western Europe, according to the Cisco VNI data, for the years 2011 and 2016.

Table 6: Internet data traffic estimates for 2011 and 2016

Parameter	2011	2016	CAGR
Average total Internet traffic (Terabits per second)	18	62	28%
Busy Hour total Internet traffic (Terabits per second)	36	154	34%
Number of Internet Households	117.3	126.7	1.55%
Average Busy hour bit rate per household (Mbps)	0.307	1.215	31.7%

Source: Cisco VNI

Extrapolating these growth rates to 2020 yields an estimated *average* busy hour bit rate of 3.66 Mbps per household.

Internet usage varies significantly between households, with the heaviest users consuming many times more data than low or average users. For example, according the UK communications regulator Ofcom, 10% of high speed broadband users account for 50% of the total high speed broadband traffic. The busy hour traffic for these higher usage households is therefore five times the average, which would imply an average busy hour bit rate for the highest usage decile of more than 18 Mbps per household by 2020.

5.1.1.2 Local broadband data traffic

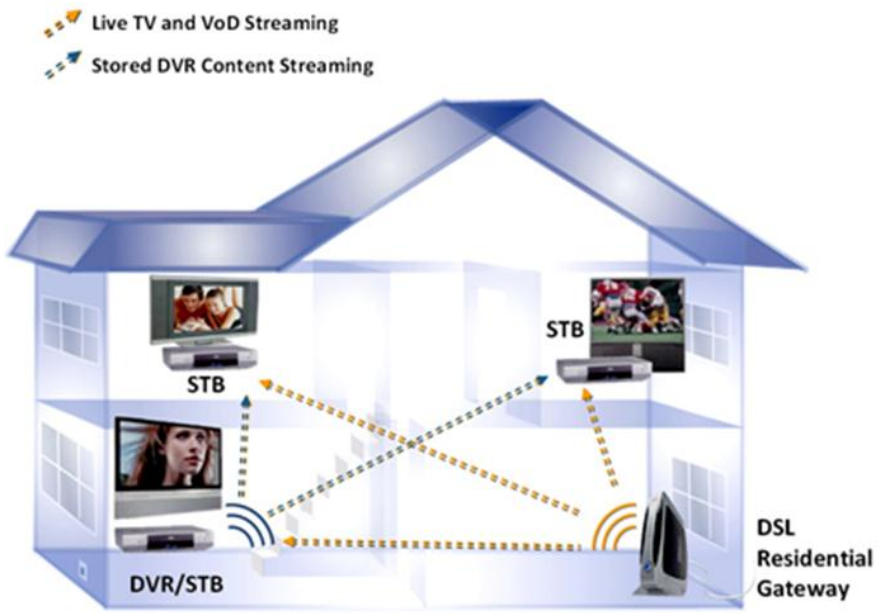
Off-network wireless data traffic may also be a significant factor in residential locations in the longer term. A number of companies are already marketing “wireless home theatre” solutions which use Wi-Fi technology to distribute high definition audio-visual content around the home. For example, Israeli company Celeno, whose backers include Cisco and Liberty Global, is marketing a product which it claims it capable of distributing up to eight simultaneous high definition video streams around the home.[56] Celeno’s products are already being deployed in Europe, for example by Bouygues Telecom in France[57] and Deutsche Telecom in Germany.[58] In Belgium, Belgacom is using Ruckus Mediaflex wireless IPTV distribution equipment, which also uses Wi-Fi, as an alternative

56 http://www.celeno.com/Products/CL1800.aspx.
57 http://www.digitaltvnews.net/content/?p=19303.
58 http://www.celeno.com/press/showPR.aspx?pr_20111206.

to indoor cabling to provide a more flexible and cost-effective approach to cable TV installation. So far, the technology has been taken up in 25,000 households.[59]

Wireless in-home video distribution is a relatively niche market currently (e.g. in Belgium about 2% of Belgacom's TV subscribers currently use the technology); however, the track record of previous technological innovations in the audio-visual sector suggests it could become a mainstream product by 2020. For example, DVD players achieved an installed base of over 100 million in Europe within seven years of launch.[60] Since a single HD video stream requires approximately 8 Mbps of bandwidth, and since it is realistic to assume a typical household may be viewing two or three independent streams at peak viewing times, this suggests such systems could over time require access to uncontended bandwidth of 24 Mbps or more.

Figure 5-1: Example of in-home video distribution system



Source: Celeno

5.1.1.3 Implications of mobile off-load for total data traffic in a home environment

In Chapter 3, we presented estimates of the total amount of mobile data traffic off-loaded onto self-provided networks, most of which is assumed to be onto home Wi-Fi connections. In Table 7 below, we use this data to estimate the busy hour off-load traffic

59 http://www.ruckuswireless.com/casestudies/belgacom.
60 Source: Screen Digest.

in each country in 2016 and to compare this with the total fixed network busy hour traffic (also sourced from Cisco's VNI).

Table 7: Estimated busy hour off-load traffic in each country in 2016 compared to the total fixed network busy hour traffic

Parameter	France	Germany	Italy	UK
Total estimated off-load traffic to self-provided Wi-Fi (PB/mo)	242.6	672.1	244.1	798.4
Total estimated fixed network Internet traffic (PB/mo)	3,900	4,400	1,900	3,500
Ratio of off-load traffic to total fixed traffic	6.2%	15.3%	12.8%	22.8%
Busy Hour total Internet traffic (Terabits per second)	29	34	14	26
Number of Internet Households (millions)	21.4	27.3	14.1	18.5
Average Busy hour total fixed traffic per household (Mbps)	1.36	1.25	0.99	1.41
Average Busy hour off-load traffic per household (Mbps)	0.08	0.19	0.13	0.32
Projected BH off-load traffic per household in 2020 assuming 50% CAGR	0.41	0.96	0.66	1.62

Source: Cisco VNI (2012), Aegis calculations

The implications for the bandwidth required in individual homes may be higher, since mobile data usage tends to be dominated by a relatively small number of users. The projected 2020 busy hour data rate for the UK (the highest of the four countries considered) is 1.2 Mbps, but if it is assumed that 10% of mobile data users account for 90% of traffic, the figure for high usage homes would be as much as five times higher, i.e. 6 Mbps.

If we assume that the highest users of mobile data are also the highest users of fixed Internet traffic and are also those most likely to be using wireless home video distribution in 2020, a potential **upper bound** on the bandwidth required to support these three services can be made as follows:

- Fixed internet bandwidth : 18 Mbps
- In-home video distribution: 24 Mbps
- Mobile off-load traffic: 6 Mbps
- **Total: 48 Mbps**

It can be seen that the proportion of traffic originating from mobile off-load (6 Mbps) is relatively small. It represents just 12.5% of the total Wi-Fi traffic.

A **lower bound** estimate can be made from the average Cisco data, and by assuming a more limited take-up of wireless home video distribution as follows:

- Fixed internet bandwidth: 1 Mbps
- In-home video distribution: 4 Mbps (assumes one HD stream per 2 households)
- Mobile off-load traffic: 170 kbps
- **Total: 5.17 Mbps**

In this case, the proportion of total Wi-Fi traffic originating from mobile off-load (170 kbps) is even lower. It represents just 3.3% of the total Wi-Fi traffic.

Note that in both cases the percentage of traffic generated by mobile off-load in the home is relatively low and hence likely to have only a marginal impact on overall demand for wireless spectrum in this scenario.

5.1.2 Using Wi-Fi for off-load in the home environment

In the home environment, the network configuration will be known to the user, and access to the network can be expected to be largely under the user's control. Once configured with the necessary authentication credentials, devices will automatically connect to the home Wi-Fi network, and assuming Wi-Fi is activated on the device this will be the default wireless connection whilst in range of the home network, rather than the macro cellular connection. In consequence, for most users of Wi-Fi enabled devices, the proportion of mobile data off-loaded when the user is in the home environment is likely to be close to 100%.

5.1.3 Using licensed femtocells in the home environment

As noted above, current home femtocell deployments have limited value as an off-load platform from a user perspective, since operators do not tend to differentiate between data carried over the femtocell and over the macro network when applying data charges and monthly caps. In the US, AT&T has claimed that regulatory requirements to monitor all data for law enforcement purposes force it to impose the same charges on femtocell off-load as on normal cellular traffic.[61] Data (along with calls and messaging traffic) is routed back to the core mobile network over a secure virtual private network (VPN) which uses the subscriber's existing domestic broadband connection. In this way, the network can ensure the security of the data carried and can maintain control of network functions such as handover between the femtocell and the macro network, even though the network has no control over the physical backhaul connection.

61 See, for example http://www.zdnet.com/vodafone-sure-signal-inside-a-femtocell-3040089380/. Some have questioned whether US lawful intercept requirements really dictate the need for the MNO to monitor mobile data off-load traffic.

A further limitation of femtocells currently is that each device is limited to a single MNO. This is in part a consequence of the VPN based backhaul arrangement. Changing this would either require operators to put in place roaming agreements to enable multi-operator access to home femtocells, or the incorporation of an active RAN sharing capability into femtocell equipment. This is likely to be cost prohibitive for the residential sector in the short term but this may change over time as the market for licensed small cells develops. Alternatively, multiple femtocells could be deployed (one for each required operator) but again this is likely to be cost prohibitive for most users.

A further factor that may have limited the widespread deployment of residential femtocells to date has been the lack of dedicated spectrum. Femtocells currently operate on the same 2 GHz frequencies as the macro 3G networks – at set-up time, the device monitors the local RF environment and selects a channel that is likely to cause the least contention to the macro network. Given that the devices have to date been used to enhance coverage rather than capacity, this has not been a problem since the devices are generally operating in areas where the macro signal is weak or non-existent; however, if femtocells were to be more widely deployed to provide off-load capability, using the same frequencies would be likely to have some impact on the capacity of nearby macro cells to support outdoor mobile traffic, particularly toward the edge of the macro cell coverage area.

The recent release of 2.6 GHz spectrum in Europe bodes well for the wider deployment of femtocells generally (see Section 3.4), although it remains to be seen whether such devices will be more widely deployed in residential environments given the near ubiquity of Wi-Fi access points, the improving coverage of macro cellular networks (e.g. by re-farming of 2G spectrum to 3G or 4G and the recent release of 800 MHz spectrum), and the likely deployment of 2.6 GHz metrocells to boost coverage and capacity in high demand areas. Qualcomm have recently suggested that the deployment of neighbourhood small cell networks, where open femtocells are deployed in homes, businesses or public areas, could provide a cost effective way to increase capacity in mobile networks.[62]

5.1.4 Off-loading third party data traffic in the home environment

Off-loading in the home environment primarily (and until recently, exclusively) involves a user connecting via his or her own residential fixed broadband connection; however, in the last few years initiatives have emerged to allow residential Wi-Fi access points to be used as proxies for public Wi-Fi hot spots, by creating a virtual connection that uses the same physical path (Wi-Fi and broadband backhaul) but maintains a clear separation between the public and private traffic.

62 Neighbourhood Small Cells for Hyper-Dense Deployments: Taking HetNets to the Next Level, 8 February 2013.

These services are addressed in Section 5.3, which deals with off-loading in public environments.

5.2 Off-loading in the work environment

In the work environment, the extent of traffic off-load will depend on organisational policy. It is likely that business data connections will be automatically routed via an internal Wi-Fi connection where this is available, but this provision may or may not extend to connection of users' personal devices. Hence the proportion of traffic off-load in many business scenarios is likely to be less than 100% (though still relatively high). The nature of off-loaded traffic in a work environment is also likely to be quite different from at home, with a lower proportion of rich multimedia content such as video streaming, resulting in a lower overall volume of off-loaded data traffic.

5.2.1 Approaches to off-load in the work environment

In an enterprise environment, off-load may take place either to Wi-Fi or to licensed small cells, although as in the home case the latter option remains relatively undeveloped at the moment. There is however growing interest in enterprise femtocells, which in addition to providing businesses with improved indoor mobile coverage also have the potential to replace inflexible desk phones, reduce calling costs, and provide higher mobile broadband speeds for corporate applications.

Unlike the residential case, many businesses are likely to require multiple access points or femtocells to provide the necessary coverage and capacity, which raises additional challenges in terms of network planning and interference management.

Larger businesses often already deploy solutions like distributed antennas (see Section 2.2.4) to optimise indoor coverage, but such solutions are likely to be out of reach of smaller enterprises because they can incur high radio planning and installation costs. Also, distributed antenna systems do not provide the capacity gains that femtocells do, since the antennas are all effectively linked to a single base station. Since femtocells make use of existing backhaul infrastructure and are essentially "plug and play" devices, costs are substantially lower. Business femtocells typically deploy higher power than residential units (because the buildings served are generally larger) and multiple cells may be deployed on a self-organising basis.

Taking these factors into consideration, it seems likely that there will be stronger growth in demand for enterprise femtocells than for residential femtocells, particularly among smaller or medium sized businesses. A recent study by Infonetics[63] found that although the enterprise femtocell segment is still very young, a number of operators are

63 See www.infonetics.com/pr/2011/Enterprise-Femtocell-and-FMC-Services-Survey-Highlights.asp.

launching enterprise femtocell solutions to improve in-building network coverage (a challenge for mobile operators that can strain relations with high-value enterprise customers). According to the study, femtocells top the list of technologies used to deliver wireless indoor coverage and capacity and show the most growth between now and 2013, followed by microcells/picocells and distributed antenna systems. Note that microcells/picocells and distributed antenna systems do not generally meet our definition of traffic off-load, because backhaul is under the control of the mobile network.

As in the residential case, enterprise femtocells may be deployed on either a dedicated frequency or on the same frequency as the macro network. They may be deployed as closed, open or hybrid cells (see Section 2.2.1). In a closed access enterprise deployment, only the enterprise users can access the femtocells, whereas in hybrid mode, any network subscriber can access the femtocells while the enterprise users have priority for getting service from the femtocell.

Larger enterprise Wi-Fi networks are more likely to benefit from additional enhancements such as co-ordination or traffic balancing between access points, but require careful planning to optimise performance and minimise interference. In large business premises where traffic levels are high, it is likely that each access point will require a different frequency channel, leading to a particularly high demand for spectrum (this is considered further in Section 6.2.2).

5.2.2 Wi-Fi traffic considerations in the work environment

Estimating traffic in a business environment is more challenging than in the home environment, owing to the wide variation in business size, nature of data traffic and premises layout. On the whole, business traffic is likely to be less dominated by high bandwidth real-time applications like HD video, and projected growth rates (e.g. Cisco VNI) are somewhat lower than for residential use.

According to the Cisco VNI (2012), business IP traffic in Western Europe is expected to grow threefold from 2011 to 2016, to a total of 3,200 PB/month, a compound annual growth rate of 20%. By comparison, total consumer IP traffic is estimated to be 21,200 PB/month, with an annual growth rate of 29%. Business traffic is therefore expected to be approximately 13% of total IP traffic in 2016. Traffic per business location is much harder to quantify since there is such a diverse range of business and premises sizes.

However, business networks typically serve a larger number of users than residential networks. A recent study by netEvidence[64] suggested that increasing use of cloud based services was leading to Internet congestion among many businesses, with as many as one in ten connections suffering regular overload at busy times. There is also anecdotal evidence that some enterprise Wi-Fi networks have suffered congestion due

64 See http://net-evidence.com/news/one-in-ten-internet-connections-are-overloaded.

to excessive data off-loading by employees. According to one report from the US,[65] several enterprise IT managers in the audience bemoaned Wi-Fi-capable smartphones because the function allowed employees to off-load their smartphone data traffic onto their office Wi-Fi network – thus clogging and slowing the entire enterprise's network. To ease the congestion, the Wi-Fi backhaul must be increased and the entire network reconfigured to address the excess traffic.

There is limited data available regarding typical traffic levels at specific business locations. Williamson et al (2013)[66] projected that by 2021 the wireless traffic generated in a typical office block would be 61 Mbps, compared to up to 100 Mbps in a typical residential scenario. We note that the latter figure is somewhat higher than we have estimated, but the estimates support our expectation that traffic density (i.e. per unit area) in business scenarios will be lower than those in home scenarios. Given that business users also have greater latitude to optimise Wi-Fi network performance by deploying enterprise technology and are also more likely to deploy licensed femtocell solutions, we expect the impact of off-loading in the work environment to have less of an impact on Wi-Fi spectrum demand than off-loading in the home environment, and the overall demand for Wi-Fi spectrum in the work environment to be lower.

One possible exception to this could be larger businesses with a large number of employees operating in an open-plan environment, where the scope to re-use frequencies may be more limited due to the lack of shielding from internal walls. In such circumstances, it may be necessary to deploy all of the available Wi-Fi spectrum in order to avoid interference between access points and obtain the optimum performance from a wireless network. Contention may also arise with any adjacent outdoor deployments (e.g. in a campus type environment).

Where smaller businesses are located adjacent to residential premises, it is likely that the same spectrum resource can be shared, since the busy hours are generally different (business busy hours tend to be in the morning and afternoon whereas residential busy hours tend to be in the evening).

5.3 Off-loading in public environments

It is likely that the growing demand for mobile data traffic, as projected by Cisco and others, will place significant strain on mobile networks in the future unless additional capacity can be provided in a cost-effective manner. Indeed, current levels of bandwidth demand from smart phones would have placed substantial strain on mobile networks had it not been for Wi-Fi off-load already occurring in the home (see Sections 4 and 7.2). Increasing the number of macro cellular sites is expensive and sometimes

65 See www.fiercewireless.com/story/enterprises-not-thrilled-wi-fi-offload-strategies/2011-05-12.

66 Op. cit.

impractical (e.g. it may not be possible to gain access to suitable sites), so off-loading traffic onto smaller licensed cells or to Wi-Fi is likely to be a more effective solution, especially at locations where mobile traffic levels are particularly high.

As we have seen, significant levels of off-load already takes place in home and business environments; however, the level of off-load is currently much lower in public environments, especially at outdoor locations or where wide area mobility is required.

Data off-load in a public environment currently differs considerably from the home or work environment in that access is less likely to an automated, seamless process and the quality and availability of connections is much less under the user's own control. A number of initiatives are under way to improve accessibility to public Wi-Fi and small cell services, but the current situation is that the volume of traffic off-loaded to public small cell networks or hot spots is a very small proportion of the total mobile data traffic carried over private (residential and business) Wi-Fi connections. For example, in the UK, the regulator Ofcom reported that in 2012[67] that the volume of data carried over hotspots operated by the large public Wi-Fi operators[68] was only 3.8% of the total traffic carried over the four UK cellular mobile data networks. Note however that this figure does not include traffic carried over BT's 4 million FON hotspots or independently managed hot spots.

Ofcom suggested a possible reason for the low traffic levels on public hotspots may be the complexity involved in authenticating to Wi-Fi access points (i.e. the need to log in or register with new hotspots when on the move). Lack of interoperability between different operators may also be a contributory factor. Interestingly Telefonica/O2, who have recently launched an outdoor Wi-Fi metropolitan area network in central London which requires only a once-off registration after which connection is automatic, told us that traffic levels on the network were several times higher than that carried over the Telefonica cellular network in the same area.

In the following sections, we review the various approaches that currently exist (or that may exist in the future) to delivering public access to Wi-Fi or small cell networks. Currently, virtually all such access is to Wi-Fi, and licensed small cell systems are generally still at the trial phase; hence, much of the following focuses on Wi-Fi deployments. Nonetheless, we also provide a review of current femtocells trials and consider how such systems might be deployed in the future, both on a stand-alone basis and in conjunction with Wi-Fi access.

67 Ofcom 2012 infrastructure report, updated 20th December 2012.
68 BT, BSkyB, O2, Virgin Media, T-Mobile and KCom.

5.3.1 Approaches to delivering public access to Wi-Fi

Public access to Wi-Fi has become well established over the last decade with millions of so-called “hotspots” now available throughout the world. There are a number of ways in which Wi-Fi can be provided for public access. The main variants include:

- Privately owned Wi-Fi hot spots
- Managed public Wi-Fi hotspots
- Public Wireless Metropolitan Area Networks (WMANs)
- Co-operative public Wi-Fi networks.

Each of these is described in detail in the following sections.

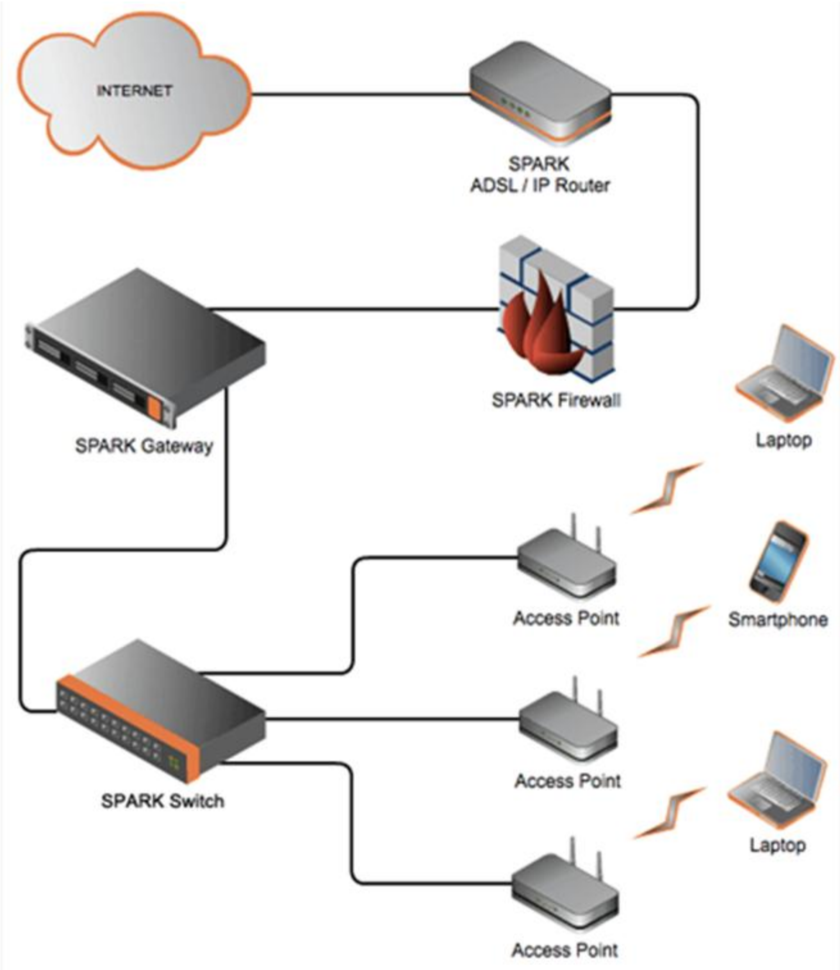
5.3.2 Privately owned Wi-Fi hotspots

Privately owned public access points or hotspots are widely deployed throughout Europe, for example in hotels, bars, restaurants, retail establishments, transport hubs and in some public areas (e.g. parks). In most cases, these simply use the establishment’s existing broadband connection and involve setting up an additional Service Set Identifier (SSID) to separate the public traffic from the proprietor’s own private traffic. The systems vary in size from a single access point serving a small shop or cafe to an extensive network serving a large hotel.

Smaller systems may simply provide unrestricted access or (more commonly) require users to enter a password that is pre-determined by the business owner. This enables access to be restricted to bona-fide customers and provides an additional degree of security. Such systems may be free to use or may require the user to pay a fee to the proprietor in order to receive the password.

Larger systems are more likely to deploy specialist hardware and software to support traffic management, billing, and the like. A number of companies supply such facilities (see Figure 5-2) in order to provide wireless internet access to virtually any environment, such as hotels, conference centres or marinas. Large systems such as this typically need to be professionally installed in order to ensure that coverage and capacity meet user expectations. Connecting to such a network for the first time typically requires a log-in procedure which depending on establishment policy may also require payment. The login process may include specifying a date and time until which access is required, in which case the user may automatically log in until that time.

Figure 5-2: Example of owner-managed large scale public access Wi-Fi network



Source: Wi-Fi Spark Ltd, UK

No information is available on the total number of privately owned hot spots in Europe; however, given their widespread deployment in hotels and other establishments we would expect the numbers to be substantial.

5.3.3 Managed Wi-Fi hotspots

Managed Wi-Fi hotspots are in many ways similar to privately owned hotspots and serve the same types of locations, but instead of being owned and run by the premises owner the systems are run by a third party. Managed hot spots can be operated on a stand-alone, premises-specific basis or as part of a larger managed network. In the former case, access to the network is similar to the privately owned case, but where payment is required this required this is direct to the company managing the hotspot. Generally, the premises owner pays a regular fee to the hotspot provider and in return receives a share of any revenue generated. The hotspot operator is responsible for maintaining the system and with complying with any security or regulatory requirements. Backhaul may be either via the existing premises broadband connection or via a dedicated connection managed by the hotspot provider.

Network hotspots can provide a more consistent and seamless experience for users, since the same login credentials can be used at all the network's hotspots. Increasingly, this enables users to login automatically when a hotspot is detected, so long as the user has pre-registered with the network concerned. In consequence, there has been a significant growth in the number of network managed hotspots, which in many cases have replaced former privately owned hotspots.

Most network hotspots are managed by established fixed or mobile network operators, although some specialist providers of managed hotspots (such as the previously mentioned UK company Wi-Fi Spark) can also provide roaming across some of their individual managed hotspots. Table 8 provides some examples of operator managed hotspots in various EU countries.

Table 8: Examples of hotspot networks in EU countries

Country	Operator	Details
Czech Republic	T-Mobile	Operates c. 100 public hotspots across the country, mainly in urban locations. Access if free for T-Mobile subscribers but other users are subject to a fee of 18.15 CZK per 10 mins.
Hungary	Magyar Telekom.	Operates a network of c. 500 hotspots in hotels and other locations. Has a roaming agreement with iPass.
Italy	TIM	Operates a network of hotspots available exclusively to TIM customers.
Netherlands	KPN	Operates c. 500 hotspots at hotels, holiday parks, petrol stations, railway stations and restaurants. Access is free to KPN subscribers but other users are subject to a fee starting at €5.95 for 50 mins.
Portugal	Portugal Telecom	Operates 1,600 conventional Wi-Fi Hotspots and has an additional 200,000 "community hotspots", whereby PT subscribers make their access points available to other PT subscribers. PT is expanding this network through hotspots in phone booths and residential IPTV routers. Service is offered free to both fixed and mobile broadband PT customers. Other users are required to buy vouchers. Mobile apps and EAP SIM authentication are available facilitate connection for mobile devices. PT is also trialling new solutions including hotspots in phone booths and 3G/4G/Wi-Fi handover. The company plans to adopt Wi-Fi Alliance Passpoint certification and Hotspot 2.0 along with 3GPP Access Network Discovery and Selection Function (ANDSF).

Country	Operator	Details
Romania	RCS&RDS	Currently provides 2,400 Wi-Fi hotspots across Romania, through its Digi Wi-Fi service, a five-fold increase since the service's launch in 2011. Access is free for RCS&RDS subscribers, while others pay a fee starting from 29 lei for 50 MB. The network has recently introduced automatic connection one an initial registration has been made.
Sweden	Telia	Operates circa 4,000 hotspots in Sweden and other Nordic / Baltic countries. Access is free to Telia subscribers but chargeable to others. Automatic connection is available to a limited range of mobile devices.
UK	The Cloud	Largest free hotspot operator in the UK, with over 16,000 active hotspots. Owned by satellite broadcaster BskyB. Free access to all users subject to initial registration.
UK	O2 (Telefonica)	Second largest free hotspot operator in the UK, with circa 7,000 active hotspots. Free access to all users subject to initial registration.
UK	BT Wi-Fi	Operates circa 3,500 hotspots in the UK and Ireland. Access is free to BT subscribers, others pay a fee starting at £6 for 90 minutes access

Hotspot networks are increasingly taking advantage of the latest Wi-Fi technology to facilitate automated login and roaming, both within the network and onto other networks in the same country and worldwide. A number of organisations also operate as roaming facilitators, whereby an agreement is reached with multiple hotspot operators around the world which enables the user to register just once with the roaming facilitator to gain access to all the partner networks, rather than having to register individually with each network. This generally requires the payment of either a regular subscription or a per-session fee for access.

We discuss these roaming facilitators more fully later in this section.

5.3.4 Wireless Metropolitan Area Networks (WMANs)

Metropolitan Area Networks (MANs) are defined by the IEEE as being "optimised for a larger geographical area than a LAN, ranging from several blocks of buildings to entire cities". Wireless MANs are technically more challenging than WLANs since users may connect to the network via multiple access points and an effective handover process between APs is required in order to gain the full benefit of the wide area coverage. Where the MAN is used to provide off-load from a cellular network, an effective roaming capability between the two is also desirable.

Whereas individual Wi-Fi hotspots are widely deployed throughout Europe, examples of WMAN deployments are far fewer, although interest in further deployments appears to be growing. Where they have been deployed, this has generally been by established fixed or mobile network operators, since these operators already have access to the necessary backhaul facilities that are required (see section 3 for further consideration of backhaul issues). There are however examples of municipal deployments, notably in Spain, and in many cases the network deployments have been undertaken in conjunction with local authorities, who conduct competitive tenders for access to street infrastructure.

Table 9 provides brief details of the WMAN deployments that we are aware of within the EU. Additional information on some of the larger deployments is provided in Section 5.3.5.

Table 9: Examples of WMAN deployments in Europe

Country	Operator	Details
Belgium	ZapFi	Provides free outdoor Wi-Fi access in the city centre of Bruges, using dual-band Alvarian infrastructure. The network is funded by targeted advertising on behalf of ZapFI's partners. The network provides enhanced capacity at key locations, such as the Jan Breydel Football Stadium which is served by 8 base stations and also provides Wi-Fi access to staff and students at Sint Lodjewijks College, Bruges' largest school. The network is largely aimed at mobile users and supports SIM-based card authentication, making the transition seamless for users when registering on the ZapFi network
Czech Republic	Widenet	Operates a network of six outdoor hotspots in Prague. The company has a roaming agreement with Boingo.
Estonia	Various private service providers	Has over 1,600 hotspots, many providing outdoor coverage. Access points can be found in most public locations: parks, squares, pubs, cafés, restaurants, airports, trains, bus stations and even on some more remote locations, such as beaches or forests. There are also almost 100 small ISPs in rural areas that use 5-GHz transmitters to provide neighbourhood broadband wireless access.
France	Orange (FT)	Orange operates over 30,000 Wi-Fi indoor public hot spots in France and has also rolled out an outdoor network using meshed Wi-Fi in the city of Issy Les Molineux. Wi-Max technology has been used for backhauling the outdoor network.
Spain	Various municipal networks	Spain has a number of municipal networks. In 2010, it was reported that over 300 city councils were offering outdoor Wi-Fi service[69]. Typically these serve both private municipal requirements (such as transport) as well as providing public access. Currently the largest network is in Barcelona (see below).
UK	BT Wi-Fi, O2, The Cloud	Operate outdoor WMANs in various locations – further details are provided below

69 http://www.muniwireless.com/2010/04/24/municipal-wireless-networks-in-spain/.

5.3.5 WMAN Deployment Case Studies

It is interesting to compare and contrast the approaches taken by different Wi-Fi network operators, both in terms of technologies and architectures employed and the underlying business models. We have so far looked in detail at three of the largest public Wi-Fi operators in the UK, namely The Cloud, O2 Wi-Fi, and Virgin Media and also at operators in France and Spain. We will be examining other examples across the EU later in the study.

The three UK networks differ quite markedly in their approach to Wi-Fi deployment and the associated business model. The Cloud is owned by the broadcaster BskyB and sees its extensive network of hotspots as a platform to support the high quality mobile delivery of its premium TV content. O2 Wi-Fi also operates an extensive hotspot network which it uses to aggregate customer data on behalf of the hotspot venue owners. Virgin Media operates a more limited Wi-Fi network and for the long term is more focussed on providing wholesale access to infrastructure (sites and backhaul) for licensed small cell operation.

These different approaches appear to have a significant impact on the traffic levels generated, as we highlight in the following sections which provide feedback from our discussions with these three network operators.

5.3.5.1 The Cloud (BskyB), UK

The Cloud is currently the biggest public Wi-Fi hotspot operator in the UK, with over 16,000 active hotspots. The company also operates a meshed outdoor WMAN in the City of London. The network is dual band throughout with automatic steering of dual band clients to the 5 GHz band. 5 GHz is also used for meshing purposes in the outdoor network, along with some 5.8 GHz light licensed spectrum. The entire network uses Ruckus infrastructure with dynamic channel selection and beam forming to maximise capacity.

The Cloud places a strong emphasis on providing high capacity for video streaming. This is largely aimed at enabling BskyB TV subscribers to access video content on the move (for which an additional subscription is payable), since the mobile networks are not considered capable of delivering video with sufficient quality. Peak usage tends to be weekend evenings, when some users can download hundreds of MB per session.

The network is free to access for up to two devices per customer, subject to pre-registration. Roaming agreements have been reached with some overseas mobile operators (most notably AT&T in the US, whose subscribers generate significant traffic on the network).

5.3.5.2 O2 Wi-Fi (Telefonica), UK

O2 Wi-Fi is the second largest public Wi-Fi hotspot operator in the UK, with approximately 7,000 active hotspots. The company also operates outdoor Wi-Fi networks in parts of central London. Most hot spots and all outdoor access points are dual band. In April 2013, O2 reported that it had attracted over 6 million customers to its free Wi-Fi service since its launch in 2011, of which over 5 million signed up in the last 12 months.

Traffic levels to date are relatively low at most hotspots (around 128 Kbps per site is typical), but significantly higher in the London outdoor networks, where traffic levels have been found to be six to seven times higher than the local traffic carried over O2's cellular data network. Interestingly, since the outdoor network went live in 2012, there has been no reduction in the traffic carried locally over the cellular network, implying that the Wi-Fi traffic is incremental to that carried over the cellular network rather than off-loaded. This could, for example, be due to a large number of Wi-Fi only devices (e.g. tablet PCs) connecting to the network.

The network currently uses MAC authorisation of pre-registered devices. SIM-based authentication for O2 mobile subscribers is planned in the future. There are no roaming agreements currently and no immediate plans to deploy Passpoint™ or Hotspot 2.0, although many of the hotspots can be software upgraded to provide this.

A key part of O2 Wi-Fi's business strategy is focussed on gathering and aggregation of customer profile data. Each time a customer visits a hot spot venue, the device automatically connects regardless of whether the network is used, and this can be used to generate valuable marketing data that can be sold back to the venues concerned, compensating for the lack of direct revenue from the Wi-Fi itself, which is freely available to all users subject to a one-time registration.

A further motivation for the outdoor networks was that these would in the future support licensed LTE small cells alongside Wi-Fi as part of O2's existing UK mobile network; however, this now appears less certain following the company's failure to acquire spectrum in the 2.6 GHz band (ideally suited to small cell deployment) in the recent UK spectrum auction. This may lead the company to place increased reliance on Wi-Fi to support network capacity, at least in the shorter term.

5.3.5.3 Virgin Media, UK

Although it is the second largest residential fixed broadband provider in the UK, Virgin Media has relatively modest ambitions with regard to public Wi-Fi and is more focussed on developing small cell solutions for licensed mobile network operators. The company has recently developed a concept known as Small Cells as a Service, which involves working alongside local municipalities to develop outdoor urban small cell networks using street furniture to support both Wi-Fi and 4G (LTE) femtocells. By partnering with the local authorities, Virgin Media gains access to the sites and power facilities necessary to roll out the small cell network. In return, Virgin is required to provide fee Wi-Fi access within the terms specified by the local authority.

Virgin currently operates two relatively large scale public Wi-Fi networks, one serving stations on the London Underground and the other an outdoor network covering the cities of Leeds and Bradford.

Unlike The Cloud and O2, Virgin Media currently uses only the 2.4 GHz band on its Wi-Fi access network and has no immediate plans to deploy 5 GHz (although 5 GHz is used to provide meshing of access points in the outdoor networks). This makes sense on the London Underground, since by its nature this is a relatively benign radio environment, but is perhaps more questionable for the outdoor networks. Access to the London Underground network is limited to subscribers of Virgin Media and various partners, which include two of the four UK mobile networks (Vodafone and Everything Everywhere). Virgin describes these arrangements as wholesale agreements rather than roaming, in that the mobile customers must first pre-register with their network, rather than access being allowed automatically e.g. via SIM authentication. Access to the outdoor networks is free to all users.

With the exception of the London Underground (where Virgin is a sole provider of Wi-Fi services and can market these on a wholesale basis to other networks), Virgin does not see public Wi-Fi as a viable business in its own right. Rather, Wi-Fi is seen as an innovation platform to prove the concept of small cell networks, which if successful will be extended to wholesale provision of backhaul and site access for mobile operators with their own licensed spectrum.

5.3.5.4 Free Mobile, France

In April 2012, Free Mobile launched what it claims is the world's largest carrier-run mobile data off-load network. Free Mobile makes use of the four million existing access points belonging to subscribers of Free's parent company Iliad. The access point sharing arrangement has in fact been in place for Iliad's subscribers since 2009, but this more recent development enables Free Mobile subscribers to connect automatically to any Iliad subscriber's access point, using SIM based authentication. The service is currently available to all Free Mobile subscribers on higher end data tariffs (€16 per month and upwards).

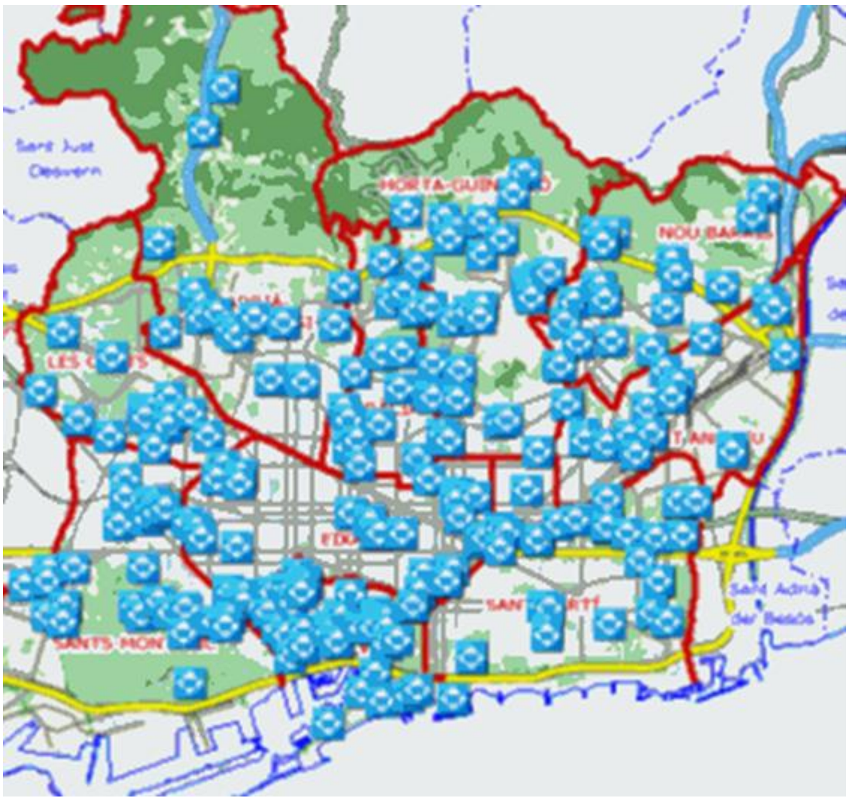
This approach is particularly attractive for Free Mobile, which has limited coverage with its own cellular networks and therefore has to rely heavily on national roaming or Wi-Fi in unserved areas. The service is however largely limited to urban areas where Iliad's broadband subscribers mainly reside, and coverage is likely to suffer from the same limitations as the FON based networks (see Section 5.3.6).

5.3.5.5 Barcelona municipal Wi-Fi network, Spain

Barcelona has a city-wide Wi-Fi network which comprises two distinct mesh networks, one for municipal use only and another one for the public. The municipal network is based on a fibre core network with access points installed on traffic and street light poles. This network is intended to cover more than 30 per cent of the city using more than 400 meshed access points. Some of the municipal services served by the network were previously served using GPRS/UMTS connectivity, so the network aims to reduce operational costs, increase service reliability and security, and make new applications available or easier to deploy. Barcelona uses its network for (among other things) parking meter control, running wireless cameras to detect traffic light violations, providing bus information, and managing the public bicycle rental service.

The public Wi-Fi network is based in public facilities such as libraries, markets, and parks, and offers indoor and outdoor connectivity. This network of around 200 hotspots offers free Wi-Fi access subject to acceptance of the terms and conditions; no further registration is required. To meet the requirements set by the CMT, and thus not alter the market (a possible State Aid consideration), the connection speed is limited to 256 Kbps, and voice over IP is prohibited.

Figure 5-3: Barcelona municipal Wi-Fi network public access points



Source: MuniWIreless

5.3.5.6 BT Wi-Fi, UK

BT Wi-Fi operates over 4.5 million Wi-Fi hot spots in the UK. The majority of these are residential BT hotspots operated in partnership with FON (see Section 5.3.6), but there are also some 300,000 BT Business Hub hotspots and some 6,000 indoor hotspots in locations such as cafes and hotels. BT also operates outdoor WMANs in twelve cities across the UK, referred to as wireless cities – these include Glasgow, Edinburgh, Newcastle, Leeds, Liverpool, Sheffield, Nottingham, Birmingham, Portsmouth, Bristol, Cardiff and London. The network in central London covers approximately 7 square miles in total. BT Wi-Fi also provides indoor hotspots at various locations in Germany, Ireland and Spain.

Although all BT hotspots now operate under the single BT Wi-Fi brand, there are two distinct approaches to providing service: (1) the premium properties comprised of the cafes, hotels, shopping centres; and (2) the wireless city networks, and the shared community hub (BT FON) hotspots. Most of BT's existing access points run at 2.4 GHz, but 5 GHz is progressively being rolled out across the premium properties, and this process should be complete in the next two to three years. Where 5 GHz has been deployed, it works well, and there have been no problems associated with DFS in the band. Residential access points (Home Hub) are still single band (2.4 GHz), but this is likely to change in the near future. BT would like to see the allocation of further Wi-Fi spectrum at 5 GHz in the future, and would like this spectrum to be licence exempt.

BT Wi-Fi is planning to rollout 802.1X across its premium properties in the near future, which will enable secure authentication including EAP-SIM and TTLS. BT already has roaming agreements with all of the UK mobile networks except Three. EAP-SIM authentication is already supported by BT's network, but currently only works with Vodafone. One of the problems with SIM-based roaming has been limited support by client devices – for example, Android smart phones prior to version 4 did not fully support EAP-SIM, resulting in a very poor user experience in terms of service provisioning and operation.

Roaming agreements are also in place with various overseas mobile networks and with other Wi-Fi networks. There are also wholesale agreements with other companies such as iPass, Boingo and Skype (where Skype Access facilitates payment Internet sessions of short duration). BT is working with its partners to try to make roaming arrangements more straightforward.

BT's view is that Wi-Fi will always remain a complement to cellular rather than a substitute. In their view, the key benefits of Wi-Fi are the additional capacity and spectrum resource that it provides.

5.3.5.7 Deutsche Telekom and FON

In March 2013, Deutsche Telekom announced a partnership with FON to provide off-load services to its own broadband customers and apparently to customers of other broadband providers as well.[70]

The arrangement is typical of agreements with FON (see Section 5.3.6), but is noteworthy by virtue of its scale. Deutsche Telekom has not only twelve million broadband subscribers, but also more than 12,000 hotspots throughout Germany.

5.3.6 Co-operative public Wi-Fi networks such as FON

Co-operative public Wi-Fi entails network users agreeing to share each other's' access points, and is facilitated either by the user's host network or by using specially configured routers that are able to identify users who are party to the agreement and carry traffic from visiting users separately from the home user's own traffic.

The main instigator of such services in Europe has been the Spanish company FON, customers agree to allow controlled access to other users who have signed up for the FON service. There are two ways in which this can take place. A few users sign up directly with FON and in return are provided with a dedicated router in exchange for access to other FON routers around Europe. The majority of users instead take advantage of agreements that FON has reached with specific network operators, whereby FON software is downloaded automatically into the participating user's router. Based on FON's certification programme for routers, they believe that about 90% of the installed base of consumer routers can accommodate their software. In either case, FON's agreements enable FON customers to access one another's access points automatically.

FON's approach works by setting up a separate Wi-Fi connection from the router – this uses the same radio signal and channel as the user's own private connection but comprises a second parallel data link with a FON-specific service set identifier (SSID) which is separated from the user's private connection by a firewall. The home user's private traffic is prioritised such that connections via the FON signal should not adversely impact the performance or the security of the home broadband connection.

Currently, FON has agreements with six European telcos, and their network is expanding rapidly. In addition, users are able to sign up directly with FON in all but two EU countries (see Table 10).

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70 See for instance Business Wire, "FON Partners with Deutsche Telekom to Create Germany's Largest WiFi Network", 4 March 2013, at http://www.businesswire.com/news/home/20130304005699/en/Fon-Partners-Deutsche-Telekom-Create-Germany%E2%80%99s-Largest.

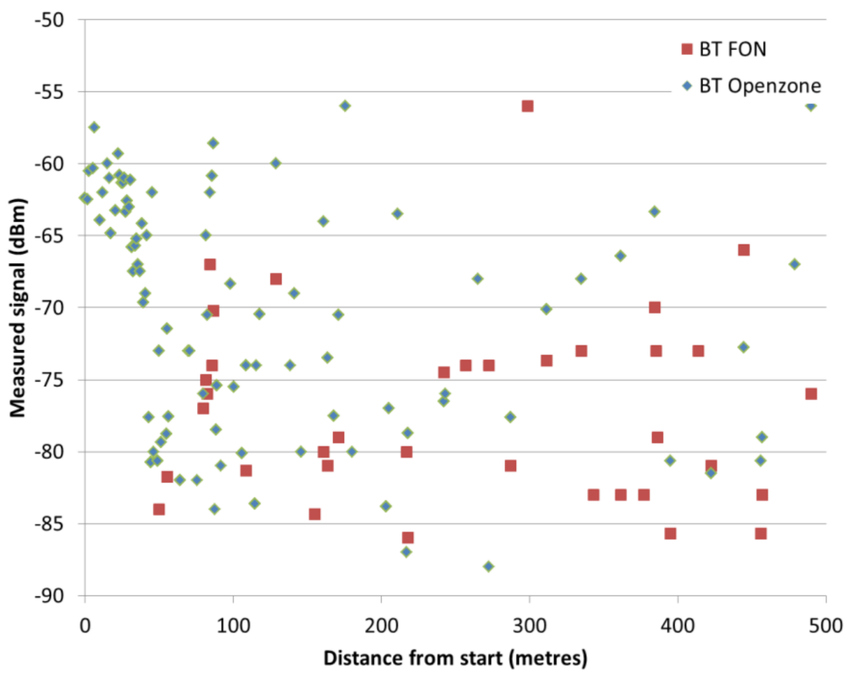
Table 10: FON availability in Europe

Country	Network	Comments
Austria	-	Available directly via FON
Belgium	Belgacom	Belgacom broadband subscribers receive unlimited free access to FON's global Wi-Fi network in addition to all Belgacom hotspots. There are currently over 600,000 Belgacom FON hotspots.
Bulgaria	-	Available directly via FON
Cyprus	Not available	Not available
Czech Rep	-	Available directly via FON
Denmark	-	Available directly via FON
Estonia	-	Available directly via FON
Finland	-	Available directly via FON
France	SFR	SFR's fixed broadband package includes access to 4 the company's 4 million FON hotspots in France as well as over 4,000 public hotspots.
Germany	T-Mobile Wi-Fi To Go	Deutsche Telekom plans to establish a network of 2.5 million FON hotspots in Germany by 2016 and the launch of the service is planned for June 2013 under the title WLAN TO GO.
Greece	-	Available directly via FON
Hungary	-	Available directly via FON
Ireland	-	Available directly via FON
Italy	-	Available directly via FON
Latvia	-	Available directly via FON
Lithuania	-	Available directly via FON
Luxembourg	Not available	Not available
Malta	Not available	Not available
Netherlands	KPN	From later this year, the FON agreement will enable access to all shared domestic connections as well as over 1,500 KPN hotspots.
Poland	Netia	Available to all Netia subscribers (Netia is the second largest fixed line operator in Poland).
Portugal	ZON	ZON is the major cable broadband service provider in Portugal with more than 500.000 ZON@Fon Wi-Fi hotspots.
Romania	-	Available directly via FON
Slovakia	-	Slovak Telekom is reported to be actively cooperating with FON and is preparing to launch the service in Slovakia
Slovenia	-	Available directly via FON
Spain	-	Available directly via FON

Country	Network	Comments
Sweden	-	Available directly via FON
UK	BT	Over 4 million FON hotspots

Whilst the sheer scale of the FON networks in some countries have the potential to provide widespread off-load opportunities, there may be limitations to how attractive this will be in practice, due to the limited ability of Wi-Fi signals to propagate significantly outside the home. This is illustrated in Figure 5-4, which compares the detected Wi-Fi signal from BT FON access points (generally located indoors) and BT's outdoor Openzone hotspots along a 500 metre route in the Covent Garden area of central London. It can be seen that the outdoor BT hotspots have typically a 10-20 dB advantage over the indoor FON hotspots (the odd exception is where a FON router is located very close to a street-facing window).

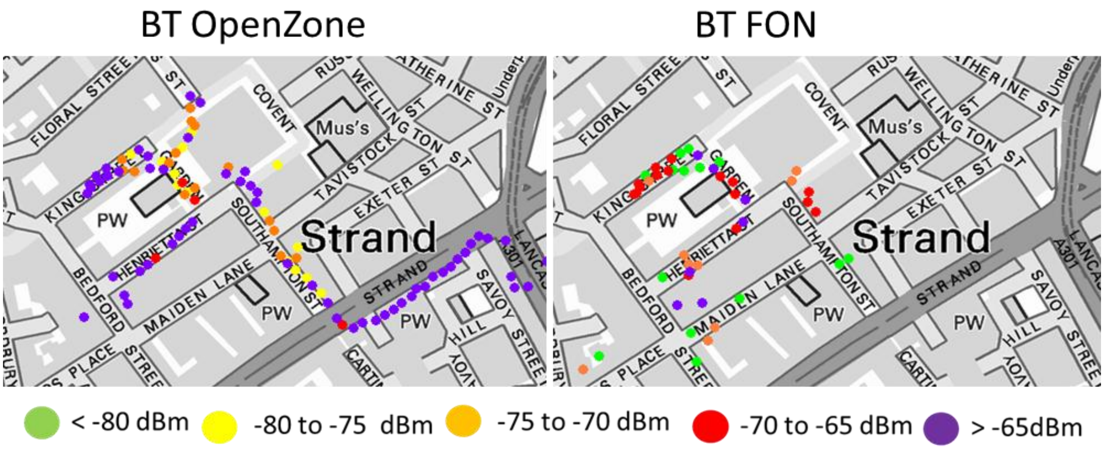
Figure 5-4: Signal attenuation for outdoor versus indoor hotspots



Source: Aegis Systems

There is also a significant difference in the continuity of coverage offered by the two networks, as illustrated in Figure 5-5.

Figure 5-5: Comparison of BT Openzone and BT FON coverage at street level along a typical urban route in the Covent Garden area of London



Source: Aegis Systems

Whilst co-operative Wi-Fi initiatives such as FON can provide clear benefits to certain users, e.g. those who are visiting locations equipped with FON routers, they are likely to be of rather less benefit to outdoor mobile users, due to the limited outdoor range of each FON router compared to a dedicated outdoor access point.

Most FON routers currently require the user to log in with a user name and password each time the service is accessed; however, the company has recently announced the release of a next-generation router which includes EAP based authentication,[71] including provision or EAP-SIM which will provide automated connection for mobile devices where the operator has a roaming agreement in place with FON or its local partner network. FON is a member of the Wi-Fi Alliance, and plans to adopt the latest Wi-Fi Alliance certified Passpoint™ and IEEE 802.11u protocols to enable automatic detection and authentication onto FON hotspots. Some FON partner networks (e.g. SFR in France) already provide automatic login to certain users, although currently in SFR's case this is limited to devices operating the latest Apple iOS5 operating system.

Another potential approach to carrying third party traffic over private Wi-Fi access points has been developed by the Swedish company AnyFi. AnyFi's approach is similar to that of FON in that special routers are required to provide users with access to one another's networks; however, it differs in that access is obtained by entering the credentials for the user's own home network. When a visiting user's device detects an Anyfi router, the Wi-Fi authentication credentials are sent via the visited router to the device owner's home gateway, using secure tunnelling technology similar to that used

71 See http://blog.fon.com/en/archivo/gadgets/fon-announces-new-fonera-simpl.html.

in virtual private networks. The user's device therefore behaves as if it were on its home Wi-Fi network, and the same security measures are put in place as the customer uses at home, ensuring a secure Wi-Fi connection.

AnyFi is targeting its offerings at Internet service providers in a similar fashion to FON, although they do not as yet appear to have any commercial agreements in place.

5.3.7 Role of Service Aggregators in supporting off-load

In recent years a number of companies have emerged that provide an intermediary service to enable Wi-Fi users to access services provided by multiple networks, both in the user's home country and abroad. In some cases these companies also operate their own managed hotspot networks. For example, Boingo operates 400 of its own hotspots at over 400 locations around the world, but has established roaming agreements with more than 100 partner networks to provide access to a further 600,000 hotspots. The European networks that Boingo has partnered with include BT, KPN, Orange, T-Mobile, Telefonica and Telia Sonera. Users who subscribe to Boingo's service are able to download a mobile app which will provide automatic login when a Boingo or partner's hotspot is detected.

A similar service is provided by iPass, which has roaming agreements with over 140 international partner networks to provide access to over 1.2 million hotspots worldwide, including 360,000 in Europe. European partners include Orange, Deutsche Telecom, Cable and Wireless, The Cloud, Everything Everywhere and eircom.

iPass supports the EAP protocols including SIM-based authentication. Devices that connect to next generation hotspots will also need to have a protocol stack that supports 802.1x, Wi-Fi network operators are able to use the iPass back office infrastructure to enable them to upgrade individual hot spots to the latest Hot Spot 2.0 standard without the need to upgrade their own back office support.

Both Boingo and iPass provide billing and revenue management services to their partner networks. For example, Boingo's billing system provides a single aggregated accounting stream to carrier and ISP partners in a wide variety of industry-standard formats or it can be used to bill customers directly.

5.3.7.1 London Boroughs / Arqiva joint venture, UK

In September 2012, a tendering process was initiated by a consortium of seventeen London borough councils, led by Camden borough, to provide public Wi-Fi and 3G / 4G small cell access in specified locations using street infrastructure owned and managed by the councils.[72] The total value of the tender was specified as between £10M and

72 See OJEU notice 2012/S 180-296448.

£20M and the contract duration between five and ten years, with the option of further renewal. Two of the boroughs (Camden and Hammersmith & Fulham) have let contracts to the communications infrastructure provider Arqiva, five others have withdrawn from the process, and the remaining ten are at the time of writing still in the procurement phase. Under the terms of the contract with each council, Arqiva will pay a fee to access the street infrastructure – for example, in the case of Hammersmith & Fulham this amounts to £500,000, the council will also receive a share of any income generated from supplying the WiFi service. The first portions of the networks are expected to go live at the end of 2013.

The contracts require the providers to offer free Wi-Fi access to individual users for up to thirty minutes per day, with unlimited access to council web sites. The contracts also provide for future deployment of 3G/4G metrocells using the same infrastructure.

5.3.8 Estimating off-load traffic in the public environment

Our research has indicated that current levels of traffic off-load to public Wi-Fi hotspots is very small compared to off-load in the home or work environments, although there are signs that this is growing as more networks adopt automated login and roaming procedures. The Mobidia/Informa data we presented in Chapter 4 also suggests that public off-load traffic via Wi-Fi is relatively small today (less than 2% of total traffic originated from Android smart phones).

We have already pointed out that one of the historic reasons for this has been the relative complexity involved in accessing public Wi-Fi networks; however, another important factor is that historic and even current levels of mobile data traffic do not generally exceed the capacity of the macro networks other than in exceptionally high traffic locations. To illustrate this, we have estimated the current and projected capacity of mobile networks in various countries and compared this with the projected levels of mobile data traffic, to estimate the extent to which offload might be required. The details of our analysis are presented in the following sections.

5.3.8.1 Assumptions used in the analysis

The assumptions we have used in estimating the capacity of a macro cellular network in each country are as follows:

- The network is planned to provide national coverage, with cell sizes based on deployment of the 2 GHz band in urban and suburban areas and 900 MHz in rural areas.

- The radio spectrum available for 3G/4G mobile data increases steadily from 2x60 MHz in 2011 (corresponding to the current 2 GHz 3G band) to 2x200 MHz in 2025 (corresponding to the 2 GHz, 1800 MHz, 900 MHz and 800 MHz bands.
- There are four competing networks in each country, each with between 20% and 30% market share and each having 25% of the available mobile data spectrum (i.e. 2x50 MHz per network).
- The spectrum efficiency of the technology deployed increases from 0.7 bps per Hz (corresponding to a mix of UMTS and HSPA technologies) in 2011 to 1.8 bps per Hz (corresponding to a mix of LTE and LTE-Advanced technologies) in 2025.
- 10% of total daily data traffic is carried in the busy hour.
- 50% of total network busy hour traffic is carried over 15% of the base stations
- Average busy hour loading at the busiest sites is 75%.
- Each base station comprises three sectors, each of which can make use of all the operator's available spectrum.
- The percentage of land area corresponding to urban, suburban and rural coverage are as follows for each country.

Table 11: Portion of land area that is urban, suburban or rural in selected Member States

Country	Land area (sq km)	% urban coverage	% suburban coverage	% rural coverage	% outside of coverage area
France	547,120	0.5	5.9	79.7	14.0
Germany	356,027	0.3	15.7	78.0	6.0
Italy	299,287	0.4	16.2	66.4	17.0
Spain	505,275	0.5	4.7	72.8	22.0
UK	244,000	1.0	16.6	51.4	31.0

The assumed cell sizes for urban, suburban and rural areas are as follows:

Table 12: Assumed cell sizes for urban, suburban and rural areas

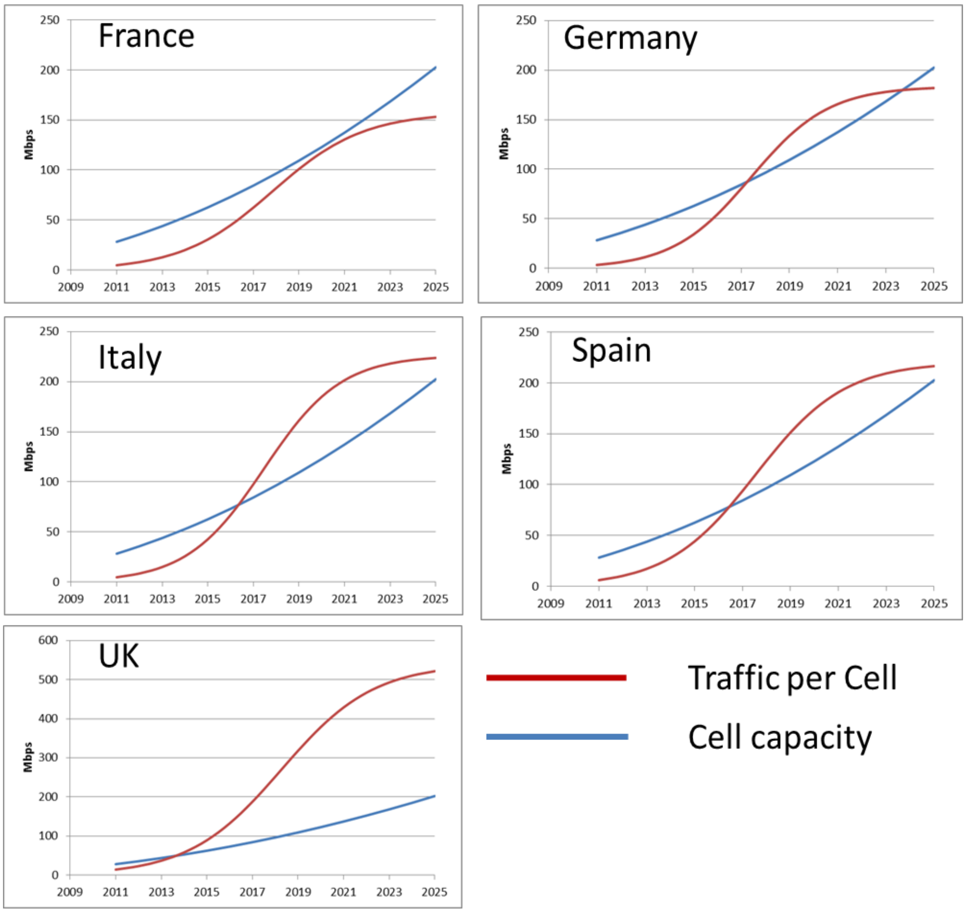
Geotype	Cell radius (km)	Cell area (sq km)
Urban	0.7	0.95
Suburban	1.5	4.39
Rural	8.8	151

For each country, the total number of cells is estimated, by dividing the urban, suburban and rural land areas by the corresponding urban, suburban or rural cell area. The capacity of each cell is estimated by multiplying the total downlink bandwidth (15-50 MHz) by the spectrum efficiency (bps/Hz) and multiplying by 3 to reflect the tri-sectored cells. The traffic per cell in the busiest cells is then calculated by dividing 50% of the total network busy hour traffic by 15% of the total number of estimated cells (to reflect the 50% of traffic over 15% of cells assumption). Note that the total network traffic is assumed to be 30% of the total national traffic (from the Cisco forecasts), reflecting the assumed maximum 30% market share.

5.3.8.2 Results of the analysis

The figures below compare the estimated traffic per cell in the 15% of busiest cells with the capacity per cell, based on the above assumptions:

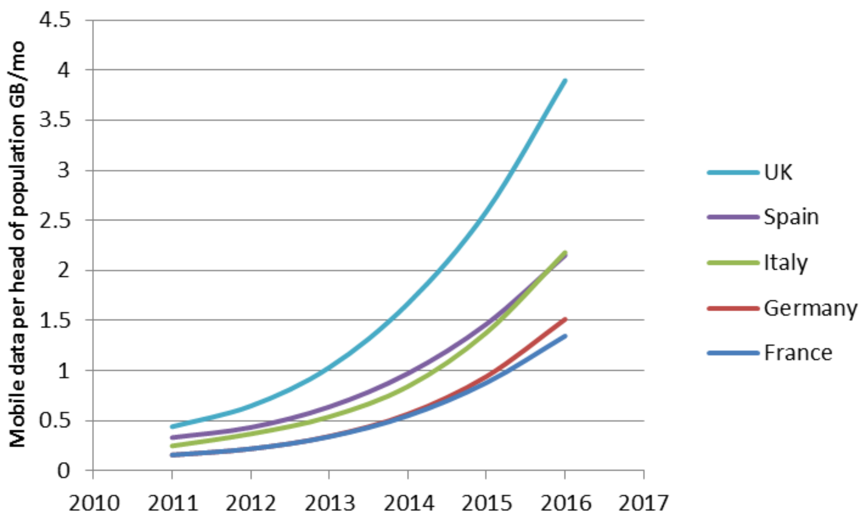
Figure 5-6: Projected macrocell capacity and traffic demand (15% of busiest cell sites)



Source: Aegis Systems

It can be seen that the UK appears to have a significantly higher level of excess traffic – this reflects the much higher projected levels of mobile data traffic in that country (see Figure 5-7). In the UK case, the excess traffic peaks at approximately 268 Mbps per macrocell, which would require up to nine additional small cells assuming an availability of 2x20 MHz in the 2.6 GHz band for small cell deployment and that the spectrum efficiency of the smell cells is the same as for the macro cells. In practice, the spectrum efficiency of small cells is likely to be greater (see Section 6.3) and it is also possible to re-use the macro cellular frequencies in the small cells, so in practice fewer additional small cells may be required.

Figure 5-7: Comparison of projected levels of mobile data per head of population by country (based on Cisco VNI data)



wik CONSULT

Source: Aegis Systems

5.3.8.3 Other licensed spectrum demand considerations

Our analysis indicates that based on extrapolation of current traffic forecasts deployment of small cells in existing frequency bands such as 2.6 GHz (where necessary supplemented by co-frequency deployment in macro cellular bands) will be sufficient to accommodate projected growth to 2025. This is based on projected traffic over 3G and 4G networks and takes account of the planned migration towards LTE Advanced technology over the next decade; however, we have not explicitly taken into account potential new demands on mobile spectrum, such as the use of LTE networks to provide fixed broadband access in areas unserved by wired broadband connections or the launch of very high bandwidth 5th generation (5G) mobile services such as those currently under study in EU-funded projects such as 5GNOW[73] and METIS (Mobile and wireless communications Enablers for the Twenty-twenty (2020) Information Society).[74]

Such developments are likely to drive demand for high bandwidth, low latency wireless connectivity requiring much wider RF channels (100 MHz or more) which may require access to additional spectrum beyond that already identified for mobile services and are likely to be heavily dependent on small cell deployments. Whilst it is important to flag this issue in the context of overall mobile spectrum demand, such new applications are unlikely to have a significant bearing on the extent of traffic offload from 3G /4G cellular networks in the 2020 time frame and therefore lie outside the core scope of the current study.

73 See www.5gnow.eu.
74 See www.metis2020.com.

6 Estimation of spectrum demand for Wi-Fi and small cell networks to reflect the DAE targets

For purposes of modelling spectrum demand, we have used Cisco VNI forecasts (which in our view are generally the most comprehensive, robust, and best validated available today) in general so as to have one consistent set of projections. We have based our analysis on the scenarios identified in Chapter 4. We have considered each of the five Member States that have been explicitly included in the Cisco VNI data, namely France, Germany, Italy, Spain and the UK. Ideally, we would also have modelled one of the newer Member States (perhaps Hungary or Poland) and a smaller country such as Portugal; however, Cisco VNI data is not individually available for those countries. We have assumed four MNOs with nationwide macro cellular networks (reflecting the current market situation in the countries analysed), and a time horizon to 2025. We have also assumed for modelling purposes that Wi-Fi equipment uses the 5 GHz band as appropriate (but consider in Chapter 7 whether steps are needed to ensure that this is in fact the case).

As much as possible, we have sought to maintain consistency between the scenarios from Chapter 5, the spectrum requirements assessed in this task, the analysis of socio-economic benefits in Chapter 7, and the Options that drive recommendations in Chapter 8.

6.1 Estimating spectrum demand for Wi-Fi and licensed small cells

There are a great many different applications that compete for bandwidth in current (and potential future) Wi-Fi bands. Data off-load is relevant, but bandwidth requirements for devices that connect (and were always expected to connect) over the fixed network and to each other is probably far greater today, and likely to remain so in the future, as our analysis of the home off-load scenario in chapter 4 illustrated.

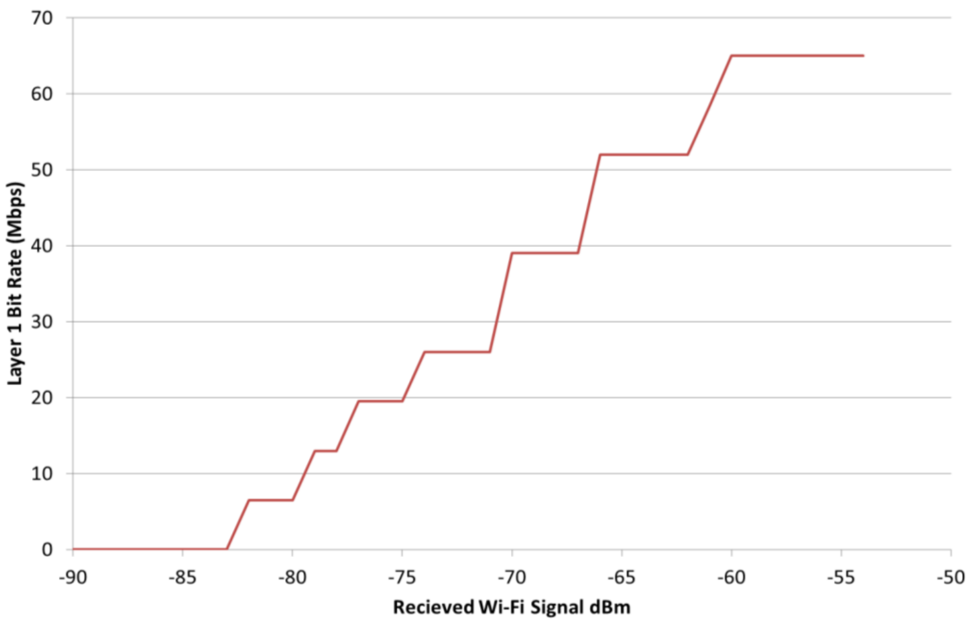
Our approach to estimating spectrum requirements is to take the traffic forecasts that we have projected in chapter 5 and to translate them into corresponding spectrum demand estimates by taking into account the likely spectrum efficiency that can be achieved by Wi-Fi and licensed small cell technologies. In the following sections, we provide details of our approach to estimating spectrum efficiency for the two off-load approaches.

6.2 Estimating Wi-Fi spectrum demand in typical off-load scenarios

When considering the potential future demand for Wi-Fi spectrum to support traffic off-load, it is necessary to consider how efficiently Wi-Fi spectrum can be used in practice, in terms of the traffic density that can be supported per MHz and taking account of anticipated future technology developments. In the following sub-sections, we consider the factors that determine the spectrum efficiency of Wi-Fi in typical real world environments, and the extent to which Wi-Fi efficiency might be impacted by new developments over the next few years.

Wi-Fi spectrum efficiency is effectively a measure of the volume of data that can be carried within a given amount of radio frequency bandwidth and a given physical space. Wi-Fi spectrum efficiency can typically be quantified in terms of bits per second per Hz. For a single Wi-Fi access point, the available bit rate depends on the quality of the signal, in terms of the signal to noise ratio (SNR) – in the absence of interference this can be expressed in terms of the received signal level. The figure below shows the specified bit rate for single stream from an 802.11n access point as a function of the received signal level[75].

Figure 6-1: Bit rate vs. received signal for a typical 802.11n access point



In practice the spectrum efficiency of Wi-Fi networks depends on the deployment scenario and is likely to differ significantly in the home, work and public (especially outdoor) environments.

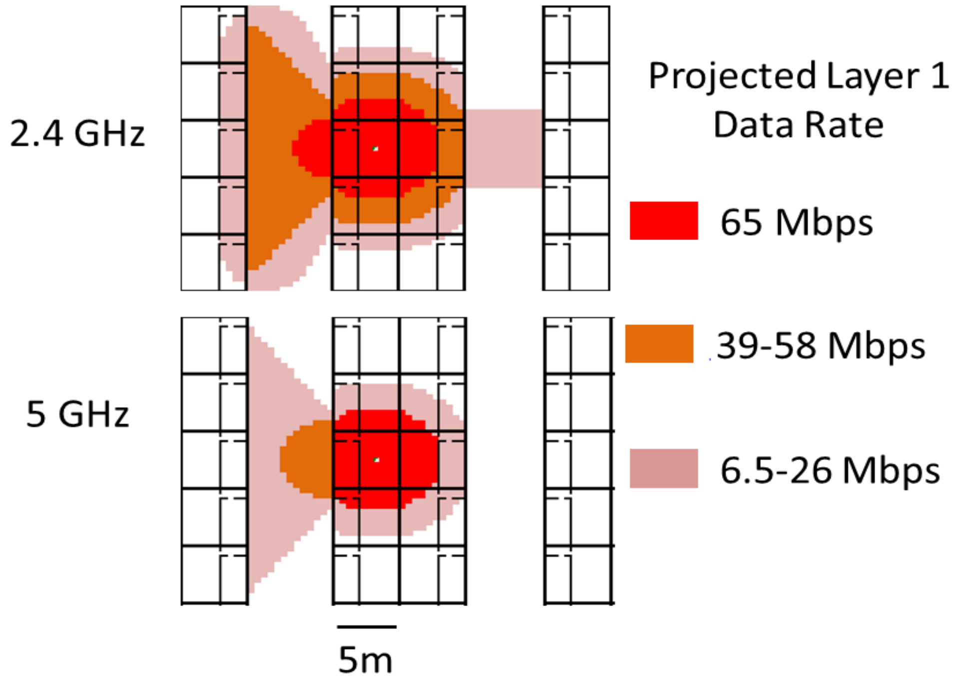
6.2.1 Wi-Fi spectrum demand in the home environment

Attaining the highest specified bit rate requires a receive signal level of more than -64 dBm, which our analysis suggests is sufficient to cover a small apartment building of

75 Source: Juniper Networks white paper “Coverage or capacity – making the best use of 802.11n.

dimensions 5m square at 5 GHz (see below). Larger buildings are likely to experience a lower bit rate when the connected device is some distance from the access point.

Figure 6-2: Indicative coverage of Wi-Fi Layer 1 bit rates in a residential environment



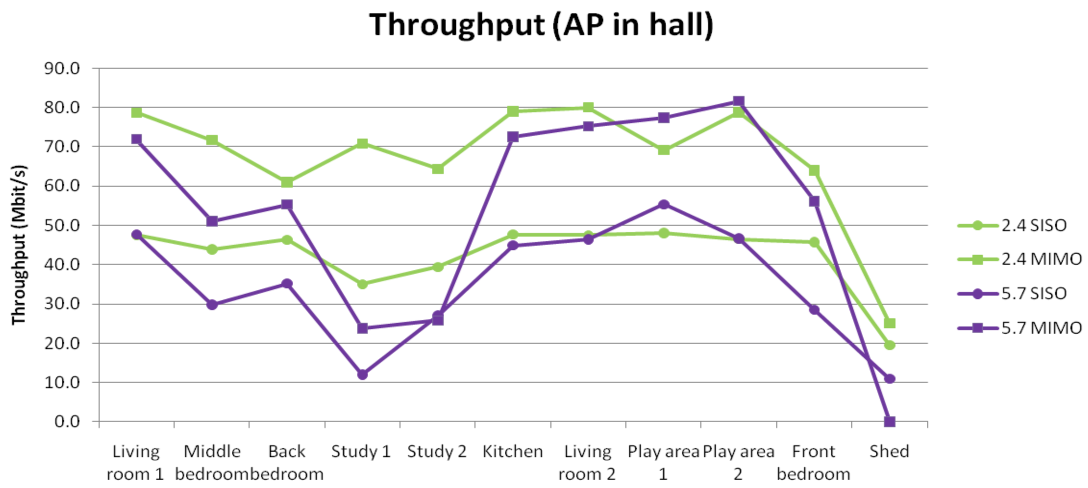
In practice, a higher bit rate can be realised by using multiple input multiple output (MIMO) antenna configurations. Indoor measurements undertaken by Aegis Systems[76] have indicated that deployment of the most common 2x2 MIMO configuration can yield an increase of 50 – 80 % in throughput in an indoor environment. The improvement is smaller outdoors – recent trials undertaken by Real Wireless[77] have suggested an improvement of 30% is more realistic for outdoor small cell deployments.

Actual usable throughput will be lower than the headline Layer 1 values referred to above. Typically the protocol overheads associated with Wi-Fi transmission account for up to 25% of the Layer 1 bit rate, hence the quoted maximum for a single stream of 65 Mbps would in practice be reduced to about 48 Mbps. The figure below shows the actual bit rates (based on file downloads) achieved in a typical suburban house from an 802.11n access point using single stream (SISO) and 2x2 MIMO configurations.

76 Indoor propagation study final report for Ofcom, June 2011.

77 "An assessment of the value of small cell services to operators based on Virgin Media trials, October 2012.

Figure 6-3: Measured throughput from an 802.11n access point in a typical suburban dwelling (20 MHz channel)



The minimum bit rate achieved with a 2x2 MIMO configuration at 5 GHz is approximately 24 Mbps in a 20 MHz channel, which equates to a spectrum efficiency value of 1.2 bits/Hz. This assumes that the access point is operating on a "clean" channel and that there are no other co-channel access points or other sources of interference within range. The implications of interference are significant in a licence exempt frequency band where the user has little control over other uses in the band. This is particularly the case at 2.4 GHz, where the presence of interference sources such as microwave ovens, wireless CCTV and other short range devices can cause significant degradation to Wi-Fi networks. The 5 GHz band is relatively lightly used at the moment, but take up is increasing as more dual band devices come on the market, and public networks in particular are making increased use of this band.[78]

Referring back to Figure 6-3, it can be seen that the Wi-Fi signal in a high density residential environment will extend well into the five immediately adjacent dwellings, and will also extend into the dwellings immediately above and below in a multi-storey environment. In effect, a given residential Wi-Fi signal is likely to overlap with at least seven other neighbouring residential Wi-Fi signals in a high density urban environment.

This implies that a minimum of eight separate frequency channels would be required to ensure that each dwelling was capable of realising the optimal performance from a Wi-Fi access point). If fewer channels are available, then contention will arise between neighbouring access points that operate on the same frequency, reducing the available

78 See for instance Brian Williamson et al., "Future proofing Wi-Fi – the case for more spectrum", Plum Consulting, January 2013.

bit rate for each user. The minimum measured bit rate of 24 Mbps at 5 GHz in a typical residential dwelling is half the value of our upper bound traffic estimate of 48 Mbps for a high usage home. We therefore consider it likely that, in the long term, uncontended access to at least two 20 MHz Wi-Fi channels may be required to provide adequate capacity to each home in a densely populated, high usage residential environment to support the full range of fixed, mobile and off-network wireless traffic.

Whilst this might be considered to be a somewhat “worst case” scenario in terms of traffic density, it should also be borne in mind that the assumed 48 Mbps per home capacity implied by two 20 MHz channels is less than half of the 100 Mbps DAE target, and the latter does not allow for off-network traffic such as in-home video distribution.

The implication of all this is that the total spectrum required to support all residential Wi-Fi traffic without the risk of degraded performance would be approximately **320 MHz** (i.e. 40 MHz per home multiplied by the eight separate frequency channels required to avoid contention). Note that the projection is based on average busy hour traffic in high usage homes in high density residential areas, i.e. those subscribers most likely to fall within the 50% DAE target group for 100 Mbps broadband.

6.2.2 Wi-Fi spectrum demand in the work environment

Spectrum efficiency in a large open plan business environment is likely to be more constrained than in a residential environment as there may be fewer walls separating adjacent access points. A large number of access points are likely to be required to meet the required coverage and capacity, but the absence of shielding means that overlap and contention are likely to be more problematic than in the residential scenario where building attenuation tends to limit the range of interfering signals.

Enterprise WLAN designers typically recommend that access points should be configured to operate at the highest available data rates to maximise application throughput.[79] Whilst this could be done by deploying wider channels, in a high-density network this may be counter-productive since there would be fewer channels available for reuse among nearby access points, resulting in channel contention which would reduce overall network capacity. In consequence, designers typically recommend a higher density of access points in preference to the use of wider channels to optimise capacity rather than deploying wider channels. In other words, having a larger number of uncontended narrower channels (e.g. 20 MHz) is likely to deliver greater overall throughput and spectrum efficiency than a smaller number of wider channels (e.g. 40 or 80 MHz).

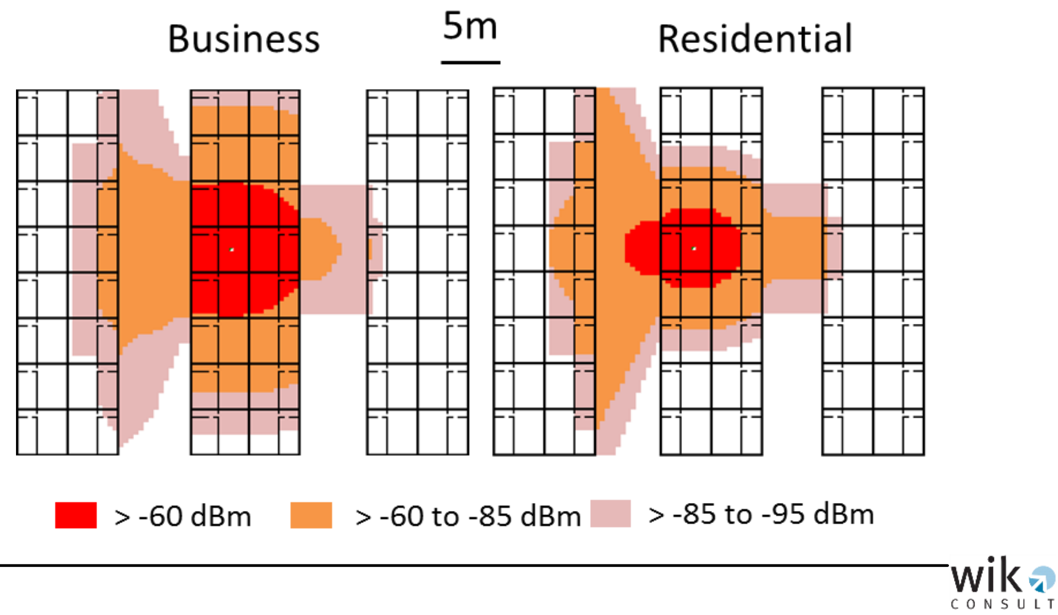
As we have already seen, to ensure connectivity at the highest speeds and to avoid contention with other co-channel access points, a minimum signal strength of approximately -64 dBm with a signal-to-noise ratio of 25-30 dB is recommended. This

79 See for example “High-Density Wi-Fi Design Principles”, Aerohive white paper, 2012.

requires a high density of access points with a good degree of separation between those operating on the same channel.

A typical open plan business environment with wood or plasterboard partitions but steel or concrete outer wall is likely to have somewhat smaller internal attenuation but greater indoor / outdoor attenuation than the residential environment considered in scenario 2. Actual values will vary considerably between buildings but a typical value at 5 GHz might be 5 dB per internal partition and 30 dB indoor / outdoor attenuation. By comparison, the wall loss value we assumed in the residential environment was 15 dB. Comparing the signal propagation at 5 GHz in the two environments, it can be seen that based on the above assumptions the signal level generated by an indoor AP in a business environment extends considerably further indoors, but is lower in the immediate outdoor vicinity to the residential case. Note that in the business case we have assumed that the indoor space is configured into individual work areas 5 m squares separated with floor standing partitions having a nominal 5 dB attenuation.

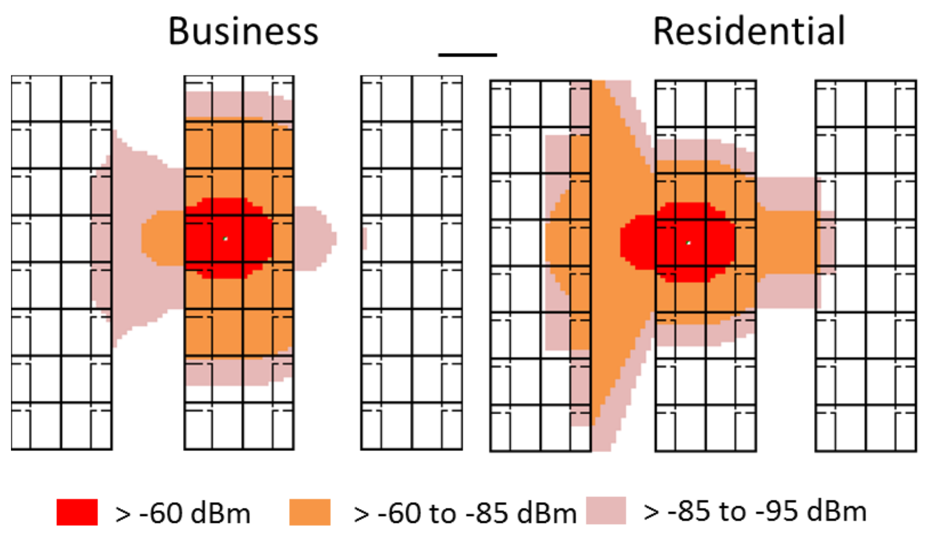
Figure 6-4: Comparison of signal level from an indoor access point in typical business (open plan office) and residential environments



This comparison assumes that the same radiated power applies in both cases, but in practice a lower power would probably be deployed in the business environment, to reflect the lower level of internal attenuation and to reduce contention with neighbouring APs. The impact of reducing the power by 10 dB in the business environment is shown below. Although there is a noticeable reduction in the distance at which contention will occur, it can be seen that that contention (represented by the yellow contour) will still arise over a significant area and that contention free operation would require access to

10 or more separate frequencies (more will be required if adjacent floors are also taken into account).

Figure 6-5: Comparison of signal level from an indoor access point in typical business (open plan office) and residential environments, with power reduced by 10 dB in the business environment



This implies a potential spectrum requirement of approximately 200 MHz to support traffic in the indoor enterprise network. If outdoor coverage is required, it is likely that a further two 20 MHz channels would be required to provide outdoor coverage (it is assumed that the same considerations as we applied to WMAN networks in the previous scenario would apply to the outdoor business coverage here. A further two channels would be required for in-band meshing of outdoor access points. It is conceivable that some applications, such as CCTV, may require access to additional or wider channels. Given that such applications generally deploy point to point or point to multipoint wireless links with directional antennas, which will tend to enhance spectrum efficiency, we anticipate that this would account for no more than one or two additional 20 MHz channels. Hence, the total spectrum requirement for business use would be in the range **200 - 320 MHz**, depending on the nature of any outdoor coverage required.

6.2.3 Wi-Fi spectrum demand in a public environment

As we have already noted, traffic carried by public Wi-Fi hotspots has historically been a relatively small proportion of total wireless data traffic, however greater ease of access through improved interworking and roaming arrangements is likely to lead to substantial growth in this type of offload in the future. For example, in the UK, O2 Wi-Fi have told us that they have seen traffic levels up to 6 times higher on some of their outdoor Wi-Fi networks in London than on their cellular network in the same area and BskyB owned network The Cloud is finding increasing numbers of users streaming video over public Wi-Fi connections. Both of these operators are now offering automated log-in facilities and are deploying concurrent dual band APs throughout their networks to provide greater speed and capacity. A significant amount of traffic is generated by portable devices such as tablet PCs that do not have a cellular connection capability but are still widely used on the move.

Future traffic on public Wi-Fi networks is difficult to project given their relative immaturity. However, in the UK BT recently stated that their public Wi-Fi network traffic had increased by 100% in six months and by over 1000% over four years, as more Wi-Fi enabled devices including smartphones, tablets, laptops, consoles and cameras entered the market.[80] Such growth rates and the experience of O2 referred to above suggest that public Wi-Fi traffic levels at some locations could become significantly higher than on macro cellular networks. In the absence of other quantitative data on public Wi-Fi traffic, we have made an estimate based on comparison between the capacity of a single mobile base station and a network of Wi-Fi hotspots serving a similar area, assuming such levels of traffic were to be maintained.

In a typical city centre location corresponding to the coverage area of a single tri-sectored cellular base station, our research indicates there are likely to be approximately 400 Wi-Fi hotspots.[81] Assuming that the cellular base stations can carry a throughput of 3 Mbps per sector per carrier and that currently 14 3G carriers are available, the current mobile network capacity for the area would be 3 x 3 x 14 = 126 Mbps. If six times that amount was assumed to be carried over the local public Wi-Fi hotspots (consistent with the ratio reported by O2), this implies a peak traffic level currently of approximately 300 kbps per access point, averaged across the 400 access points. Our extrapolation of Cisco's VNI projections for mobile data traffic in the UK suggests a 35-fold increase by 2025. Assuming the ratio of traffic carried over the local public Wi-Fi network remains the same, this would imply a long term traffic demand of approximately 11 Mbps per hotspot access point.

Public Wi-Fi access points typically serve a wider coverage area than a domestic or business access point (e.g. many indoor hotspots can also be accessed outdoors in the immediate vicinity and outdoor access points by design are intended to serve a relatively wide area. This will increase the likelihood of users being located towards the edge of the coverage area, leading to lower spectrum efficiency compared to the residential scenario. In consequence, it is likely that reliable delivery of 11 Mbps throughput in a public hotspot environment would require access to a single uncontended 20 MHz channel per access point. Assuming a similar re-use capability to

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80 Source: BT interview in connection with 2013 Global Broadband Traffic Management Conference (http://broadbandtrafficevent.com/bt-speaker-interview/).

81 Based on a survey of the Covent Garden area of London.

the residential scenario (i.e. 8 separate frequency channels required) this would imply a total spectrum requirement for public Wi-Fi deployment of up to 160 MHz. If in-band meshing of access points is used to support backhaul of an outdoor Wi-Fi network, up to twice this amount of spectrum could be required.

6.2.4 Estimating the future spectrum requirement for Wi-Fi

Our analysis of potential traffic levels and spectrum efficiency in the home environment suggest that up to eight 40 MHz channels (i.e. 320 MHz total) would be required. A similar quantity of spectrum may be required in large enterprise environments where there is a mix of indoor and outdoor access point deployment. High density public Wi-Fi deployments are likely to require between 160 MHz and 320 MHz of spectrum in the longer term, depending on the extent to which Wi-Fi is used to interconnect adjacent access points. Hence the total spectrum requirement to support private and public Wi-Fi in the longer term is likely to be in the range 480 – 640 MHz.

The currently available spectrum in the 5 GHz band is 455 MHz; however, the current fragmentation of the band means that only nineteen 20 MHz channels or nine 40 MHz channels can be accommodated (i.e. the actual usable spectrum is reduced to 380 or 360 MHz depending on the channel configuration). It should also be noted that some of the channels have restricted geographic availability in order to protect radar use in the band, particularly weather radars in the 5600 – 5650 MHz range.

A further 83 MHz is available in the 2.4 GHz band, but again constraints arising from the way the band is configured mean that only three non-overlapping 20 MHz channels are available at any given location. The total available Wi-Fi spectrum, assuming 40 MHz channels are deployed at 5 GHz, is therefore currently 420 MHz, which is between 60 and 220 MHz less than the spectrum we have identified as being required to support private and public Wi-Fi deployments in the longer term.

The latest 802.11 standard (802.11ac) enables the use of wider channels in the 5 GHz band (80 MHz and 160 MHz) to deliver headline bit rates of 1 GB or more (though as with existing equipment actual throughput is likely to be much lower, typically on the order of 200 – 300 Mbps in a good RF environment). A consequence of the wider channel width however is that far fewer channels are available – only four in the case of 80 MHz channels, and only two in the case of 160 MHz channels. It will therefore be much more difficult in practice to achieve the *signal-to-noise ratio (SNR)* levels required to ensure optimal performance with these wider channels.

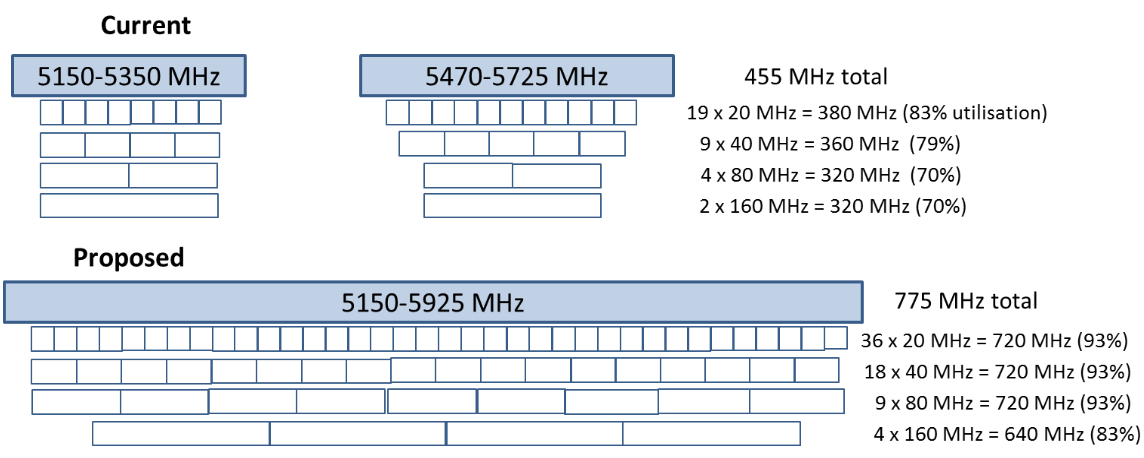
Some stakeholders that we spoke to expressed concern that deployment of 802.11ac systems using wider channels may impact on the quality of existing 20 MHz and 40 MHz systems, since a single 802.11ac carrier overlaps several of these narrower channels. The 802.11ac standard explicitly addresses this concern by mandating automatic fall back to narrower channel operation where other co-channel users are detected. This “dynamic bandwidth” approach is intended to ensure fairness of medium access for legacy 20 and 40 MHz channel devices.

We note that our stakeholder discussions have indicated a strong consensus that there will be future excess demand for spectrum in 5 GHz, and that additional spectrum will be required to cater for the anticipated growth in Wi-Fi and related traffic in the band. Our analysis supports this argument, and the likelihood of increasing demand for the wider channels provided by the new 802.11ac standard would strongly favour any additional spectrum being located adjacent to the existing 5 GHz bands.

In the interest of global harmonisation, we suggest that Europe consider aligning with the recent FCC proposal to make spectrum in the 5350-5470 MHz and 5725-5925 MHz available for Wi-Fi use, subject to establishment of appropriate co-existence mechanisms to protect incumbent users where required. This would provide a contiguous block of 775 MHz which we believe would be sufficient to cater for the foreseeable future demand for Wi-Fi traffic, and would be particularly advantageous for deployment of the latest wider bandwidth Wi-Fi standards.

Figure 6-6 illustrates the benefit that extending the 5 GHz band would have for deployment of wider Wi-Fi channels and increasing the proportion of usable spectrum in the band. Whilst the increase in total allocated bandwidth is just 70%, it results in an increase of 100% or more in usable spectrum for channels of 40 MHz or greater.

Figure 6-6: Comparison of current 5 GHz band with proposed extended band



Source: Aegis

6.2.5 Current use of the 5 GHz band

To date, the 5 GHz band has been very lightly used, largely because the vast majority of commercially available access points have until recently only been capable of operating in the 2.4 GHz band.[82] Furthermore, many of the dual band access points currently in use and as substantial proportion of those currently on sale are “single radio” devices that cannot simultaneously support 2.4 GHz and 5 GHz connections. Instead, the user has to select which band to deploy and given the limited historical availability of 5 GHz client devices it is likely that the majority of these dual band, single radio devices are in fact set to operate at 2.4 GHz. There is now an increasing trend in the market place towards “concurrent” dual band access points which do support both bands simultaneously, and these have adopted by public networks that have migrated to dual band technology, such as those operated by O2 and The Cloud in the UK. However there is an argument for ensuring consumers are better informed about the limitations of single radio dual band devices when upgrading their hardware, if the full benefit of the 5 GHz spectrum is to be realised (see Section 9.4.3).

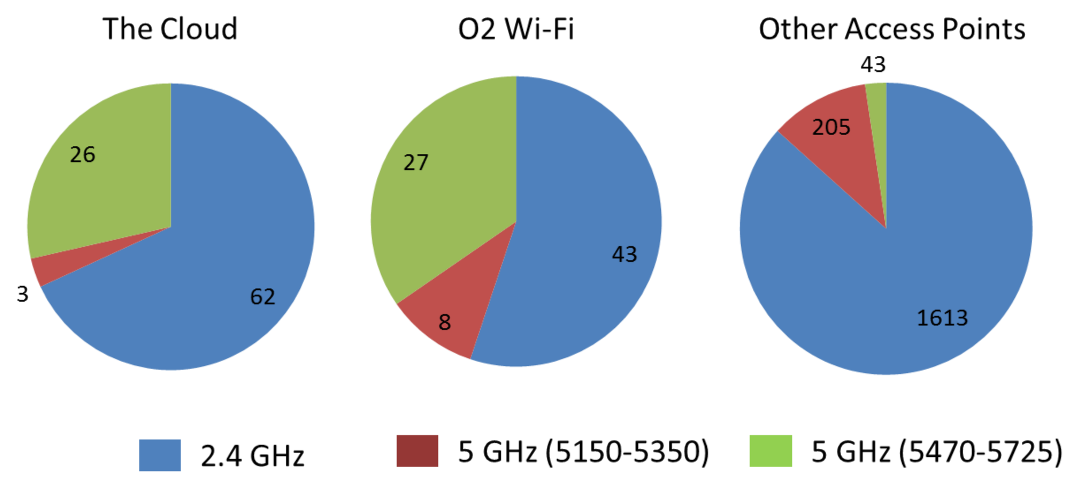
There is little practical evidence at this stage to indicate at what point the 5 GHz band might become congested. There are, however, signs that take-up is at last increasing, with an increasing number of client devices including smart phones and tablets now having dual band capability. There are also signs that public Wi-Fi networks in particular are recognising the potential of 5 GHz to enhance network performance and capacity. For example, the two largest public Wi-Fi networks in the UK are now deploying dual band access points throughout their networks, with automatic band steering to direct dual band clients to the higher band. As a result, up to 30% of connected clients are now using the 5 GHz band, and this proportion is expected to grow significantly over the next few years. Furthermore, those clients using 5 GHz tend to consume significantly more data. For example, a recent presentation by UK network operator The Cloud revealed that one busy hotspot location, 5 GHz clients accounted for 53% of the total data carried over the hotspot, despite representing only 30% of the users.[83]

Figure 6-7 compares channel utilisation in central London between access points operated by the two largest public Wi-Fi networks (The Cloud and O2 Wi-Fi) in comparison to channel utilisation by all other detected access points.

82 Even access points with 5 GHz capability are often not designed to simultaneously support 2.4 GHz operation and 5 GHz operation. See Williamson et al. (2013), op. cit.

83 “Wireless in your home”, presentation by Sami Susiaho to Cambridge Wireless event on 21st May 2013 (www.cambridgewireless.co.uk/crmapp/EventResource.aspx?objid=43005).

Figure 6-7: Comparison of channel utilisation (in terms of detected access points) in Central London between all access points and those of the two largest public networks



It can be seen that large scale public Wi-Fi networks are a significant driver of 5 GHz use today, particularly where outdoor coverage is being provided. By comparison, residential Wi-Fi use is almost exclusively in the 2.4 GHz band at present, and even in business environments private use of 5 GHz appears to be relatively small. It is likely, however, that as fixed broadband speeds continue to increase over the next few years, the limitations of 2.4 GHz will become more apparent, prompting migration to dual band systems.

6.3 Spectrum Efficiency for LTE small cells

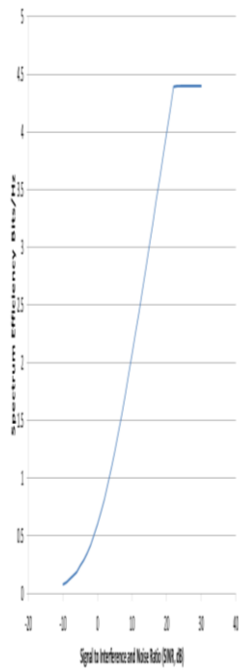
An LTE femtocell is in many respects similar to a Wi-Fi access point, e.g. in terms of the area covered and the powers deployed, however there is one key difference between the two technologies which can have a significant impact on the spectrum efficiency that can be realised. The difference is that LTE is capable of operating at significantly lower signal to interference + noise ratios (SINR) than Wi-Fi, by deploying a technique called inter-cell interference cancellation (ICIC) to reduce the impact of adjacent co-channel cells on one another. This is intended to enhance cell edge performance and also enables much more intensive frequency re-use, indeed the technology is designed to be capable of operating in a single frequency re-use mode, with all cells operating on the same frequency.

The superior performance of LTE at lower SINR values has a significant impact on the extent to which frequencies can be re-used and the spectrum efficiency that can be achieved. For example, consider the deployment of LTE and Wi-Fi in a dense urban scenario where a large number of co-channel access points are deployed in close proximity, such as in a large apartment block.

In the case of Wi-Fi, the available channel capacity will be contended between all the visible access points (as noted above), so for bursty traffic with a low average bit rate and reasonable delay tolerance (such as web browsing or e-mail) performance is likely to be adequate even if all access points use the same frequency. However, if each access point is fully loaded to the maximum available capacity, this will be shared between up to eight different access points and the available capacity per access point will be reduced accordingly.

In the LTE case, the available throughput per femtocell depends on the level of inter-cell interference (SINR), in accordance with Figure 6-8.[84]

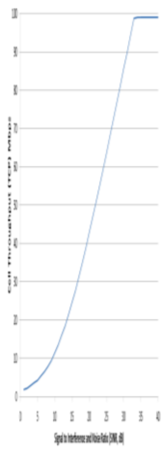
Figure 6-8: LTE downlink spectrum efficiency as a function of SINR



Translating this to throughput in Mbps, assuming 2 x2 MIMO with a 50% improvement over a single stream and a 25% allowance for transmission and protocol overheads yields the following values:

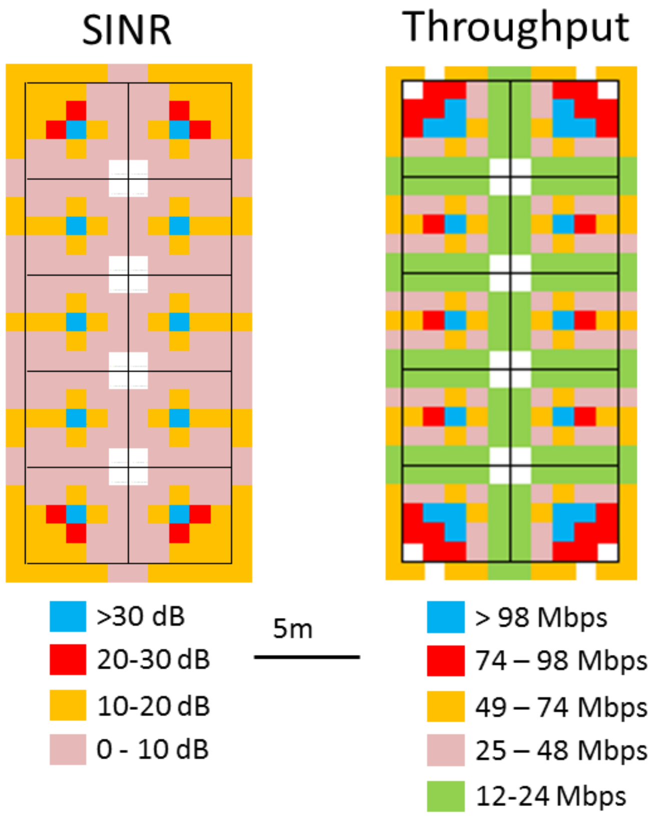
84 Source: 3GPP specification TR36.942, version 11.00.00. table A.2.

Figure 6-9: LTE downlink throughput as a function of SINR



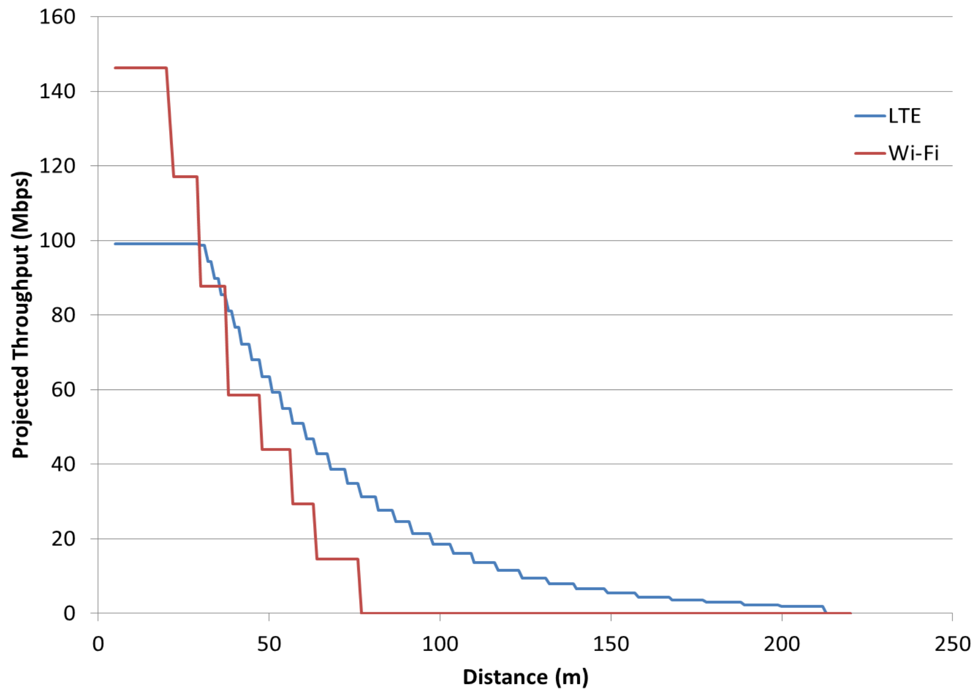
We have modelled the likely SINR and corresponding LTE throughput in a dense residential environment with all households operating a femtocell on the same 2 x 20 MHz channel (see Figure 6-10).

Figure 6-10: Projected LTE throughput in a dense residential environment, single frequency re-use (based on Hata indoor SRD propagation model)



By comparison, Wi-Fi throughput in a similar scenario where the same frequency was used throughout would be between 18 Mbps and 146 Mbps depending on the traffic loading and distribution across the visible access points and assuming a 40 MHz channel (equivalent in total bandwidth to a 2 x 20 MHz LTE channel) This compares with a range of between 12 Mbps and 98 Mbps for LTE. Thus Wi-Fi can deliver greater throughput under optimal conditions, but its performance degrades more quickly as one moves away from the access point, or as the level of interference increases. This is illustrated in Figure 6-11 below, which compares the coverage range that can be expected from an LTE small cell relative to that of a Wi-Fi access point for a given bit rate.

Figure 6-11: Comparison of Wi-Fi and LTE throughput vs. outdoor range (2 x 20 MHz LTE, 40 MHz Wi-Fi, 2.5 GHz) based on COST-Hata urban propagation model



Source: Aegis Systems

In conclusion, both technologies provide a high degree of spectrum efficiency, but LTE performs better under high traffic loading conditions due its ability to deploy more intensive frequency re-use. By contrast, Wi-Fi has the potential to provide a higher peak bit rate owing to the wider RF channel bandwidths that are available.

6.4 Potential impact of other technology developments on spectrum demand

The study terms of reference call on us to consider the implications of a number of potential technology developments for spectrum demand for wireless broadband services over the next five years:

- Increased (economical) use of higher frequencies (e.g. 3 GHz and above);
- Channel aggregation (e.g. to address increasingly asymmetric use);
- Potential use of multicast/broadcast (IMB, MBMS) technologies; and
- Accelerated/operator-managed switchover from GSM to UMTS/LTE.

Spectrum above 3 GHz is particularly suitable for small cell deployment due to the limited transmission range. A number of equipment vendors are already actively developing LTE equipment for this band. Indeed, it is likely that many of the existing WiMAX networks licensed in this band will migrate to LTE over the next few years (UK Broadband in the UK has already done so, and Clearwire in Belgium has announced such a move); however, there has been little interest in these higher frequencies to date from established mobile operators, and our analysis indicates that the existing bands below 3 GHz (including the recently licensed 2.6 GHz band) will provide sufficient capacity to accommodate projected traffic growth over the next five years.

Channel aggregation, or the ability for operators to combine spectrum in different frequency bands to provide higher speeds and network capacity, may provide opportunities to enhance downlink capacity by using additional bandwidth in unpaired frequency bands. Candidate bands include the time division duplex (TDD) portions of the current 2 GHz and 2.6 GHz bands, and the former L-band DAB allocation (1452-1492 MHz) which is largely unused currently in Europe. TDD spectrum is particularly well suited to low power, small cell operation, since shorter guard intervals are required and transmit-receive synchronisation is less of a problem than in macro networks.

Mobile broadcast and multicast technologies provide a more efficient way of delivering streamed content to a large number of users simultaneously. Mobile broadcast and multicast could thus help to relieve pressure on both cellular networks and backhaul capacity arising from excessive numbers of individual real-time video streams, such as may arise during major sporting or cultural events; however it is uncertain how great a benefit this will be in practice. Much mobile multimedia traffic is currently on-demand rather than broadcast, and thus does not benefit from the use of multicast/broadcast technologies. Previous attempts to introduce mobile broadcast platforms such as DVB-H have been unsuccessful.

Finally, growing volumes of data traffic should provide operators with an incentive to migrate existing spectrum towards 4G LTE technology. Whilst the higher speed provided by LTE may itself stimulate additional traffic growth, this will be largely offset by the improved spectrum efficiency, particularly in comparison with existing 2G networks (see Figure 2-1).

Overall, we do not therefore envisage any additional demand for licensed cellular spectrum arising from technology development in a five year timeframe. There may however be additional demand arising if LTE is widely deployed as a fixed broadband substitute (e.g. in rural areas where no fixed infrastructure exists) or in the longer term to support next generation mobile technologies such as those currently under study in various research and development fora (see section 5.3.8.3 for example).

In the case of Wi-Fi, we expect growing traffic levels and demand for higher speed devices using the latest 802.11ac standard in wider RF channels to increase pressure for further spectrum in the 5 GHz band (see section 6.2.4).

7 Net socio-economic benefits of data traffic off-loading at EU level

In Section 3.1, we estimated the bandwidth demand for data traffic off-load for several Member States. In Chapter 6, we estimated spectrum requirements. In this chapter, we will assess the net socio-economic benefits of using data traffic off-load.

This analysis is generally independent of whether DAE broadband goals are achieved or not. As we explain in Chapter 8, off-load has only minimal influence on coverage of basic broadband or 30 Mbps broadband; however, it has an influence on costs, prices, and adoption of mobile broadband.[85] It thus has strong societal welfare implications.

7.1 Overall approach

It is important to distinguish among a range of factors:

- Human activities tend to have both *costs* and *benefits*. Policy interventions also have costs and benefits.
- We speak of *socio-economic* costs and benefits so as to keep in mind that these costs and benefits often have not only measurable economic aspects, but often also have harder-to-quantify social aspects.
- Some of those costs and benefits are relevant to *consumers*; others are relevant to *suppliers* or *producers* of the product or service.
- The benefits to consumers, net of all costs, are referred to as *consumer welfare* (or *surplus*). Analogously, benefits to producers, net of all costs, are referred to as *producer welfare*.
- *Societal welfare* is generally taken to be the sum of consumer welfare plus producer welfare.
- From the perspective of public policy, societal welfare is typically what we are seeking to optimise or maximise.

Off-load could in principle deal with a small fraction of all mobile traffic, or a large fraction of mobile traffic. Consumers can be expected to benefit from achievement of DAE objectives, but the level of consumer benefits need not be greatly influenced by the degree to which those objectives are met by fixed, mobile, or off-load solutions. The need to meet DAE objectives thus does not, in and of itself, dictate the traffic that should be carried by the mobile network together with off-load solutions, and consequently does not alone dictate the spectrum needed for off-load.

85 Adoption of 30 Mbps services is not an explicit DAE objective; however, it is obvious that it is important. Coverage without adoption would be meaningless.

The fraction of mobile traffic carried by off-load solutions does, however, influence costs to service providers and network operators, and their prices, and therefore directly influences producer welfare. These effects are presumably reflected in total payments made by consumers; thus, the level of off-load influences the costs of the MNOs, and thus also influences consumer welfare (benefits net of costs).

It is not just the case that consumers pay less for the same amount of service; they also *consume more services* as a response to prices that are low or zero (in the case of home Wi-Fi, for example. They also *consume different kinds of services* (e.g. more bandwidth hungry services such as YouTube and downloads) when fast, reliable, and inexpensive or free off-load is available (see Section 4). This increased consumption represents a distinct gain of consumer welfare.

Finally, small cell off-load enables greater re-use of spectrum over a given geographic area. This efficiency gain enables more consumption within a given quantity of spectrum (a gain to consumer welfare). Alternatively, the efficiency gain reduces the amount of spectrum required to provide a given level of consumption, enabling the spectrum to be used for other worthy purposes (a reduction in opportunity costs, and thus a benefit to society as a whole).

For public and private services, the costs include the incremental cost of building the off-load network. (The reduction in cost for the macro cellular network is in effect considered as a benefit.) For off-load to existing Wi-Fi in the home or office, however, the cost impact of mobile data back-haul traffic on the fixed network is small.

For public services, the cost of all infrastructure must be considered.

If additional spectrum is to be assigned to data off-load, the costs also include (1) the opportunity cost associated with allocating the spectrum to this use rather than some other beneficial use; and (2) any costs of relocating incumbent applications. In many such analyses, the opportunity costs dominate; however, given that the spectrum in this case will presumably be above 1 GHz, and much of it presumably above 5 GHz, we believe that the opportunity costs in this case will be more modest. This cost must also be considered net of reduced opportunity cost if less spectrum is needed for the macro cellular network.

7.2 Estimation of net benefits of mobile data off-load

In Section 4, we estimated the traffic that has been available, or can be expected to be available, for mobile data off-load in France, Germany, Italy and the UK from 2011 to 2016. We did this under a range of simplifying assumptions, including the assumption that we would analyse the offered load, that is, the load that would be present in the absent of constraints (e.g. limited network capacity, limited spectrum availability).

That analysis provides one relatively simple means of assessing what would have happened in the hypothetical, counter-factual world where off-load were somehow impossible. Suppose, to give an extreme example, that it were technically infeasible to include Wi-Fi support in a smartphone or tablet. What might have happened?

We put forward the following outcomes:

- A portion of the traffic now being off-loaded would be ***carried over the macro cellular network***. This traffic would likely impose (1) substantial additional costs on MNOs, (2) additional usage-based charges for consumers, and (3) congestion on mobile networks with complex implications. As an alternative to modelling congestion, we will instead model the costs (especially opportunity costs) of allocating sufficient spectrum to provide congestion.

- A portion of the traffic now being off-loaded would ***shift to conventional fixed network devices and applications*** (e.g. personal computers). This represents a cost to users in the form of a loss of convenience, since they do not execute the application on what would otherwise be their device of choice.

- A portion of the traffic would ***disappear, because the consumer would not choose to use the network in this way***. Some YouTube videos, for example, would not have been downloaded in the counter-factual world that in the real world were in fact downloaded. The consumer might have judged either that the time required, or that the usage-based expense under a tiered or capped pricing plan, were greater than the perceived value of the service. This is a function of the price elasticity of demand on the part of the consumer, and represents a loss of consumer welfare.

The relative proportions among these three possibilities thus represent a range of possible outcomes, each with its own implications for socio-economic costs.

None of these are particularly easy to quantify, but the first is easier to express in monetary terms than the others, at least in terms of the investment cost impact on MNOs.

Based on off-load to Wi-Fi (i.e. in licence-exempt spectrum), we estimate the savings in network cost already generated in 2012 for the EU-27 to be 35 billion euro, and the projected savings in 2016 to be 200 billion euro; however, this rough estimate should be understood to represent a generous upper bound. In reality, consumers would choose instead to do somewhat less with their mobile devices, or to use fixed network devices and interfaces instead of mobile. In these cases as well, however, consumers clearly benefit from traffic off-load.

7.2.1 The magnitude of offered load

Based on the analysis of Section 4, the offered load magnitude of off-load traffic is as shown in Table 13. Broadly speaking, the ratio of off-load traffic to cellular traffic rises from 1.90 in 2011 to 3.5 in 2016, which implies that cellular traffic was about a third of total offered load in the recent past and declines to just over one fifth of total offered load in 2016. The change over time reflects the declining role of personal computer traffic (for which it is not relevant to speak of off-load) in the total, and the increasing role of smart phones and tablets.

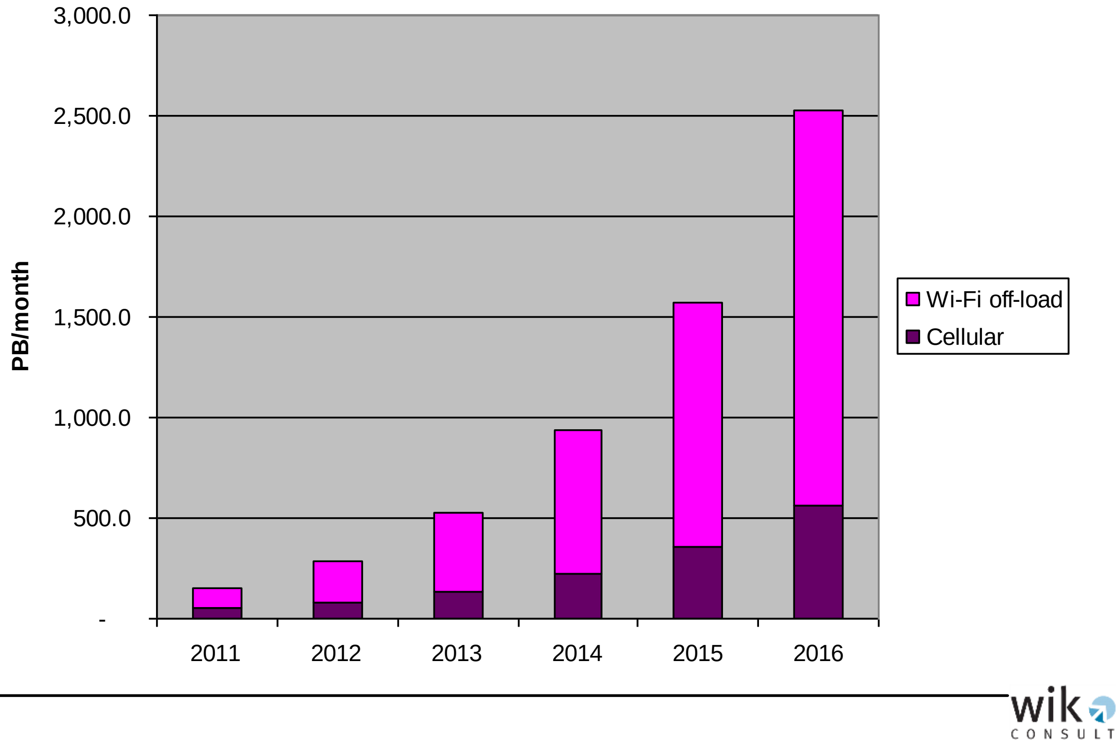
Table 13: Estimated cellular traffic and data off-load traffic (PB/month)[86]

		2011	2012	2013	2014	2015	2016
Cellular traffic	France	9.8	13.6	21.1	34.1	54.5	83.4
	Germany	7.5	13.5	24.3	42.5	72.5	118.6
	Italy	8.7	16.7	28.1	46.6	78.3	125.9
	UK	26.4	38.8	61.9	100.2	155.4	233.8
Cellular		52.4	82.6	135.5	223.3	360.7	561.7
Wi-Fi off-load traffic	France	13.5	26.0	50.0	90.3	152.9	244.7
	Germany	31.7	62.4	122.9	226.8	400.4	673.6
	Italy	12.7	26.6	48.8	85.4	148.4	245.3
	UK	41.8	85.8	170.8	309.7	509.4	802.1
Wi-Fi off-load		99.8	200.8	392.5	712.2	1,211.1	1,965.8
Ratio off-load to cellular		1.90	2.43	2.90	3.19	3.36	3.50
Cellular fraction of total		34%	29%	26%	24%	23%	22%

Graphically, we see in Figure 7-1 that off-load greatly exceeds traffic that remains on the macro cellular network.

86 WIK calculations based on Cisco VNI (2012) and Mobidia/Informa data, as described in Section 4.

Figure 7-1: Observed or predicted mobile data off-load



Source: WIK

7.2.2 Costs and benefits to the macro-cellular network of traffic shifting

The dominant benefit by far of mobile data off-load is the reduced cost to MNOs of carrying a majority of the traffic from smartphones and tablets, thanks to the use primarily of private Wi-Fi. As a related matter, consumers benefit from greater speed, reduced (or negligible) cost, and the ability to do more with their mobile devices. Our focus in this section is on costs to the MNO.

We have estimated these benefits as if the reduced costs merely enhanced the profits of the MNOs. In practice, the benefits would be shared between consumers and providers, but in a ratio that is difficult to predict and that likely varies from Member State to Member State, and from MNO to MNO, largely as a function of a degree of competition in the market for mobile data services. Under perfect competition (which never exists in practice), MNOs would compete all of their savings away, and all advantages would flow to consumers. We assume that most European Member State markets for domestic services are reasonably competitive, but with variations from one Member State to the next. This implies that a substantial but competition-dependent fraction of the savings can be expected to be passed on to consumers, while the MNOs also benefit. Since this implies a win-win arrangement that benefits both sides of the market, it seems to us to be a positive outcome.

An MNO's investment costs are driven primarily by the need for (1) coverage and (2) capacity. A shift of traffic from mobile data off-load to the macro cellular network would increase the capacity required, but would have little or no effect on the coverage needed.

This observation has important implications for spectrum usage, which is the key driver for this study. Spectrum below 1000 MHz is scarce (thus expensive), and is particularly important in order to achieve coverage. Since shifting traffic to the macro cellular network primarily implies a need for more capacity, it would not necessarily imply the need for more spectrum below 1000 MHz; rather, the needs could appropriately be met with spectrum above 1800 MHz.

In order to provide a rough estimate of the magnitude of the network investment costs that MNOs may have saved due to data off-load it is necessary to make a great many simplifying assumptions. It is also necessary to draw on many years of WIK experience with *Long Run Incremental Cost (LRIC)* cost modelling of mobile networks. Among our assumptions are:

- For this report, we are assessing the *maximum* reduction in annual cost if *all* traffic that is currently off-loaded to Wi-Fi were instead transmitted over the macro cellular network. As explained earlier, some applications would instead be run over the fixed network using a personal computer, while others would not be run at all. The traffic that disappears from the mobile network represents a loss of consumer welfare rather than a cost to MNOs.

- Our estimates here are for the period 2012-2016, corresponding to Cisco VNI data from 2012.

- The vast majority of off-load traffic today corresponds to private Wi-Fi off-load. The incremental cost of carrying this traffic on the fixed network today over the end-user's broadband connection is probably small enough to ignore today. By 2020, these costs would likely be more substantial.

- The (relatively small) mobile network cost benefits due to public Wi-Fi off-load at today's levels in percentage terms are included in this analysis. In fact, we believe that the level of public off-load is likely to grow, and also feel that it is more appropriate to project public off-load for femtocells and Wi-Fi together (as we have in Section 5.3.8), particularly in light of the growing tendency for the same devices to serve both.

- The level of off-load to femtocells today is quite small in comparison to that of Wi-Fi, to the point where it is challenging to make a forward-looking projection of femtocell off-load. The analysis of off-load in this chapter does not include femtocells.

- Based on WIK's experience, the combined one-off LRIC investment costs of all mobile networks in Germany computed on the basis of 3G technology would be between 15 and 20 billion euro. The one-off LRIC investment costs per end-user for France, Italy and the UK should be similar. We have assumed that these costs are proportionate to the population per Member State rather than the number of subscriptions in order to reduce distortions to differences in the average number of SIMs per user among the Member States.

- Based again on WIK's cost modelling experience, and as a rule of thumb, doubling the capacity of a 3G mobile network without changing the coverage increases one-off LRIC investment costs by about 50%. Increased traffic on an existing mobile network, without changing coverage, tends to result in increased "economies of fill".

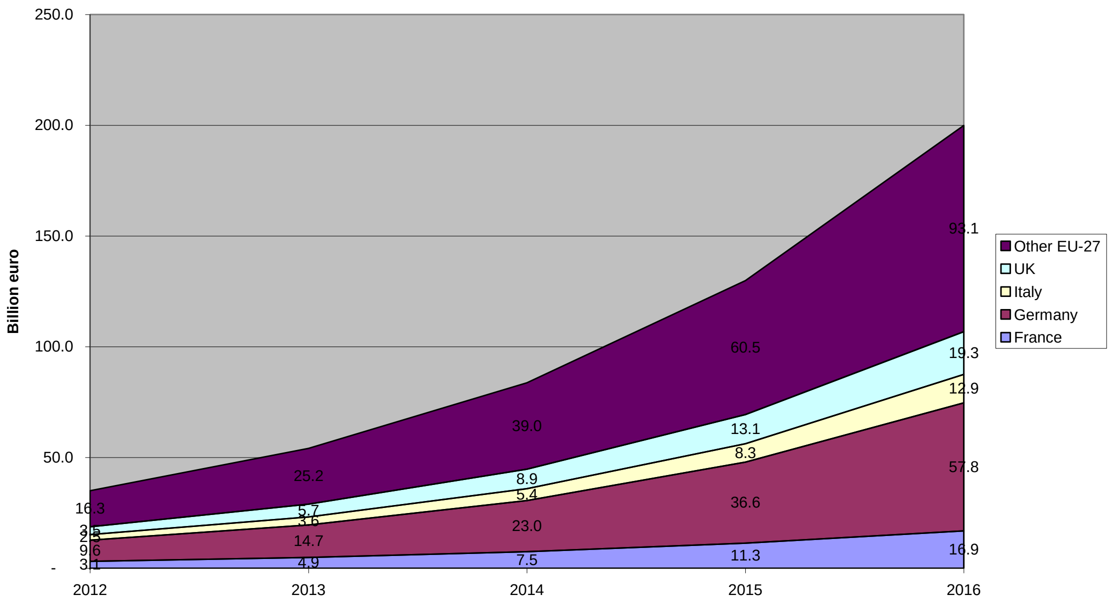
Under these assumptions, it is possible to translate the offered load estimates of Section 7.2.1 fairly directly into network savings of investment costs. The computations appear in Section 7 of the Annex to this report. The difference in cost is large, even after taking into account gains in fill as traffic increases.

Since these are incremental costs in a counter-factual scenario, this is really a measure of the amount of money that network operators have already saved, or can be expected to save extrapolating forward to 2016, thanks to data traffic off-load.

The annualised savings in network costs, and cumulative savings, appear in Figure 7-2, followed by cumulative savings in Figure 7-3. Again, the savings are large, perhaps surprisingly large. We estimate 35 billion euro in savings for 2012, and 200 billion euro in savings for 2016.

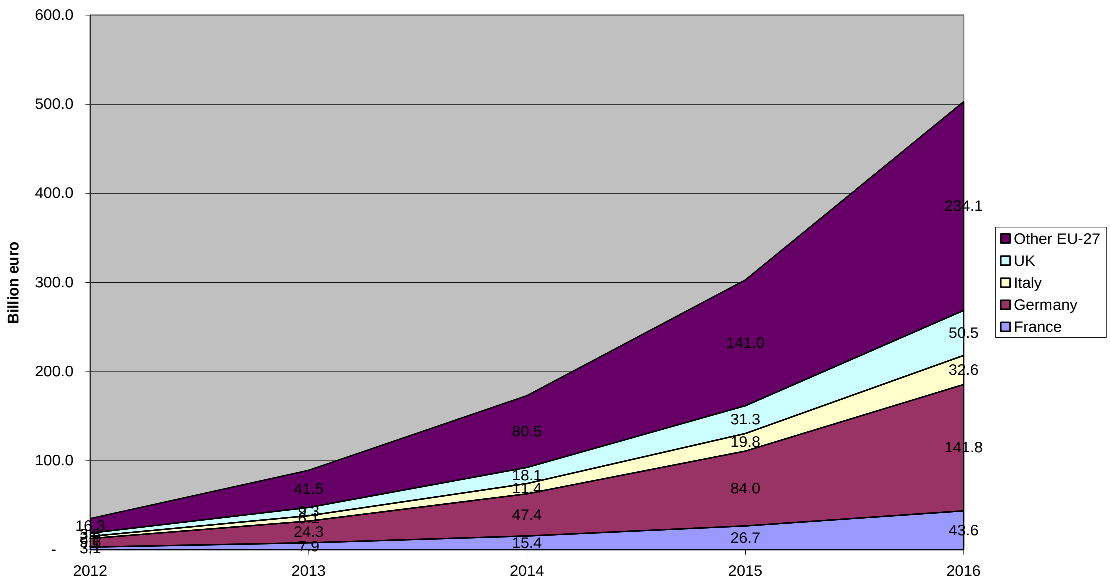
Again, we emphasise that in reality, consumers would choose instead to do somewhat less with their mobile devices; that they do more in the real world than in this counter-factual world represents a consumer benefit. Also, some of the MNO savings would be competed away, and provided to consumers in the form of lower prices. Thus, some of the benefits of mobile off-load that are here attributed to the MNOs accrue in reality to consumers.

Figure 7-2: Annualised savings in network cost due to off-load (€ Bn)



Source: WIK calculations

Figure 7-3: Cumulative savings in network cost due to off-load (€ Bn)



Source: WIK calculations

7.2.3 Benefits due to greater use of the wireless network

To the extent that increased off-load results in lower costs for Mobile Network Operators, or in more operators being in the market, lower prices are likely to result. The lower prices transfer welfare from producers to consumers, and also result in greater consumption, possibly benefitting producers.

Off-load also tends to provide a faster and more reliable service. These factors, together with little or no cost to the consumer (especially important as the mobile industry moves increasingly to capped or tiered plans) result in a different pattern of consumer use when using off-load (e.g. Wi-Fi at home). There is far greater use downloading, and of services such as YouTube (see Section 4).

We have not quantified these effects. The vast majority of work that has been done to date on the consumer benefits associated with broadband assesses the consumer benefits of the *subscription*, not the benefits of *increased usage* of a given subscription. There should in principle be economic benefits from the use of a faster service, but only a small number of papers exist, and the results are not robust.[87]

7.2.4 Benefits of increased spectrum re-use

A key advantage of off-load, and of the increasing use of small cell approaches, is that a given spectrum allocation can be used by more devices and in more ways in a given geographic area.

This is, in effect, an efficiency gain. It could signify that more can be accomplished with a given spectrum assignment/allocation, or it could mean that less spectrum is required to support a given level of consumption over a geographic area.

There can in some cases also be a gain if higher frequency (relatively inexpensive) spectrum is used to substitute for lower frequency (more expensive) spectrum. It is also possible that spectrum that is used to support off-load where mobile traffic levels are particularly high could be used in other geographic areas where mobile traffic demand is lower to support other applications, such as delivery of fixed wireless broadband connections in rural areas.

In each of these cases, there is a gain to society in terms of *opportunity costs*. If that spectrum had not been re-purposed to support traffic off-load, what would it have been used for instead, and what would the value have been? The relevant opportunity costs have to be assessed in terms of the band or bands in question.

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87 For a comprehensive review of a wide range of studies, see Analysys Mason and Tech4i2 (2012), “The socio-economic impact of bandwidth”.

Auction prices for similar bands can provide a reasonable estimate for these opportunity costs.

Table 14: Index of incremental value/MHz/pop for harmonised allocations by application and frequency band[88]

	400-700MHz	700 MHz-1 GHz	1-2.1 GHz	2.1-3 GHz	3-4 GHz	4-6GHz
Cellular/BWA	0.01	1	0.5	0.1	0.01	0.001
Broadcasting (Terrestrial)	0.5	0.1	0.01	0.001	0	0
PMR/PAMR	0.1	0.1	0.01	0.01	0	0
Fixed links	0.01	0.01	0.001	0.001	0.0001	0.0001
PMSE	0.1	0.1	0.01	0.001	0.0001	0.0001
Satellite (civil)	0.001	0.001	0.001	0.001	0.001	0.001
SRDs	1	1	0.1	0.01	0.001	0.001
WTDS (WiFi)	1	1	1	0.1	0.01	0.01

All values are relative to 1, which is the value for public mobile services for frequencies in the range 700 MHz – 1 GHz.

Source: WIK/Aegis/IDATE/Plum

7.2.5 Costs of off-load

In contemplating costs of traffic off-load, a range of costs must be assessed. Once again, the opportunity costs associated with any spectrum that is or would be re-purposed to traffic off-load must be reflected.

It is also necessary to consider the costs to incumbents of clearing any spectrum that is to be re-purposed. The actual costs are heavily dependent on the incumbent use of the band in question. It is in principle possible to establish rough bounds based on the experience of for instance the French ARCEP in compensating French Government users for the costs of vacating spectrum over a period of many years (as we did in our study of PPDR for the German Government in 2010).[89]

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88 J. Scott Marcus, John Burns, Phillipa Marks, Frederic Pujol et al (2012), "Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency".

89 J. Scott Marcus, John Burns et al. (2010), "PPDR Spectrum Harmonisation in Germany, Europe and Globally".

Table 15: Historic experience with re-farming costs

Country	Year(s)	Band	Spectrum quantity in MHz	Transferred from	Relocation Cost in 000€	Population Affected in 000	Cost MHz/POP
US	2007-2010	1710 MHz	45	12 Fed Agencies & DoD	737,288	301,290	€0.05438
FR	2001	1800 MHz	150	Defence	7,000	59,476	€0.00078
FR	2001	2 GHz	140	Defence & FT	38,000	59,476	€0.00456
FR	2001	2.4 GHz	83.5	Defence	8,000	59,476	€0.00161
FR	2002-2010	DTT	320	Analogue broadcast	57,000	61,181	€0.00291
FR	2001	PMR446	0.1	SNCF & RRs	120	59,476	€0.02018

Source: NTIA, ANFR and WIK estimates

In estimating costs in the 5 GHz band, however, it is more useful to consider the specific characteristics of the incumbent applications, and the form of sharing or re-farming to be achieved. Costs are in fact modest in these bands (see Section 9.4.1).

8 Traffic off-load and the broadband objectives of the DAE

The Commission has asked us to consider the relevance of off-load to the achievement of the broadband objectives of the Digital Agenda for Europe. As previously noted, these goals are:

- by 2013, to bring basic broadband to all Europeans;
- by 2020, to ensure that all Europeans have access to much higher Internet speeds of above 30 Mbps, and
- by 2020, to ensure that 50% or more of European households subscribe to Internet connections above 100 Mbps.[90]

We focus here on the first two of these objectives. We assume that 100 Mbps objectives will generally be met using fixed telecommunications and cable networks.

8.1 Coverage objectives for basic broadband

Traffic off-load plays only a minimal role in achieving basic broadband coverage.

Analysis conducted for the European Commission by Point Topic demonstrates that there are significant gaps in broadband coverage today (see Figure 3-2). These are most noteworthy in newer Member States to the east of the former Iron Curtain, where the fixed telephone network never reached very far outside of large cities.

Mobile (and fixed wireless) networks can be expected to play a large role in achieving coverage in these areas.

Off-load techniques, however, are of limited benefit in expanding coverage into these rural or remote areas. Off-load, as we have seen in Chapter 3, is heavily dependent on the availability of back-haul. Where the fixed network does not reach, there is little scope for traffic off-load.

The areas where the fixed network does not already reach will also tend to be areas where the intensity of data traffic is low; consequently, the mobile network is unlikely to be over-loaded. Thus, there is limited scope for off-load as regards achievement of basic broadband coverage, the first of the DAE broadband objectives.

90 DAE, page 19.

8.2 Coverage and adoption of 30 Mbps broadband

Traffic off-load plays a complex role relative to the deployment and adoption of 30 Mbps broadband. In understanding the role of off-load, it is important to consider first the firms that are employing, and their motivations.

As we have seen in Section 5, the motivations of commercial parties are diverse.

- Firms such as Virgin and BT that have existing networks that can be used for back-haul, but little or no mobile network capability today, see off-load technology as a relatively inexpensive and synergistic means of entering a different market segment. Virgin does not view Wi-Fi as a viable business in its own right.
- Hot spot networks such as The Cloud (BskyB) and O2 Wi-Fi view off-load as distinct business, but the business objective may have more to do with acquiring customer data (in the case of O2) than with direct revenue generation.
- Firms such as FON view themselves as enablers for a new and synergistic business opportunity.
- Existing large MNOs such as Deutsche Telekom appear to view the use of off-load (e.g. by FON) as a means of reducing deployment cost, and increasing customer satisfaction and retention, but not necessarily as a revenue opportunity[91] nor as a strategic direction. Free Mobile apparently benefits from the use of off-load to reduce its need for expensive domestic roaming.

Taken together, these examples strongly suggest that *off-load is unlikely to result in the deployment of a network in an area where coverage is not already available*.[92]

In urban and semi-urban areas that are already served by the fixed network, however, the effects are likely to be substantial, but complex.

- Off-load facilitates competitive entry on the part of firms such as Virgin and BT.
- Off-load reduces expense for existing MNOs. This does not necessarily increase revenues; however, it probably increases profits. The net effect on MNO profits is difficult to predict, since the downward effect of off-load on costs is partly off-

91 The increased traffic from consumers who permit others to use their broadband connections for FON traffic will tend to generate little or no fixed network revenue because most subscribers are on flat rate plans, and the volume of traffic is unlikely to be large enough to change the flat rate price. Per the Eurobarometer e-communications Household Survey of June 2012, 60% of European households purchase Internet service through a bundle (EBS-381, page 89).

92 None of our case studies, none of our interviews, and none of our analysis suggests a significant tendency for off-load or for associated back-haul requirements to substantially increase broadband coverage.

set by the downward pressure that increased competitive entry places on revenues.

- Consumers receive more service, and better service, at no net increase in price (see also Sections 4.2 and 7.2.3).

- Consumers can be expected to consume more data than would otherwise be the case as a normal demand elasticity response to the effectively lower unit price of data transmission.

- More consumers are likely to take up mobile data services, again as a demand elasticity effect.

The broad implications of these assessments would appear to be that traffic off-load is unlikely to have much impact on the coverage of 30 Mbps services, but can be expected to generate substantially greater traffic from mobile devices than would otherwise be the case, and also a somewhat greater number of subscriptions than would otherwise be the case.[93]

In other words, traffic off-load is likely to promote increased *adoption* of 30 Mbps services, but will not necessarily have much impact on *coverage*. Coverage of 30 Mbps broadband services is an explicit DAE objective; adoption is not. Nonetheless, increased adoption must be seen in a positive light. Coverage would be meaningless in the absence of adoption.

Off-load helps more, then, in delivering benefits once the DAE goals are achieved than in initially achieving them. *The substantial increase in consumer welfare (more service at lower cost), together with a likely increase in producer welfare (increased profits), represents a substantial welfare gain overall*.

93 The magnitudes of these effects cannot be predicted without a detailed understanding of consumer price elasticity of demand, differentiated between usage elasticity and subscription elasticity.

9 Achieving the potential benefits of traffic off-load

In this chapter, we summarise the impediments to traffic off-load that were identified earlier in the report, and provide recommended public policy interventions where appropriate to address them.

For the most part, traffic off-load is a somewhat unanticipated success story for Europe and the world. The network cost reductions provided by traffic off-load can be expected to generate improved price/performance of mobile broadband for consumers. This can be expected to lead in turn to consumer welfare benefits, and to increased adoption and usage of mobile broadband.

Relatively little action is needed at European level; however, a few interventions should be considered in order to ensure that the momentum is maintained.

Section 9.1 summarises our key findings. Sections 9.2, 9.3, 9.4, and 9.5 provide a summary of impediments, a SWOT analysis of the opportunities and threats associated with traffic off-load, the rather limited policy interventions that we would recommend at European level, and an abbreviated Impact Assessment associated with the policy interventions.

9.1 Key findings

Spectrum demand is being driven both by current consumer demand for data and by European policy goals. The user demand for mobile data (and for wireless data in general) is growing at explosive rates. At the same time, European policy in the form of Digital Agenda for Europe (DAE) calls for full availability of basic broadband to all Europeans in 2013, and full availability of 30 Mbps broadband to all Europeans in 2020. Wireless is likely to play a significant role in achieving these DAE objectives. Off-loading of data from the macro cellular network onto shorter-range alternatives such as Wi-Fi, picocells or femtocells can (and already does) provide much greater capacity at a lower cost and potentially and presently offers a more flexible alternative. Wireless off-load is especially relevant to the 30 Mbps objective, since deployment of “small cell” architectures could provide a cost effective means to deliver high data capacity in areas where alternative wired access platforms are not available, provided that adequate backhaul capacity is available.

These off-load solutions potentially provide relief in many dimensions. They do not necessarily depend on licensed spectrum. To the extent that they are shorter range, they permit much greater spectrum re-use over a given geographic area than does the macro cellular network alone and hence much greater capacity for a given amount of radio spectrum. And they potentially help “bridge” the time period until additional macro network spectrum can be cleared from incumbent use.

9.1.1 The meaning of "traffic off-load"

The Commission provided an unusually detailed definition in the Terms of Reference: "For the purpose of this Study, 'data traffic off-loading' should be defined as routing wireless data that could be served by macro cellular networks (UMTS, LTE or WiMAX) over alternative access network technologies that use local coverage (shorter transmission ranges) and operate in frequencies that may or may not be exclusively accessible by the network operator. Alternative access to wireless broadband is typically based on "small cells" such as Wi-Fi hotspots or the so-called femto- or picocells of cellular networks and could be provided as integral part of a managed cellular network by an MNO or based on user-owned infrastructures, such as self-organising Wi-Fi networks, e.g. run by a Wireless Broadband Operator (WBO)."

In practice, it was necessary to further refine the definition. Key distinguishing characteristics of off-load, as distinct from a mere re-grooming of the network of the *Mobile Network Operator (MNO)*, are (1) that some aspect, either spectrum or backhaul, is *not under the MNO's control*; and (2) that, in the nature of the end user device, it is reasonable to assume that the traffic *would have been sent over the macro cellular network if it had not in fact been off-loaded*.

9.1.2 Technological evolution

In recent years, equipment vendors and standards bodies have invested considerable effort in developing both Wi-Fi and cellular standards to improve interworking between the two and to optimise use of the available spectrum. Whilst most legacy Wi-Fi equipment is based on the 802.11g standard with a maximum bit rate of 54 Mbps and operating exclusively in the 2.4 GHz band, more recent devices use the 802.11n variant which uses both 2.4 GHz and 5 GHz and incorporates additional enhancements such as MIMO and wider (40 MHz) RF channels to extend the available bit rate to hundreds of Mbps. The latest 802.11ac standard will enable even higher bit rates by deploying even wider channels (80 MHz or 160 MHz).

Interworking standards have been developed by both the Wi-Fi and cellular industries and are now becoming available commercially, with the potential to simplify greatly the ease of roaming between the two network domains. Of particular importance is Wi-Fi Alliance certified Passpoint™ (sometimes referred to as HotSpot 2.0) and the 3GPP's Access Network Discovery and Selection Function (ANDSF). The former is intended to simplify the authentication process for accessing Wi-Fi networks, for example by allowing SIM-based authentication for mobile devices, whilst the latter provides mobile network operators with a greater degree of control over which networks their subscribers' devices connect to (whether Wi-Fi or cellular), with automatic discovery and connection to the preferred network. Our view is that these developments will largely overcome a key barrier to greater mobile traffic offload to Wi-Fi, namely the historic complexity of the connection and authentication process.

On the cellular side, small cell technology has evolved to enable low cost “plug and play” devices to be deployed in operators’ licensed spectrum without the need for the complex planning that is required for macro networks. Femtocells (typically deployed in homes and enterprises) and metrocells (typically deployed in outdoor or public locations) can co-exist with macro cellular networks either using the same frequencies or in dedicated bands, resulting in significant increases in network capacity and spectrum efficiency.

9.1.3 Market evolution

The Wi-Fi market as a whole is very mature in Europe, with over 70% of households already having a Wi-Fi access point in some Member States. Wi-Fi capability has also become increasingly a standard feature on smart phones, and in consequence off-load to Wi-Fi is now also well established. Currently, the great majority of this off-load is onto private (mainly home) Wi-Fi connections, with only a few per cent being off-loaded to public Wi-Fi hotspots. We expect this situation to change over the next few years, partly as a result of the technology improvements highlighted above and partly due to the greater availability of Wi-Fi connections in public locations, particularly outdoors. In Europe, the greatest progress in this area appears to have been made in the UK, where there are now at least five operators providing Wi-Fi metropolitan area networks, mainly in city centres and often in conjunction with local municipalities.

Another key development relates to community based public Wi-Fi access, which has been pioneered by the Spanish company FON in partnership with a number of national telcos such as BT, DT and Belgacom. This approach typically involves the use of specially adapted access points which enable participating subscribers to the partner network operator to access other subscribers’ access points. For example, BT’s partnership with FON in the UK provides participating BT Broadband subscribers with access to over four million BT FON hotspots in the UK as well as other FON partner hotspots elsewhere it the world. A number of Wi-Fi roaming aggregators have also emerged (examples include iPass and Boingo) who specialise in facilitating national and international roaming between Wi-Fi hotspot operators, thus making public Wi-Fi access more convenient and affordable for many users.

One strong message that has emerged from our stakeholder discussions is that Wi-Fi and licensed small cells are very much complementary to one another rather than substitutes. This is reflected in the growing market interest in “hetnets” that combine both cellular and Wi-Fi access in the same base station hardware, maximising the use of available spectrum and the devices that can be served whilst minimising costs by using common backhaul and other site infrastructure.

9.1.4 Volume of traffic off-load

The surprisingly and little recognized reality is that, according to credible data captured from a range of sources, the visible growth in macro cellular mobile network traffic appears to be only the tip of a much larger iceberg. The volume of traffic that is already being off-loaded, chiefly to Wi-Fi in the home, already exceeds that of the mobile network, and can be expected to grow even faster as well (see Figure 7-1 and Figure 4-11).

9.1.5 Socio-economic benefits of traffic off-load

The largest and most readily quantified socio-economic benefit of traffic off-load is the cost that MNOs have saved, or can be expected to save, by virtue of being able to build a smaller network thanks to data traffic off-load. The annualised cost savings (primarily attributable to off-load to private Wi-Fi in the home or at work) are surprisingly large (see Figure 7-2, and Figure 7-3). Given that European mobile markets are reasonably competitive, a substantial portion of these savings would be competed away and passed on to consumers.

We estimate the savings in network cost already generated in 2012 for the EU-27 to be 35 billion euro, and the projected savings in 2016 to be 200 billion euro; however, this rough estimate should be understood to represent a generous upper bound. In reality, consumers would choose instead to do somewhat less with their mobile devices, or to use fixed network devices and interfaces instead of mobile. In these cases as well, however, consumers clearly benefit from traffic off-load.

9.2 Potential impediments to traffic off-load

Traffic off-load has deployed with amazing rapidity; nonetheless, there are any number of foreseeable threats to its on-going deployment. Were this to happen, there would be *opportunity costs* to society. The socio-economic benefits identified in Section 7 would not be fully realised.

9.2.1 Availability of sufficient spectrum

We see a likely shortage of licence-exempt spectrum for Wi-Fi in the longer term, not only for off-load but due to all of the other uses made of Wi-Fi and the likely increasing demand for wider bandwidth Wi-Fi equipment. As regards licensed spectrum, requirements for additional spectrum are more likely to be driven by the macro cellular network and in the longer term by potential new developments such as the use of LTE macro networks to provide a fixed broadband substitute in areas unserved by wired broadband or the emergence of new 5G mobile technologies and applications. Our analysis suggests that the capacity gains realised from small cell deployment in existing cellular bands (including the recently licensed 2.6 GHz band) will be sufficient to meet future offload requirements from existing 3G and 4G macro cellular networks.

9.2.1.1 Licence-exempt spectrum

As explained in Section 2.7, the 2400 MHz band is crowded. This is partly because the band is already used for multiple purposes, and partly because the majority of existing Wi-Fi routers are either unable to use 5 GHz or else are unable to use it simultaneously with 2400 MHz (see section 6.2.5).

The 5 GHz band is not crowded at present, but will become crowded if rates of traffic growth persist as we project. We estimate a potential shortfall of between 60 and 180 MHz in the longer term based on our estimates of future private and public Wi-Fi traffic Furthermore, the current fragmentation of the band means that substantially less spectrum is available to cater for the wider bandwidths offered by the latest Wi-Fi technology.

Additional spectrum adjacent to the existing 5 GHz allocations would address this shortfall and remove the inefficiencies arising from the current fragmentation.

9.2.1.2 Licensed spectrum

The need for additional licensed spectrum in licensed bands is largely driven by the overall traffic load on the macro cellular network. To the extent that licensed small cells can operate in the same bands as the macro cellular network and in doing so provide substantial capacity gains, they do not impose needs for additional spectrum.

The recently licensed 2.6 GHz band is particularly is particularly attractive for small cell deployment, requiring relatively small antennas and a very high degree of spectrum re-use. The 3.5 GHz band, which has been extensively licensed for WiMAX and BWA networks in Europe but to date has been only lightly used, is also well suited to small cell deployment. There may be scope to consider more geographically granular assignments at a local or regional level rather than a Member State level in this band, although our discussions with equipment vendors suggests there is little demand for such use. The band is also suitable for providing backhaul to small cells or Wi-Fi access points in some locations and in the longer term could be attractive for deployment of new services such as LTE based fixed broadband substitution or delivery of 5G mobile services.

We anticipate increased use of microwave back-haul for traffic off-load, particularly in the mm wave bands above 50 GHz; however, existing allocations appear to us to be adequate. It should be noted however that such wireless links are limited in range due to the need for a clear line of sight, which is more difficult to achieve with small cells as they are generally less elevated and in more cluttered environments than macro cell sites. Hence nearby access to high capacity wired backhaul (fibre or VDSL) is likely to be an important consideration for widespread deployment of small cells. This is considered further in the following section.

9.2.2 Back-haul capabilities

Back-haul capabilities are crucial to the effectiveness of off-load solutions. Today, for private off-load in the home and also for many service provider solutions, basic or ultra-fast broadband is often used (ADSL, VDSL, or cable). Going forward, higher capacity solutions (leased lines or Ethernet-based equivalents) may play an increasing role in service provider public off-load.

9.2.2.1 Fixed based broadband and ultra-fast broadband

Many forms of Wi-Fi and femtocell off-load depend on the end user's own fixed broadband connection. The upgrade of the end user's fixed broadband connection, and especially to ultra-fast broadband with speeds of 30 Mbps or more, is beneficial not only for the end user's own traffic but also for the traffic of other users (for example, if the end user is a FON subscriber).

There has been significant interest in wireless solutions as an alternative to fixed broadband for reaching rural users in areas where the fixed network does not reach, or has capacity limitations (indeed as previously noted this may be one of the future drivers of additional demand for macro cellular spectrum). The fixed back-haul requirements that we are discussing here represent a quite different interaction between the fixed and the mobile networks. In areas of moderate to high density, where fixed network coverage is available, broadband becomes important as a means of avoiding overload of the mobile network. It is not particularly relevant in rural areas, because the mobile network is unlikely to be overloaded with traffic.

In sum, *fixed broadband is needed to support some forms of traffic off-load*. Mobile broadband does not substitute for this use of the fixed network, because the off-load of traffic depends on the fixed network. Thus, any impediments to achieving the broadband deployment goals of the DAE would also undermine traffic off-load, and with it potentially the effectiveness of mobile broadband in areas where traffic is great enough to call for off-load.[94]

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94 This interdependence between fixed and mobile technologies may be relevant when assessing, in the context of market analysis, whether and to what extent fixed and mobile broadband can be considered substitutes rather than complements.

9.2.2.2 Leased lines and leased line equivalents

Wholesale terminating segments of leased lines continue to be susceptible to ex ante regulation wherever Significant Market Power (SMP) exists; however, the implementation of these provisions has been somewhat uneven among the Member States. Some impose and enforce leased line remedies much more strongly than others. For example, Germany applies regulation to leased lines only below 155 Mbps, while Romania, the Czech Republic and Hungary apply regulation only to leased lines of less than 2 Mbps. Conversely, following a recent market review in the UK, all lines are susceptible to regulation irrespective of speed.[95] These differences may possibly reflect legitimate differences in the markets of the respective Member States; if not, however, it would tend to imply that regulation of terminating segments of leased lines is less effective than it ideally should be. Meanwhile, some countries such as Spain and Italy do not apply cost-orientation to modern Ethernet leased lines, or may exempt lines above a certain speed from cost-orientation.[96]

This issue has become more prominent over the past year as large enterprise users have become increasingly vocal with their complaints. A January 2013 survey carried out by WIK-Consult on behalf of end-user organisation INTUG and ECTA[97] found that business end-users were often unable to source competitive offers for high-speed communications services. A February 2013 study prepared by CSMG on behalf of Ofcom concerning very high bandwidth leased lines also highlighted end-user dissatisfaction with supply outside the London area.[98] Inability to obtain leased lines at cost-oriented prices was also cited as a problem for competitive network operators.

It stands to reason that difficulties in obtaining leased lines or Ethernet equivalents at cost-based prices could also put competitive providers of off-load services at a significant disadvantage relative to incumbent mobile network operators that also have their own fixed networks. That would represent a form of *economic foreclosure* (the projection of market power in one segment into upstream or downstream market segments that would otherwise be competitive). Under the logic of the European regulatory framework, that would clearly be a restriction of competition that ought to be addressed appropriately.

95 March 2013 Business Communications market review Ofcom http://stakeholders.ofcom.org.uk/consultations/business-connectivity-mr/final-statement/.

96 Terminating segments of less than 10 Mbps are exempt from cost orientation in France.

97 "Business communications, economic growth and the competitive challenge", WIK-Consult, January 2013, at http://www.wik.org/index.php?id=studiedetails&L=1&tx_ttnews%5Btt_news%5D=1495&tx_ttnews%5BbackPid%5D=85&cHash=bc7c6a73b3dcfd972d0e28ae98fd47c5.

98 Research on Very High Bandwidth Connectivity, CSMG, February 2013, at http://stakeholders.ofcom.org.uk/binaries/consultations/business-connectivity/statement/CSMG-report.pdf.

9.2.3 Administrative impediments

The network operators and equipment vendors that we interviewed did not initially identify administrative challenges as an impediment to deployment of off-load networks; however, once we began to ask the question, they confirmed that obtaining permits can be a quite substantial problem. We suspect that they are so inured to the problem that they take it for granted.

It is never easy to acquire the rights to put up a mast. There is often local opposition, sometimes referred to as *NIMBY* (for *Not In My Back Yard*). Small cells tend to be much less intrusive than large ones, but can still raise concerns.

Local impediments to the construction of masts can vary greatly from one Member State to the next. Interviewees reported that deployment tends to be much easier in the UK than in France, for instance.

Emission standards as regards human exposure to electromagnetic fields (EMF) can also play a role. A general framework for the permissible level of emissions has been in place at European level since 1999;[99] however, a number of Member States including Italy and Belgium implement standards that are substantially stricter than those advocated at European level.[100] In light of the principle of subsidiarity, Member States are free to do so. Municipalities sometimes also play a role, for instance by imposing stricter EMF rules on locations that the municipality itself rents to network operators.

One might well imagine that emission standards should have little bearing on small cells. They are subject to the same emission limits as other wireless devices; however, femtocells operate at low power, typically not more than 100 milliwatts.[101] Emission concerns can nonetheless raise concerns, because femtocells tend to operate in much closer proximity to human beings than the large antennae of the macro cellular network.

Even though these administrative barriers are probably less problematic for a single, individual small cell than for a large cell used by the macro cellular network, they likely represent a substantial potential impediment to service provider off-load because an off-load network requires a huge number of cells. The interviews that we conducted seem to confirm this view.

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99 See the Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), at http://ec.europa.eu/enterprise/sectors/electrical/files/lv/rec519_en.pdf. The RTTE Directive is also relevant.

100 See for instance http://www.elektrosmoginfo.de/ under “Grenzwerte”. Some values are more stringent than those in Annex II of the Council Recommendation of 12 July 1999 (ibid.).

101 As previously noted, femtocells typically radiate less than 100 mW (i.e. less than a standard Wi-Fi access point), and more typically operate at well below 20 mW.

9.2.4 Technological impediments

In general, the technology for off-load seems to be developing quickly in positive directions.

Historically, the need for convenient user authentication was something of a barrier to usage. Today, it seems clear that smart phones have progressively simplified the process, and that automated authentication solutions such as the Wi-Fi Certified Passpoint™ programme (certified by the Wi-Fi Alliance) represent considerable progress in regard to public Wi-Fi. All indications are that consumers can and do use private Wi-Fi off-load on a massive scale today, and that easier authentication will play a decreasing role as a barrier to the use of public Wi-Fi off-load.

The limited deployment of 5 GHz enabled Wi-Fi equipment (both client devices and access points) is also something of an impediment currently, in that the resulting congestion in the 2.4 GHz band can result in an unsatisfactory experience when connecting to Wi-Fi. We note that there is increasing take-up of 5 GHz, particularly in public Wi-Fi networks and in higher-end consumer devices; however, this is far from universal even in relatively new devices such as the recently launched Google Nexus 7. For access points, even where 5 GHz functionality is provided, it is often not available concurrently with 2.4 GHz, which means if any user wishes to connect a non-5 GHz client device the benefits of 5 GHz must be foregone for all concurrent users. There is therefore a case for enhancing public awareness of 5 GHz and the limitations of non-concurrent dual band access points. This is largely an industry issue rather than a public policy issue, in our view, but there may be a role for public policy in raising awareness.

Other than the 2.4 GHz / 5 GHz issue, we have not identified any technological impediments that seem to call for a public policy response.

9.2.5 Market structure and competitive aspects

Many electronic communication markets are to some extent natural monopolies. The high cost of initially building facilities, together with low usage-based costs, may make it difficult for competitors to achieve market entry once an incumbent provider is well established. Regulation is consequently needed in order to address the market distortions caused by the presence of incumbent firms who possess *Significant Market Power (SMP)*.

There are no obvious indications as of now that off-load is experiencing market power problems, nor that it is likely to in the near future. The supply of equipment seems to be competitive. Consumers provide their own private Wi-Fi in the home, using Wi-Fi routers (or femtocells) that they purchase at competitive prices. Firms that are well established in the provision of public traffic off-load may enjoy a significant first mover advantage, but there are no obvious indications that new entrants face high barriers to competitive entry.

The most noteworthy concern that we have identified relates to the supply of leased lines and equivalent services, as noted in Section 9.2.2.2.

As SIM-based authentication becomes increasingly prevalent (see Section 2.8), it is also possible that providers of the software and/or handsets (especially the MNOs) might attempt to lock customers in to specific networks. That would appear to be an undesirable and anticompetitive outcome.

9.3 Traffic off-load opportunities and threats

It can often be helpful to analyse a new development in terms of the Strengths and Weaknesses that the responsible parties potentially provide, and the external Opportunities and Threats associated with the new development. These four dimensions can then be summarised in a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats). The Weaknesses in this case are largely the impediments identified in Section 9.2.

Table 16: SWOT analysis of traffic off-load

<table>
<tr><th></th><th>Helpful</th><th>Harmful</th></tr>
<tr><td>Internal Origin</td><td>Strengths
• Increasing speed and capability of devices and services, enhanced price performance (Moore’s Law).
• Emergence of simplified authentication schemes such as Passpoint™.
• Progressive deployment of basic and ultra-fast fixed broadband as a back-haul medium.</td><td>Weaknesses
• The risk that licence-exempt spectrum becomes too crowded to support Wi-Fi at sufficient quality.
• The risk that basic and ultra-fast fixed broadband does not deploy fully enough.
• The risk that administrative arrangements stifle the deployment of service-provider broadband.
• The risk that leased line back-haul (or equivalent) is not available at competitive prices, terms and conditions.</td></tr>
<tr><td>External Origin</td><td>Opportunities
• Lower costs for network operators.
• Faster and more reliable service, together with lower prices, for consumers.</td><td>Threats
• Risk that the Opportunities are not realised.</td></tr>
</table>

9.4 Potential measures to address impediments to wireless data off-load

In most respects, the market is already moving with amazing speed to make wireless data off-load available. Nonetheless, we identified a number of actual and potential impediments in Section 9.2. There would appear to be net benefits to Europe in taking a number of steps, many of them fairly modest, in order to facilitate an orderly development of wireless off-load and to ensure that the potential impediments do not needlessly block its further deployment.

9.4.1 Allocation of sufficient spectrum

We see a distinct need for additional licence-exempt spectrum in the 5 GHz band in support of Wi-Fi, not only for off-load but due to all of the other uses made of Wi-Fi. Given that Wi-Fi devices "roam" throughout the world, this should if at all possible be harmonised on a global basis. We see the recent FCC proposal to release additional spectrum in the 5350-5470 MHz and 5850-5925 MHz as setting a helpful precedent in this regard.[102] We note also that the 5725-5850 MHz band is already available for Wi-Fi use it the US and propose that this be extended to Europe.

Freeing up this spectrum has multiple implications as to costs and impacts for incumbents.

- The 5350 to 5470 band is used by airborne aeronautical radars to detect local weather conditions such as wind shear. Re-farming to achieve exclusive use would be time-consuming, since it would mean that the installed base of radars would have to be upgraded or replaced to operate in a different frequency band; however, shared use could be appropriate. Given that Wi-Fi operates at low power and thus over short ranges, the risk of interference with airborne radars is not great. It might possibly be prudent to prevent the use of this band for Wi-Fi near airports. We note that work is already under way in the US to assess potential co-existence requirements between Wi-Fi, aeronautical and other services in this band, including space-borne synthetic aperture radar (SAR systems such as those used in Europe for Global Monitoring of Environment and Security (GMES).[103] Deployment limitations (e.g. restriction of outdoor use), power constraints or other mitigation measures (such as dynamic frequency selection) should be considered.
- The 5725 to 5875 MHz band is available for licence-exempt use in Europe today, and is employed for SRDs and for fixed wireless access. Shared use with

102 See FCC document 13-22 of February 20, 2013.

103 See NTIA report "Evaluation of the 5350-5470 MHz and 5850-5925 MHz bands pursuant to section 6406 (b) of the Middle Class Tax Relief and Job Creation Act of 2012", January 2013.

SRDs and with FWA is not problematic. Global harmonisation on a shared basis should be sought.

- The 5875-5925 MHz band is currently identified for Intelligent Transport Systems in Europe, but there is currently little use made of this spectrum and the technologies deployed are likely to be compatible with Wi-Fi deployment provided that suitable sharing mechanisms such as dynamic frequency selection (DFS) are put in place.

If these measures were all successfully undertaken, Wi-Fi devices would have access to a contiguous band from 5150 MHz all the way up to 5925 MHz. This would be an increase in total bandwidth of 320 MHz, or 70%; however the amount of spectrum available for Wi-Fi deployment using channel widths of 40 MHz or more would increase by 100% or more, due to the elimination of the current fragmentation within the 5 GHz band. This would not only alleviate potential congestion in the Wi-Fi bands, but would also enable Wi-Fi to operate at substantially higher speeds than those that are achievable today.

Recommendation 1. Seek to make spectrum from 5150 MHz to 5925 MHz available globally for Wi-Fi.

> The EU should seek to make licence-exempt spectrum available through as much of the 5 GHz band as feasible. The goal should be to enable Wi-Fi to operate on a non-exclusive basis in a contiguous band from 5150 MHz all the way to 5925 MHz.

Requirements for licensed spectrum are primarily driven by the needs of the macro cellular network. Off-load plays a role in reducing that demand, but for the most part does not impose spectrum demand of its own since the same frequency bands can be used for licensed small cells as for the macro cellular network. Given the particular suitability of the 2.6 GHz band for small cell deployment and potential demand for additional spectrum in the 3.5 GHz band either to support new mobile applications or small cell backhaul, continued attention should be given to clearing these bands of incompatible incumbent applications in all Member States[104] and in ensuring that these bands are available for such use where required. If the bands are fully available on a WAPECS basis, the network operators should be able to determine the mix of macro cellular, small cell or backhaul use that best meets their needs.

Global harmonisation is desirable in these bands, but is less crucial than in the case of the licence-exempt bands because the equipment in question is less likely to be transported between Europe and other regions of the world; nonetheless, the femtocells are sufficiently portable to raise some concerns if the bands are not fully harmonised at global level. There are also potential benefits from economies of scale where global

104 There continues to be use of the 3.5 GHz band by, for instance, the military in some Member States.

harmonisation is achieved. We note that both of these bands are at least partially available for mobile use in all ITU regions, although specific usage conditions vary (e.g. the US is currently deliberating over whether to permit licensed or licence exempt use of part of the 3.5 GHz band).

Recommendation 2. Continue seeking to make 2.6 GHz and 3.5 GHz fully available for mobile use.

The Union should continue to seek to make the 2.6 and 3.5 GHz bands in all Member States available for WAPECS use, thus enabling their flexible use for macro cells, small cells or backhaul as required.

9.4.2 More flexible spectrum assignment for small cells

Licensed WAPECS spectrum assignments are typically made at national (Member State) level. As the use of smaller cells increases, both for off-load applications and as a normal part of the MNOs' re-grooming of their networks to enable more spectrum re-use, a more geographically granular spectrum assignment may be appropriate. Such an approach has recently been taken in the case of the 3.5 GHz band in Europe and has found mixed success. Some equipment vendor interviewees indicated little support for such an approach, and felt that national licensing provides operators with greater flexibility in how they deploy the spectrum; however, we believe wider consultation on potential licensing options mobile services in the 3.5 GHz band and other potential new frequency bands for licensed mobile services should be undertaken.

Recommendation 3. Consult on future licensing options for 3.5 GHz and other potential new licensed mobile frequency bands.

The Commission should initiate a consultation process on the future licensing options for the 3.5 GHz band and other potential new mobile bands, covering options such as national licences, regional licences, spectrum sharing between one or more licensed operators or a registration process for individual small cell base stations.

9.4.3 Ensuring that Wi-Fi takes full advantage of 5 GHz spectrum

Our assessment is that a substantial proportion of Wi-Fi access points are provided by devices with a single radio. This means that, even if the access point is capable of supporting Wi-Fi at both 2400 MHz and 5 GHz, it cannot support both at the same time. If any of the devices using the access point lack 5 GHz capability, the access point will necessarily be forced to operate solely in the (often crowded) 2400 MHz band (see section 6.2.5).

Technology has already solved this issue for the most part – concurrent dual band access points are available at modest additional cost and are being increasingly deployed especially by public Wi-Fi providers. Nonetheless, a large fraction of the installed base, particularly in the residential sector, consists of single radio access points. Our sense is that consumers will often opt for the lower cost single radio option without fully realising the limitations this will impose.

We are hesitant to suggest an intrusive intervention. It is quite possible that a simple awareness-raising campaign would be somewhat effective, since the incremental cost of dual radio devices is small relative to the benefits likely to be realised.

Recommendation 4. Raise awareness of the value of dual radio hotspots.

The Commission should use its good offices to raise awareness on the part of Wi-Fi equipment providers and the public at large of the benefits of dual radio hotspots.

9.4.4 Promotion of basic and ultra-fast broadband

As previously noted, many forms of Wi-Fi and femtocell off-load depend on the end user's own fixed broadband connection. The upgrade of the end user's fixed broadband connection, and especially to ultra-fast broadband with speeds of 30 Mbps or more, is beneficial not only for the end user's own traffic but also for the traffic of other users (for example, if the end user is a FON subscriber).

Many forms of public, service provider off-load also depend on basic or ultra-fast broadband (ADSL, VDSL, or cable).

The Digital Agenda for Europe (DAE) already calls for universal availability of basic broadband to all Europeans in 2013, and of ultra-fast 30 Mbps broadband to all Europeans in 2020. An extensive array of supporting mechanisms are already being brought into play. The need for fixed broadband as a back-haul medium does not appear to call for additional measures; however, it provides some additional reinforcement for the need to push ahead to achieve these Digital Agenda broadband objectives.

Recommendation 5. The need for back-haul for traffic off-load provides yet another reason to press ahead with DAE broadband goals.

The need for fixed broadband as a back-haul medium for traffic off-load provides yet another reason to press ahead with the Digital Agenda for Europe (DAE) objectives to ensure universal availability of basic broadband to all Europeans in 2013, and of ultra-fast 30 Mbps broadband to all Europeans in 2020.

9.4.5 Promotion of competitive supply of leased lines and equivalents

For high end service provider off-load, a competitive supply of leased lines (and increasingly of Ethernet-based equivalents) is likely to prove to be essential, particularly as traffic volumes increase over time. As previously noted in Section 9.2.2.2, wholesale terminating segments of leased lines are formally susceptible to ex ante regulation, but Member State NRAs have not been consistent in imposing or enforcing obligations. Moreover, Recommendations introduced by the European Commission in 2005 concerning charges for leased line terminating segments and provisioning time scales[105] now appear to be outdated, and in particular may not reflect the lower cost of Ethernet technologies.

Recommendation 6. Ensure effective and consistent imposition and enforcement of remedies on firms that have SMP in regard to leased lines and equivalents.

> The Commission and BEREC should endeavour to ensure stronger and more consistent and effective imposition and enforcement of ex ante obligations on the provision of leased lines and Ethernet-based equivalents on incumbents that possess Significant Market Power (SMP) in regard to these critical inputs. In particular, an update of the 2005 leased line Recommendations, together with other measures to standardise best practice in leased line regulation across the EU, may be warranted.

Steps taken in this direction would have many positive effects, and not only for off-load. Measures to improve access to leased lines at competitive prices would likely benefit enterprise business users of communications, as well as competitive network operators (both fixed and mobile). This would likely have spill-over effects to society at large.[106]

9.4.6 Dealing with administrative impediments

We are of the view that administrative impediments pose significant challenges for network operators today, and may loom large for future off-load service providers due to the large number of locations involved (even though individual sites are less problematic, in general, than macro cellular network sites).

A number of Commission initiatives have sought to simplify the deployment of fixed network basic and ultra-fast broadband, but we are not aware of any efforts to do the same for the mobile network.

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105 European Commission Recommendations on the provision of leased lines in the European Union 2005 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32005H0268:EN:HTML and http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:024:0039:0044:EN:PDF.

106 The previously cited WIK-Consult study estimated potential benefits of achieving best practice harmonised leased line regulation at up to €90 billion per annum. See “Business communications, economic growth and the competitive challenge”, op. cit.

A detailed study of these issues seems to us to be warranted, but it seems to be beyond the scope of our current remit; moreover, it would appear to be just as relevant to the macro cellular network as to public off-load services.

Recommendation 7. Consider further studies on administrative impediments to mobile and off-load deployment.

The Commission should consider undertaking further studies relating to administrative impediments to the deployments of macrocells and off-load small cells (including Wi-Fi). Any recommendations should pay due consideration to the principle of subsidiarity.

9.4.7 The risk that technological improvements might stall

As noted in Section 9.2.4 and Section 9.2.5, technological improvements are proceeding rapidly.

The Commission has tools that could be used in the event that technological progress were to stall, including (1) mandates to the European Standardisation Organisations (ESOs), and (2) research programmes under for instance the Framework Programme (FP). As things stand, however, we see no need for concerted action at European level.

9.4.8 The risk that market power might develop

If market power problems were felt to be emerging, the Commission or the Member States could in principle identify some new market susceptible to ex ante regulation. The perceived problems could be analysed using the familiar three criteria test (high barriers to competitive entry, no likelihood that the problem would correct itself in the next few years, and inability of competition law alone to correct the problem), and action could be taken if needed.

That would be a strong intervention. At the moment, we see no indications of problems in the market for off-load services that might call for such an intervention (other than the previously noted challenges regarding leased lines). Indications are rather that this is a dynamic, emerging market that is subject to healthy competition.

9.5 Alternative approaches for dealing with the impediments

Our Terms of Reference did not call on us to provide an Impact Assessment; however, we find it methodologically convenient to produce an Impact Assessment in abbreviated, “skeleton” form as a means of expressing and evaluating possible policy interventions at European level.

Under the Commission's 2009 Guidelines,[107] the impact assessment consists of:

- Procedural issues and results from consultation of interested parties.
- Policy context, problem definition, and subsidiarity.
- Objectives.
- Policy options.
- Analysis of impacts.
- Comparing the options.
- Monitoring and evaluation.

Many of these required elements are of limited interest to readers who are not specialists in Impact Assessment methodology. Since the problem definition and the objectives are fairly obvious, we have concentrated on (1) defining the problem that public policy can solve, (2) developing Options that address the potential impediments to wireless data off-load, and (3) analysis of the impacts of these Options.

9.5.1 The nature of the problem

The Problem Definition follows directly from the SWOT analysis.

As explained in Chapter 8, traffic off-load does little to facilitate the achievement of DAE broadband objectives; however, it plays a large role in facilitating *adoption* of mobile ultra-fast broadband (not an explicit DAE goal at 30 Mbps) and in producing consumer and producer welfare enhancements.

Off-load appears to represent a *Pareto improvement* where many parties benefit and nobody conspicuously loses. It is a positive development both for network operators and for consumers. In general, deployment and adoption seem to progressing rapidly, far more rapidly in fact than most have realised. Indeed, the Pareto character of off-load probably has a great deal to do with the rapid pace of deployment.

The only problem here consists of ensuring that nothing gets in the way of the continued growth of traffic off-load.

9.5.2 Objectives

This implies a relatively modest role for public policy. The objective should be to recognise and address the potential impediments to traffic off-load. Following the structure of Section 9.2, this means that policymakers need to ensure:

107 Impact Assessment Guidelines, 15 January 2009, SEC(2009) 92.

- That there is sufficient spectrum available going forward, and with the right technical characteristics, to support anticipated levels of traffic off-load;
- That there are no shortfalls or bottlenecks in regard to back-haul of off-loaded traffic;
- That administrative blockades do not needlessly slow the roll-out of public traffic off-load capabilities; and
- That no unanticipated technical barriers emerge.

9.5.3 Options to address current and future challenges

For the Impact Assessment, we identify “business as usual” as Option 1. This represents a continuation of present practice, with no special accommodation at European level of the needs of traffic off-load. This is a general methodological requirement, and also a requirement of the Commission’s Impact Assessment methodology. This Option (implying no change) provides a conceptual baseline against which other Options can be compared.

Option 2 diverges from the Option 1 baseline by undertaking the modest recommendations we have put forward to reduce the risk of blockages to the continued healthy evolution of traffic off-load. Notably, it includes:

- Recommendation 2. Continue seeking to make 2.6 GHz and 3.5 GHz fully available for mobile use.
- Recommendation 3. Consult on future licensing options for 3.5 GHz and other potential new licensed mobile frequency bands.
- Recommendation 4. Raise awareness of the value of dual radio hotspots.
- Recommendation 6. Ensure effective and consistent imposition and enforcement of remedies on firms that have SMP in regard to leased lines and equivalents.

Option 3 includes all of these interventions, plus the making available of licence-exempt spectrum in the 5 GHz band.

- Recommendation 1. Seek to make spectrum from 5150 MHz to 5925 MHz available globally for Wi-Fi.

Table 17: List of options

Policy option	Description
OPTION 1: Business as usual	A business as usual option that expresses the most likely trajectory if the European institutions take no further action that is specifically geared toward facilitating data off-load. This serves as the primary baseline for the assessment of incremental benefits.
OPTION 2: Clearing away obstacles	Modest interventions to avoid blockages: • Ensure availability of 2.6 and 3.5 GHz spectrum for mobile use. • Ensure competitive supply of leased lines. • Raise user awareness of the benefits of dual radio Wi-Fi hotspots.
OPTION 3: More licence-exempt spectrum	• All of the interventions put forward under Option 2. • Allocation of additional licence-exempt spectrum in the 5 GHz band.

9.5.4 Analysis of impacts and comparison of Options

In this case, we think that the analysis is fairly obvious, so there is no need to dwell on details.

Things are generally going well under Option 1, the business as usual baseline; however, there are a range of (possibly modest) threats in the medium term.

The interventions put forward for Option 2 mitigate most of the risks that were identified. Given that the costs of most interventions are low, the benefits (in terms of effectiveness and especially of efficiency) are substantial. We have not studied the costs or benefits of providing more consistent design and implementation of remedies for SMP regarding the provision of leased lines and equivalents in full detail (it is rather tangential to the focus of this study), but it is likely that it provides a range of benefits for enterprise users and for competitive network operators that greatly exceeds the benefits that it potentially provides for providers of off-load services. It seems fairly clear that benefits will exceed costs.

Option 3 addresses the one notable risk not dealt with under Option 2: the risk that licence exempt spectrum will be insufficient to satisfy realistic demand. The costs of freeing up additional spectrum in the 5 GHz band are not trivial, but neither are they daunting if the work is thought through and planned with due care, as explained in Section 9.4.1. Additional licence exempt spectrum would benefit numerous applications, not just traffic off-load.

Table 18: Overall assessment of options

	OPTION 1: Business as usual	OPTION 2: Clearing away obstacles	OPTION 3: More licence-exempt spectrum
Effectiveness	0	+	+
Efficiency	0	+	++
Coherence	0	0	0
Overall assessment	0	+	++

0 = no change; **+** = better ; **++** = much better ; **—** = worse; **— —** = much worse

Source: Study team

Consistent with Impact Assessment practice, the objective of an Impact Assessment is to clarify options for policymakers, not to make decisions; however, in this case, our sense is that the trade-offs are reasonably self-evident.

Annex: Figures, tables and supporting calculations

This Annex provides underlying figures, numerical data (where available) and calculations for the assessments that appear in this report.

1. Overall growth of mobile data

Figure 1-1: Predicted growth of mobile data (2012-2017)

The figure is taken directly from the Cisco VNI Mobile Traffic Forecast (2013) dated 6 February 2013, where it appears as Figure 3. The detailed data appear in Table 6 in the same report. As Cisco note in Annex A, their data derive in turn from a variety of public and commercial sources.

Table 6. Global Mobile Data Traffic, 2012–2017

	2012	2013	2014	2015	2016	2017	CAGR 2012–2017
By Application Category (TB per Month)							
Data	313,550	526,838	871,942	1,369,022	2,011,512	2,778,386	55%
File Sharing	92,574	142,411	214,889	298,095	369,068	395,342	34%
Video	455,216	858,026	1,603,384	2,834,963	4,714,310	7,418,322	75%
M2M	23,566	49,973	106,827	198,405	343,620	563,481	89%
By Device Type (TB per Month)							
Nonsmartphones	35,401	47,383	64,187	88,226	122,629	161,249	35%
Smartphones	391,024	854,642	1,672,271	2,947,545	4,852,994	7,531,736	81%
Laptops	402,877	523,330	708,908	981,904	1,269,683	1,563,861	31%
Tablets	29,707	97,035	237,273	474,432	833,633	1,309,324	113%
M2M	23,566	49,973	106,827	198,405	343,620	563,481	89%
Other portable devices	2,331	4,886	7,576	9,974	15,949	25,881	62%
By Region (TB per Month)							
North America	222,378	378,611	630,820	989,712	1,468,040	2,085,309	56%
Western Europe	181,397	276,405	426,152	655,201	975,681	1,384,072	50%
Asia Pacific	310,394	613,699	1,167,631	2,053,003	3,377,458	5,256,979	76%
Latin America	54,907	96,617	179,361	304,239	480,840	722,986	67%
Central and Eastern Europe	66,084	116,012	210,841	365,498	577,265	844,887	66%
Middle East and Africa	49,747	95,905	182,237	332,833	559,225	861,298	77%
Total (TB per Month)							
Total Mobile Data Traffic	884,906	1,577,248	2,797,042	4,700,486	7,438,510	11,155,531	66%

Source: Cisco VNI Mobile Forecast, 2013

2. Fixed wired, fixed Wi-Fi, and mobile data

Figure 1-2: Fixed wired, fixed Wi-Fi, and mobile data projections (2011-2016)

This figure derives from the Cisco VNI (2012). It reflects data that is some eight months earlier, at a time when Cisco apparently anticipated a somewhat faster growth of mobile data traffic than that reflected in the February 2013 Mobile Forecast eight months later. The data for total mobile traffic is visible in Table 3 of that document (and also in the companion document on methodology); however, the breakdown between fixed/wired and fixed/WiFi does not appear to have been included.

Table 3. Global IP Traffic, 2011–2016

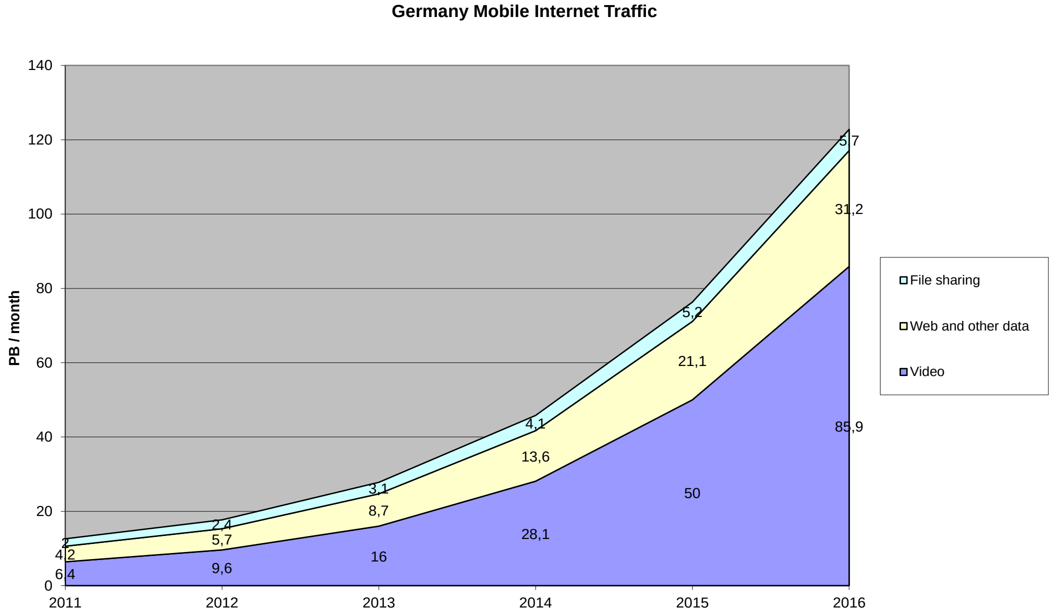
IP Traffic, 2011–2016							
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**CAGR 2011–2016**
By Type (PB per Month)							
Fixed Internet	23,288	33,049	44,883	59,096	70,622	80,562	28%
Managed IP	6,849	9,199	11,830	14,063	16,231	18,131	21%
Mobile data	597	1,252	2,379	4,215	6,896	10,804	78%
By Segment (PB per Month)							
Consumer	25,792	37,304	51,332	67,637	82,189	96,367	30%
Business	4,942	6,198	7,760	9,737	11,561	13,130	22%
By Geography (PB per Month)							
North America	10,343	14,580	18,866	22,810	25,464	27,486	22%
Western Europe	7,287	10,285	14,116	18,536	21,791	24,259	27%
Asia Pacific	10,513	14,792	20,463	27,567	34,220	40,488	31%
Latin America	1,045	1,570	2,355	3,619	5,349	7,564	49%
Central and Eastern Europe	1,162	1,673	2,377	3,382	4,578	5,987	39%
Middle East and Africa	384	601	914	1,460	2,349	3,714	57%
Total (PB per Month)							
Total IP traffic	30,734	43,501	59,092	77,374	93,750	109,498	29%

Source: Cisco VNI, 2012

3. Projections of the volume of mobile data traffic

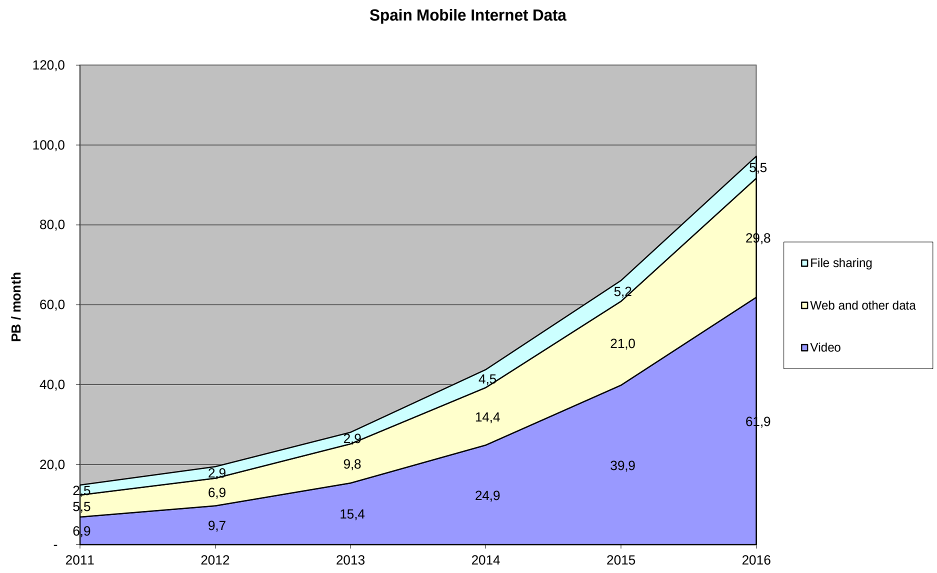
Our estimates of mobile traffic are taken directly from the Cisco VNI online data base, viewed in March 2013.

Predicted mobile data traffic in Germany (2011-2016)



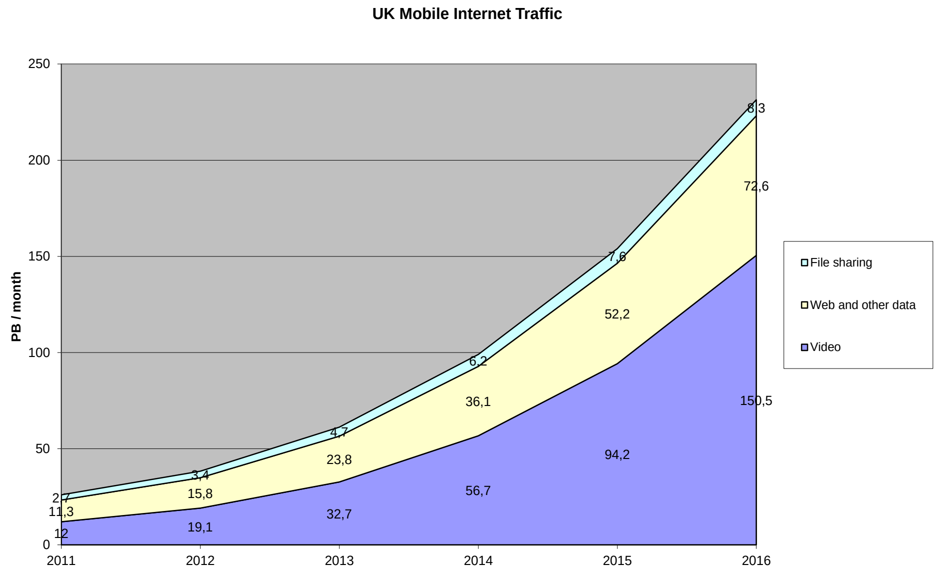
Source: Cisco VNI (2012), WIK calculations

Predicted mobile data traffic in Spain (2011-2016)



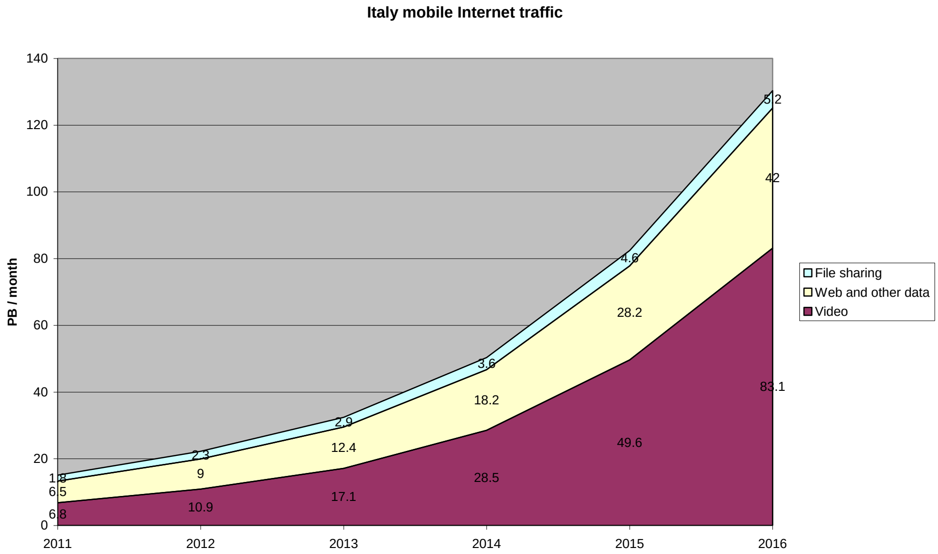
Source: Cisco VNI (2012), WIK calculations

Predicted mobile data traffic in the UK (2011-2016)



Source: Cisco VNI (2012), WIK calculations

Predicted mobile data traffic in Italy (2011-2016)



Source: Cisco VNI (2012), WIK calculations

Figure 4-3: Cisco VNI estimates for mobile Internet traffic in Germany projected forward to 2020

The data for Germany were taken from Cisco's online version of the VNI database, viewed in March 2013. These figures appear to correspond to the June 2012 VNI, not to those in the later February 2013 Mobile VNI. The forecast to 2020, developed by WIK, is based on a logistics curve ("s curve").

t	Label	y	Y	y '	e
Period	Year	Cellular traffic	Transform	Forecast	Errors
1	2011	7.5075	3.9447	7.4	-0.1
2	2012	13.48853309	3.3433	13.5	0.1
3	2013	24.34308899	2.7240	24.4	0.1
4	2014	42.46104456	2.1176	43.0	0.6
5	2015	72.52462668	1.4932	73.1	0.5
6	2016	118.6097399	0.8473	117.1	-1.5
7	2017			173.4	
8	2018			233.9	
9	2019			288.2	
10	2020			329.4	

4. Fraction of data off-loaded to public and private Wi-Fi networks

Figure 4-7: Fraction of Android smart phone originated traffic sent over cellular, private Wi-Fi, and public Wi-Fi networks

The figure derives from the Informa / Mobidia March 2013 report. Their measurements of public versus private Wi-Fi are based on whether an IP proxy redirect is used. Self-provisioned Wi-Fi is assumed to be private, managed Wi-Fi is assumed to be public. Many of the underlying data appear in Figure 13 in the same report.

The estimates that we used for France, Italy and the UK come directly from this table. Based on Figure 11 in the same report, we estimated that 83% of Android smart phone originated traffic in Germany was off-loaded to private Wi-Fi. For Spain, we assumed that the off-load proportion was similar to that in Italy.

Fig. 13: Distribution of total Android smartphone traffic by connectivity and hotspot type, selected countries, Jan 2013

	Distribution (%)			
Country	Cellular	Self-provisioned/ private Wi-Fi	Managed public Wi-Fi	Managed public Wi-Fi as % of total Wi-Fi
Thailand	27.9	67.2	4.9	7.0
France	20.6	77.1	2.3	3.0
Brazil	19.2	78.9	2.0	2.0
USA	31.6	66.4	2.0	3.0
Canada	22.9	75.2	1.9	3.0
Italy	29.2	69.2	1.6	2.0
India	47.0	51.7	1.3	3.0
UK	18.3	80.4	1.3	2.0
Hong Kong	27.5	71.3	1.2	2.0

Source: Mobidia

5. Traffic generated using different mobile operating systems and devices

Figure 4-9: Megabytes per month by operating system

We made no direct use of these data. Supporting numerical data appear in the Cisco Mobile VNI Forecast (2013).

Table 12. MB per Month Usage per Mobile Operating System in Tiered Pricing Plans

Operating System	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12
Android	623	741	731	833	831	917	932	971	1,190	1,231	1,024	1,122
iOS	456	539	549	599	586	647	692	673	809	818	793	840
Proprietary	182	199	215	244	261	365	387	436	467	559	603	806
Windows	281	310	280	339	372	389	410	392	432	420	421	438
Palm OS	357	446	321	480	372	327	359	300	418	401	320	434
Blackberry	208	218	240	279	280	283	295	293	359	289	251	304
Linux	24	29	38	17	26	20	33	34	79	100	67	78
Symbian	32	60	40	30	109	37	4	3	3	5	1	4

Source: Cisco, 2013

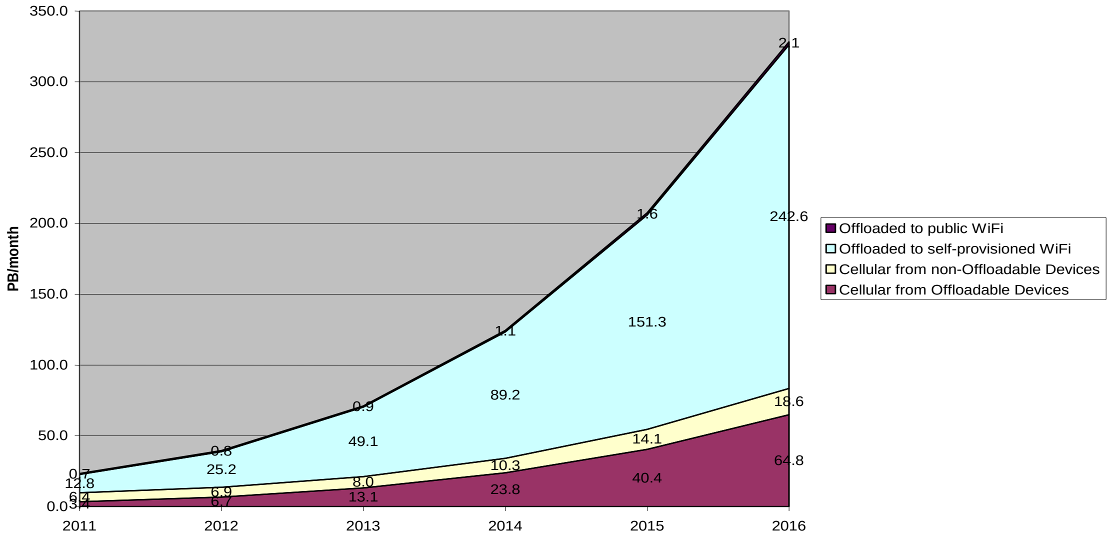
Figure 4-10: Per cent of mobile traffic attributable to different device types

See our explanation for Figure 1-1: Predicted growth of mobile data (2012-2017).

6. Estimated traffic off-load 2012-2016 for France, Germany, Italy and the UK

Our analysis of the volume of traffic off-load in Section 4.2 leads to the results shown in the figures below. We emphasise that these are rough approximations, and that they rest on many assumptions, as explained in the text.

France data traffic off-load (offered load)



Source: Cisco Mobile VNI (2012), Informa/Mobidia (2013), WIK calculations

Germany data traffic off-load (offered load)

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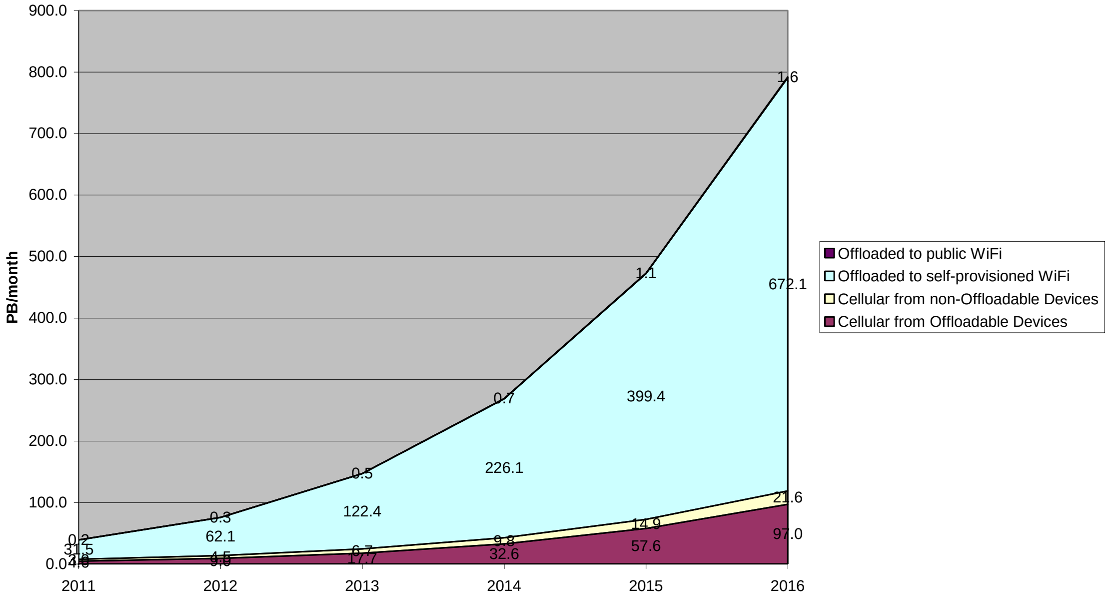
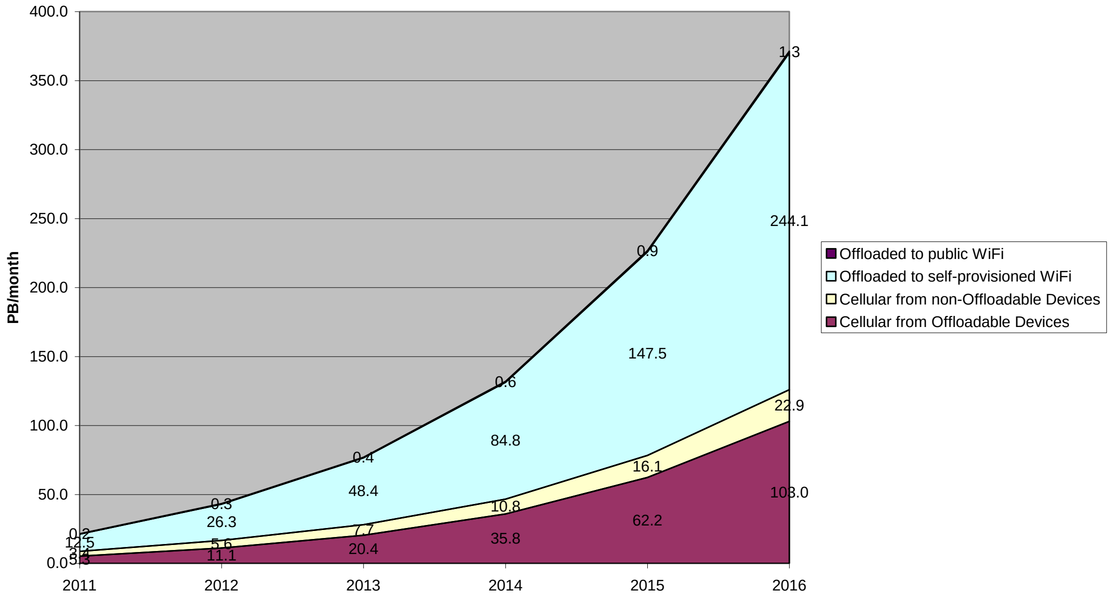


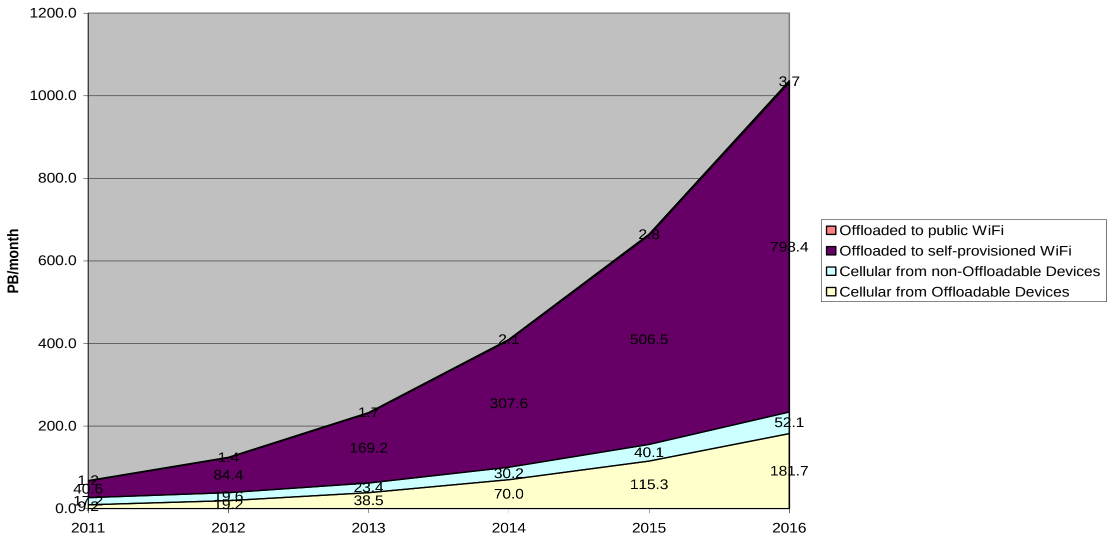
Source: Cisco Mobile VNI (2012), Informa/Mobidia (2013), WIK calculations

Italy data traffic off-load (offered load)



Source: Cisco Mobile VNI (2012), Informa/Mobidia (2013), WIK calculations

UK data traffic off-load (offered load)



Source: Cisco Mobile VNI (2012), Informa/Mobidia (2013), WIK calculations

Figure 7-1: Observed or predicted mobile data off-load

Figure 4-11: Contribution of selected Member States to observed or predicted data off-load

Both figures are based on WIK calculations. Mobile traffic is derived directly from the Cisco VNI online forecast database, viewed March 2013, and reflecting June 2012 data. Fraction of off-load traffic was estimated using Informa / Mobidia data.

		2011	2012	2013	2014	2015	2016
Cellular traffic	France	9.8	13.6	21.1	34.1	54.5	83.4
	Germany	7.5	13.5	24.3	42.5	72.5	118.6
	Italy	8.7	16.7	28.1	46.6	78.3	125.9
	UK	26.4	38.8	61.9	100.2	155.4	233.8
Cellular		52.4	82.6	135.5	223.3	360.7	561.7
Wi-Fi off-load traffic	France	13.5	26.0	50.0	90.3	152.9	244.7
	Germany	31.7	62.4	122.9	226.8	400.4	673.6
	Italy	12.7	26.6	48.8	85.4	148.4	245.3
	UK	41.8	85.8	170.8	309.7	509.4	802.1
Wi-Fi off-load		99.8	200.8	392.5	712.2	1,211.1	1,965.8
Ratio off-load to cellular		1.90	2.43	2.90	3.19	3.36	3.50
Cellular fraction of total		34%	29%	26%	24%	23%	22%

7. Estimation of cost savings resulting from Wi-Fi traffic off-load

Section 7.2.2 presents our estimate of network costs in Europe with and without traffic off-load, and subject to assumptions that appear in that section. Supporting computations appear here.

The ratio of Wi-Fi off-load traffic to cellular traffic by country, based on current measurements from an application running in Android smartphones and tablets, is as shown in the table below.[108] Since these are simple ratios, no units are relevant.

Ratio of predicted Wi-Fi off-load traffic to cellular traffic in selected countries

	2011	2012	2013	2014	2015	2016
France	1.38	1.91	2.37	2.65	2.81	2.93
Germany	4.23	4.63	5.05	5.34	5.52	5.68
Italy	1.46	1.59	1.73	1.83	1.89	1.95
UK	1.58	2.21	2.76	3.09	3.28	3.43

Estimated total investment cost of all mobile networks (in billions of euro) is as shown in the table below. Again, these are rough estimates, using population (per EuroStat 2012 data, viewed in April 2013) as a measure of the relative sizes of the respective networks. The relative population size is shown as a simple ratio (without units), with Germany taken to be 1.0.

Estimated total cost to date of all mobile networks in selected countries (€ Bn)

	Estimate	Low	High	Population
France	13.9	11.6	15.5	0.77
Germany	18.0	15.0	20.0	1.00
Italy	13.4	11.1	14.9	0.74
UK	13.9	11.5	15.4	0.77

Using the off-load ratios of and the network costs in the tables above, and assuming that all traffic that is carried by Wi-Fi off-load (public and private) today would still be carried in the absence of off-load,[109] it is straightforward to estimate the mobile network

108 Informa, "Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience: A global analysis of smartphone usage trends across cellular and private and public Wi-Fi networks", February 2013.

109 As already noted, this probably represents an upper bound on the cost savings. In practice, some users would simply use the network less in the absence of off-load, while others would use it from fixed network devices. Each of these represents a gain in the presence of off-load, but the gains are not all of the same magnitude.

one-off LRIC investment cost saved to build a network able to carry the traffic shown for each specified year.

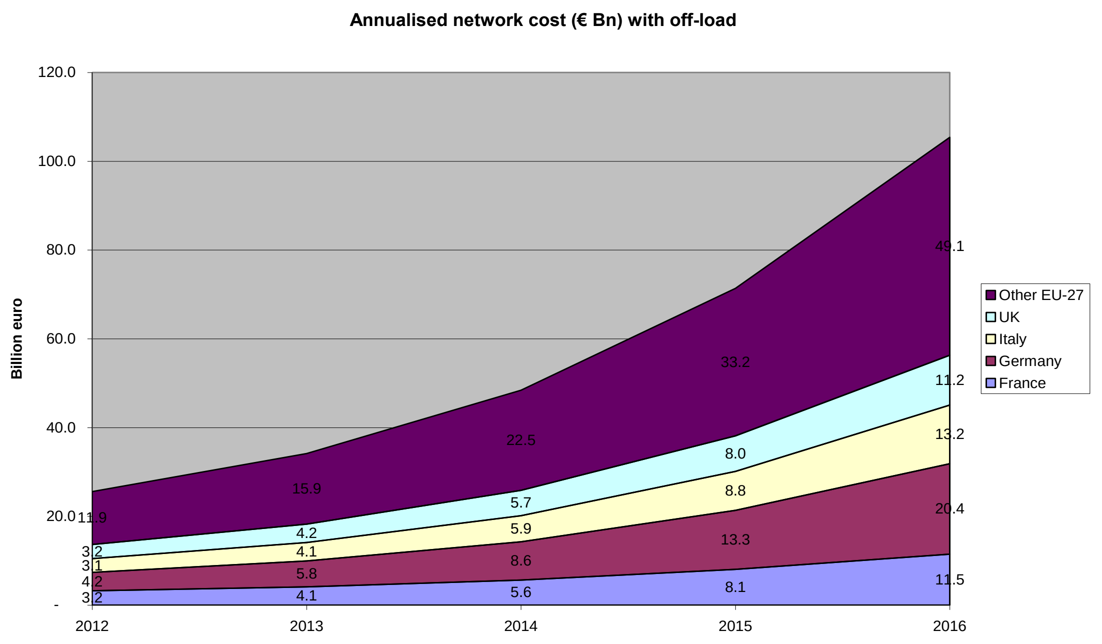
For an MNO, however, it is generally the annualised cost that is important, not the one-off investment. The annualised cost is routinely calculated by multiplying the one-off investment cost by the sum of operating expense plus the *Capital Recovery Factor (CRF)*. Since the OPEX for a mobile network is typically in the range of 10%, we now turn our attention to the calculation of the CRF.

The CRF is a function of the Weighted Average Cost of Capital (WACC) and the average asset lifetime of the network in question. The correct value could differ somewhat from country to country, and from network to network, but it is not unreasonable to assume a WACC of 10% and an average asset lifetime of 15 years. With those figure in hand, the CRF can be computed according to the formula:

$$CRF = WACC * (1-1/(1+WACC)^n)$$

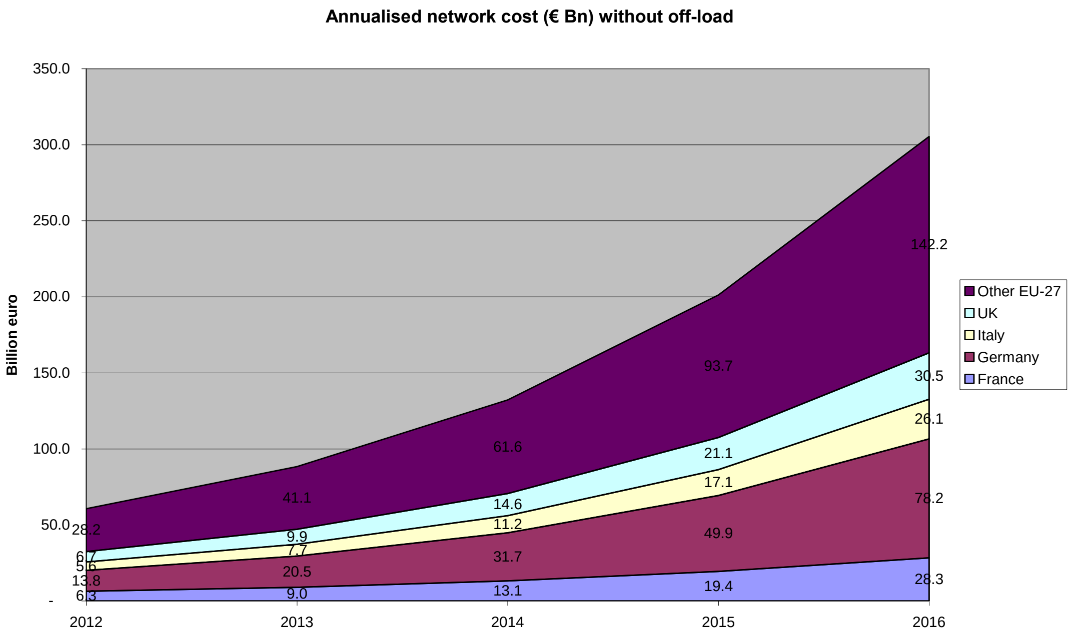
This yields a CRF of 0.131. Applying this to the total one-off investment costs yields an estimate of the network cost each year with and without off-load, as shown in the figures that follow. The difference in cost is large, even after taking into account gains in fill as traffic increases.

Annualised network cost (€ Bn) with off-load



Source: WIK calculations

Annualised network cost (€ Bn) without off-load



Source: WIK calculations

European Commission

Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum

Luxembourg, Publications Office of the European Union

2013 – 153 pages

ISBN 978-92-79-30575-7
DOI: 10.2759/19531

01-13-239-EN-N

DOI: 10.2759/19531 ISBN 978-92-79-30575-7