Will Wi-Fi relieve congestion on cellular networks?

prepared for

GSMA

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0. Executive Summary

Wi-Fi provides an invaluable complement to cellular in the delivery of high quality broadband services to smartphone users, particularly indoors. Cellular offers high performance, wide area blanket coverage but does not always cover indoor locations well. Wi-Fi fills these gaps at venues where local owners and users need improved coverage and access speed. However, we see little evidence that today's Wi-Fi networks significantly reduce traffic levels on the cellular network. On the contrary, there are signs that when high quality Wi-Fi and cellular are both available to users, the traffic on both increases. Qualitative and quantitative analysis of some of the most advanced markets reveals that the majority of today's Wi-Fi traffic is incremental or complementary to cellular traffic. Venue based Wi-Fi will play an increasing role in providing indoor broadband connectivity. It will be used by cellular operators to deliver an "always best connected" value proposition but will not reduce demand for capacity on cellular networks.

While there are some outdoor Wi-Fi networks which provide connectivity in the absence of sufficient 3G or LTE capacity, they are not an equivalent substitute for building additional 3G and 4G capacity to cater for the surge in mobile broadband traffic. We have identified a range of drawbacks to the Wi-Fi approach based on technical, integration, availability, timing and operational factors. In order to deliver a good mobile broadband experience, cellular operators require more LTE capacity. Where necessary, mobile network operators will tend to use small LTE cells to relieve congestion in traffic hotspots rather than relying on Wi-Fi.

The prospects for Wi-Fi delivering significant capacity relief in areas of the cellular network facing congestion are limited. On the contrary, Wi-Fi and cellular traffic are expected to grow in parallel and rapidly, offering complementary capabilities. Both technologies will require additional spectrum to deliver ubiquitous broadband connectivity.

1. Introduction

Wi-Fi today offers an invaluable complement to cellular through low cost, venue-specific, broadband coverage.

This paper addresses the potential of Wi-Fi also to reduce cellular capacity and spectrum needs.

Wi-Fi has proved to be immensely popular with smartphone users as a low cost solution for improved localised coverage and mobile broadband experience, at venue specific locations especially indoors. Industry sources state that between 60% or 80% of traffic on a smartphone today is carried over Wi-Fi[1]. What is less evident is the extent to which Wi-Fi can provide capacity relief to the cellular networks, either from existing Wi-Fi networks or potentially from new implementations such as small cells. With such high traffic volumes on Wi-Fi, it would be easy to infer that a high proportion of traffic is being offloaded from the cellular networks[2], reducing the need for additional cellular spectrum. But is this view valid?

This paper examines this question from a number of perspectives.

1. Is traffic carried over Wi-Fi incremental or replacement?
2. Do today's coverage led Wi-Fi networks reduce cellular traffic load where it matters?
3. How suitable is Wi-Fi as the base technology for small cell solution for cellular capacity expansion?
4. What is the business motivation model for Wi-Fi networks to be built for cellular capacity relief?

The term Wi-Fi Offload is used in a variety of ways by the industry. In this paper, we use two different terms to distinguish the categories

- Incremental/complementary. Wi-Fi traffic that, if it were not for the availability of Wi-Fi access, would most probably not be generated at all. This could be for reasons of cost, quality of service, applications restricted to Wi-Fi access. This type of traffic is complementary to cellular and has a limited impact on cellular traffic load.
- Replacement. Traffic that could equally well be carried over Wi-Fi or cellular but is in fact carried over Wi-Fi for any reason. This reduces the traffic load on the cellular network.

In the rest of the document, we use these two terms to qualify the different types of Wi-Fi traffic.

The paper does not attempt to estimate spectrum needs for either cellular or Wi-Fi (see for example ITU document[3]). Rather, the aim is to examine the long-term dynamic between Wi-Fi and cellular usage, the suitability of Wi-Fi as a capacity solution, the user and business motivation of Wi-Fi implementations and the resultant traffic loading on the cellular network. It is traffic loading per site which ultimately drives cellular spectrum needs.

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1 Understanding today's smartphone user. Informa. June 2013.
2 In the context of this paper, we use the term "Wi-Fi offload" to refer to traffic carried over Wi-Fi that would otherwise be carried over cellular i.e. replacement rather than incremental traffic
3 ITU-R Report M.2290: Future spectrum requirements estimate for terrestrial IMT, January 2014.

2. Wi-Fi Applications and Usage

Smartphones are Wi-Fi hungry. Whilst Wi-Fi traffic accounts for up to 50% of the traffic, only a small percentage of Wi-Fi is carried over public hotspots.

Wi-Fi usage has expanded considerably over the past 3 years with additional spectrum being allocated in the 5 GHz band and data intensive applications developing. In this section we look at the venues where Wi-Fi usage occurs and analyse the reasons why subscribers choose Wi-Fi over a cellular network.

Any Wi-Fi connection can be initiated by one of the following methods:

- The end user selects an SSID and provides, at least once, credentials to be authenticated on the network,
- The device itself can store an SSID that was previously selected and automate the authentication process without any further end user intervention.
- If a mobile network is linked to a Wi-Fi network, SIM/IMSI authentication supported by HOTSPOT 2.0 can provide a seamless experience.

Free/Iliad in France, O2 in the UK and Deutsche Telekom have made forays into operator initiated Wi-Fi to benefit from their owned Wi-Fi networks where cellular network would either be difficult or economically not justified.

The initiation process is key as it eventually allows a user to connect on a Wi-Fi network seamlessly.

The venues where Wi-Fi are heavily used by the user/device/operators can be divided into 7 categories:

- Private Wi-Fi: Home
- Private Wi-Fi: Office; home office or customer/partner/serviced office
- Public Wi-Fi: Transport hubs (airport, railway tube stations)
- Public Wi-Fi: Retail venues (branded shops, food outlets, shopping malls, open markets)
- Public Wi-Fi: Deep indoor coverage of public buildings (hotels, schools, universities, hospitals, museums)
- Public Wi-Fi: Hyper-dense venues (conferences, concerts, stadia)
- Public Wi-Fi: Metropolitan networks possibly publically subsidised by local authorities

Exhibit 1: Initiator of Wi-Fi Access

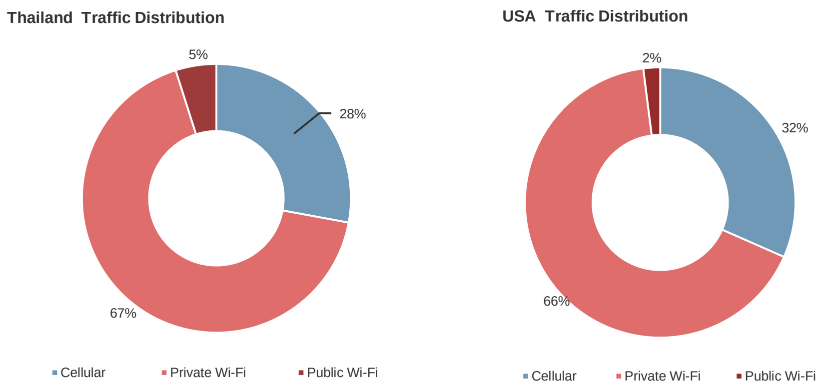
Initiator	Home	Office	Transport	Retail	In-building	Hyper-dense	MAN
User	■	■					
Device	■	■	■	■	■	■	■
Operator			■	■	■	■	■

Source: Coleago

Exhibit 1 shows in blue the most likely initiator of the Wi-Fi access. It is interesting to note that the device is central to any Wi-Fi experience and that most of the venues targeted by Wi-Fi networks are highly social venues.

Exhibit 2 also shows that whilst a large percentage of traffic is being carried on Wi-Fi networks, the role of managed public Wi-Fi generally remains marginal in both emerging and developed countries. Managed public Wi-Fi is a network that essentially provides the same seamless experience as a cellular network and does not require any manual authentication. It uses technologies such as EAP-SIM and Hotspot 2.0 which are only now starting to be rolled out to any extent. Examples include London Underground Wi-Fi and MNO provided Wi-Fi.

Exhibit 2: Traffic distribution



Source: Mobidia - Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience (2012)

These venues are often inadequately serviced by cellular networks as the costs of providing ubiquitous, deep indoor coverage for high quality broadband are prohibitive. TCO analysis for an incremental GB of data on cellular vs Wi-Fi shows ratios sometimes above 200% depending on the venue and the availability of backhaul. The key difference is that the Wi-Fi coverage is highly localised and targeted, whereas cellular coverage is wide area. Given the very high costs of wide-area coverage, MNO's have to prioritise investments in terms of locations covered and the depth of coverage. This inevitably leaves gaps and MNO's are interested in deploying Wi-Fi or partnering with Wi-Fi network providers where the economics are justified.

The perception by the end user and their motivation for deliberately using a Wi-Fi network is based on simple decision criteria:

- Wi-Fi networks are free
- Wi-Fi networks are fast, mostly because the perception is based on private Wi-Fi,
- Wi-Fi networks are venue sensitive with bespoke marketing content.

Venue sensitivity may become important in the future with, for instance, McDonald's currently launching an app allowing its customers to order in the shop without placing their order at the till.

Whether the smartphone is 2G, 3G or 4G, the share of Wi-Fi traffic above 50%

Traffic has been growing in both developed and developing markets. Forecasts from Ericsson[4], Cisco[5] and Informa[6] show that the usage per smart device will grow between 6 and 10 fold in the next 5 years. According to the analysis from Informa, whilst some countries have moved from 3G to 4G, the share of Wi-Fi traffic as a percentage of the total traffic does not deviate much from around 50% for Android smartphone devices. This is despite the fact that LTE offers excellent broadband experience at least in areas with good coverage. See Appendix A for further.

Home Wi-Fi is a good example of venues where users download GBytes of data every month. Coverage from the cellular network in the home can be of insufficient quality for a good broadband experience resulting in low usage. On the other hand, home Wi-Fi is in effect free when the resident has chosen to sign up for a fixed line package. It should be noted though that young adults often prefer not to have a fixed line subscription at

4 Mobility Report. Ericsson. 2013
5 VNI Mobile Forecast Highlights, 2012 – 2017. Cisco. 2012
6 Understanding today's smartphone user. Informa. June 2013

all. For household with a fixed line connection, there are no barriers to content and the broadband experience is good; Wi-Fi access then becomes very attractive, driving very high usage. This resultant traffic volume due to development of Wi-Fi networks is largely incremental and does not cannibalise the cellular traffic but on the contrary increases the overall data consumption.

The conclusion relating to usage is that Wi-Fi is socially rooted in the user's expectations of getting the best out of the local network from an availability, price, application and traffic perspective. Wi-Fi networks are only available where the venue owner has deployed Wi-Fi at its own cost as the MNO's are still working up monetisation strategies to push their Wi-Fi plans further. There is little evidence of an arbitrage strategy between a cellular network and a Wi-Fi network. However, the considerations above lead us to conclude that Wi-Fi traffic is mainly complementary to cellular, not replacement. Whatever the precise categorisation and underlying drivers of the different traffic types, what is certain is that traffic on Wi-Fi and cellular are both growing rapidly and need to be served.

3. Wi-Fi traffic in areas of peak cellular traffic load

Traffic congestion can occur in many parts of the cellular network not just city centres. Wi-Fi availability varies across these areas and the opportunity for offload is often limited.

From an MNO perspective, the simplest way to increase capacity on a site is to add another carrier on an existing frequency band (assuming extra spectrum is available). If this is not possible, then progressively more complex and expensive solutions have to be implemented until a point is ultimately reached where some form of small cell solution is needed (see Appendix C.1). Small cells, while delivering impressive capacity gains, present technical, planning and commercial challenges and are only implemented when other simpler solutions have been exhausted. In addition, acquiring access to new sites, whether small cell or standard capacity sites, especially in built-up areas already heavily occupied by cellular sites is a challenge which will only become more severe. Additional spectrum provides relief to all these considerations. A similar result would also be given if a significant proportion of cellular traffic were carried over local Wi-Fi networks instead. We consider in this section the extent of Wi-Fi availability and traffic replacement with today's Wi-Fi networks in those areas of the cellular network experiencing the highest traffic levels.

Cellular traffic is heavily skewed across the network (see Appendix B for further information). The highest traffic densities per unit area (e.g. Gbps per sq. km) tend to occur in business districts and city centres, but this is not the case for traffic load per site (e.g. Gbps per site). Cells are generally smallest in city centres and progressively increase in size in urban, sub-urban and rural areas. The traffic catchment area increases in proportion. The result is that in some residential, urban areas, the traffic density is still high and the cell sizes are larger, potentially creating very high traffic loads per site. The busiest sites on real networks are therefore distributed across many areas, including city centres and many urban and even suburban areas.

In city centres, high Wi-Fi availability (often from Public Wi-Fi networks) and high cellular traffic levels often overlap. This creates opportunity for offload. However, this overlap is not planned or consistent. Moreover, as seen in the previous section, Public Wi-Fi accounts for a small fraction of total mobile traffic and the traffic is for the most part incremental.

In residential areas, the most significant form of Wi-Fi access is Home Wi-Fi. Most of this traffic is incremental but some will be genuine replacement.

In more residential areas, Wi-Fi availability is present mainly in the form of home Wi-Fi. However, as argued in Section 2, the majority of Wi-Fi traffic generated in the home is incremental to cellular constraining the offload opportunity. As for the potential use by passing outdoor users, Home networks are generally private, blocking access to passers-by. However commercial developments such as FON and Free Mobile (France) enable authentication to Home Wi-Fi networks, albeit only to registered subscribers. There are other obstacles for passing users of Home Wi-Fi such as the limited coverage leakage from the indoor AP, and the handover from one AP to another, or from an AP to the cellular network. These factors tend to limit the extent of Wi-Fi offload in residential areas.

Some cities are deploying Metropolitan Area Networks (MANs), outdoor Wi-Fi networks which on the face of it could provide valuable offload. They tend to be deployed in city centre and business districts, mainly as an access alternative to cellular rather than as a capacity solution. However, if the density of Wi-Fi sites were high enough, they could achieve significant offload, relieving cellular traffic load. While there have been a number of launches of such networks over the years, they remain untypical and have had limited success to date.

In practice therefore, while the opportunity for Wi-Fi offload can arise in some public spaces, there are many areas of high cellular traffic load where the Wi-Fi opportunity is limited. This is even more pronounced in developing countries where the availability of Wi-Fi and fixed broadband is often poor, especially beyond the city centre.

4. Suitability of Wi-Fi as a cellular capacity solution

Wi-Fi and HSPA/LTE are both potential technologies for small cell solutions for cellular capacity.

Most Wi-Fi today is deployed, independently of MNOs, at specific venues for improved coverage and performance. But how suitable is Wi-Fi as a purpose-built capacity solution for cellular networks? As Wi-Fi is short-range, the main opportunity as a capacity solution is probably as part of an outdoor, small cell layer.

Unlike coverage led Wi-Fi, the purpose-built capacity layer needs to be fully integrated with the main network to ensure full transparency of service and network management. The need for integration places significant additional demands on the technical solution in terms of the functionalities required and its operation.

We consider here some of the factors at play. As the issues are complex, we have just highlighted the critical points. These are summarised in Exhibit 3; the row marked "Duration" indicates whether the factors or drawbacks are likely to persist long term and some are. Further assessment is given in Appendix C.

Exhibit 3: Factors influencing technology choice for small cell capacity solutions

	Fundamental	Functional	Operational	Complexity	Timing / availability
Feature	Sharing of spectrum	Authentication Network discovery and selection	Traffic management	Duplication of functions	Acceptance / deployment of standards
	Cell size / Power levels	Traffic management	OSS	Interworking of Wi-Fi / cellular	Widespread device compatibility
	Interference cancellation	Mobility	Policy management	OSS across multiple RATs	
		Security	SON		
Duration	Fundamental	Solvable in time	Solvable in time	Fundamental	Critical in near term

Source: Coleago

Wi-Fi Spectrum

From an MNO perspective, a major concern of Wi-Fi spectrum is the fact that it is shared with many other users and operators, usually unknown, and the traffic is unmanaged or coordinated. In busy areas, this can lead to congestion in public areas, manifesting itself as slower data rates or no connectivity. The opening up of the 5 GHz spectrum bands with devices supporting them will help considerably to alleviate this situation but rapid growth of Wi-Fi may still make this an issue in the longer term.

Traffic management

For MNOs, the ability to monitor traffic levels in the band, steer traffic between bands and cells and implement policy rules are key requirements. Wi-Fi does not provide this level of visibility and control, except for Wi-Fi deployed by the MNO itself.

Until recently, this was a significant gap with Wi-Fi but new developments such as ANDSF (see Appendix C.3) are becoming available allowing better traffic monitoring and policy control of traffic. This is primarily a client-based solution and a risk for the MNO is that it is difficult to ensure that policy is being implemented consistently. The feature would have to be widely supported on devices, demanding concerted effort and widespread support from MNOs and vendors, backed by a certification regime for this to happen. This could be challenging as MNO and vendor strategies on Wi-Fi vary.

OSS integration and Service management

It is important that the cell sites are properly managed, configured, monitored and integrated into the network maintenance procedures. As the number of sites, technologies and bands increase, features such SON (Self-Organising Networks) become increasingly important for interference management and capacity optimisation. Subscriber policies must also be managed consistently across all access types. These capabilities and processes are common on cellular networks and would need to be extended to a Wi-Fi based solution.

Advanced functionalities

Carrier grade capacity solutions demand much the same service functionality as found on the macro network. In addition to the functions already highlighted, they include SIM-based authentication, network search and selection, security and roaming support.

There have been many recent developments closing the gap between the Wi-Fi and cellular functionality. These primarily concern automated authentication (Hotspot 2.0, Passpoint), roaming and traffic steering (ANDSF) (see Appendix C.3 for more detail). These would be important capabilities for a small cell layer.

Over the 5 to 10 year time-frame relevant to new spectrum, these technical solutions should mature and stabilise. Given the huge diversity of Wi-Fi deployments, it may still take a long time for these more advanced techniques to be deployed universally. Some capabilities such as mobility, authentication, security mechanisms[7] have been available for years, some over 10 years, but have been slow to be implemented. For custom-built, Wi-Fi small cell capacity solutions, the prospects for realising the required functionality are much better, but still subject to the necessary device clients being widely adopted.

Limited cell range of Wi-Fi

As cellular technologies, HSPA and LTE are designed to support large cells of many km radius, whereas Wi-Fi is designed for low cost, short-range either indoors or outdoors. Wi-Fi traffic is also moving towards the 5 GHz band which further reduces the propagation range, although this may be offset by the use of MIMO technologies. For outdoor small cell capacity solutions, the optimum size of the small cells will depend on the capacity gain required, the level of in-building coverage, whether the spectrum is dedicated or re-used, and the coverage area being targeted. In urban or sub-urban areas where the macro layer cells are larger and a traffic more evenly distributed, the area to be covered by small cells can be extensive. The flexibility afforded by cellular technology regarding power levels and cell size allows both a more effective solution (better coverage and capacity) and lower costs with fewer small cells[8].

Summary

As a potential technology for outdoor capacity small cells, Wi-Fi has rf performance, operational, timing and functional draw-backs when compared to HSPA or LTE

The main issues that we believe MNOs will have to contend with in selecting a base technology (Wi-Fi or HSPA/LTE) for small cells are:

- Sharing of the Wi-Fi spectrum with multiple, uncoordinated users and the lack of ubiquitous traffic management.
- Time taken for the necessary functionalities to mature and be widely available on Wi-Fi networks and devices, recognising that small cell solutions are likely to be needed in the near future. Better opportunities exist with purpose-built Wi-Fi small cell layer off, but device compatibility remains a concern.
- Operation, Configuration, Optimisation, SON and maintenance of Wi-Fi small cell networks along side the main cellular network.

7 e.g. EAP-SIM, EAP-AKA, I-WLAN, Mobile IP
8 A Comparison of LTE Advanced HetNets and Wi-Fi. Qualcomm. October 2011.

- Added complexity of running duplicate implementations (Wi-Fi and cellular) of corresponding functionalities.

As many MNOs will face traffic congestion challenges over the next 5 years, they will need to make technology choices regarding capacity enhancement in the near future. Opting for small cells based on mature cellular based standards may be seen in some markets as the technically superior and least risky option. At the current time, this is the route favoured by many MNOs.

While there exist functional and performance short-falls with the use of Wi-Fi for small cells, they should not prevent its use in some scenarios. It could be challenging for example for operators with limited 3G or 4G spectrum allocations or those unable to deploy small cells and backhaul on their own. In this case, a Wi-Fi based solution could be justified.

5. Business motivation for building Wi-Fi for cellular capacity

The future of Wi-Fi in MNO networks is predicated on the monetisation of its traffic

For MNO's, Wi-Fi presents coverage improvement and extension opportunities as well as raising brand awareness and improving "stickiness". However, there are reasons why they also have a tendency to resist Wi-Fi as a capacity technology embedded into their radio networks. LTE is currently the predominant area of focus for the MNO's mobile broadband strategy. They operate various LTE strategies, such as acquiring new spectrum at auction or re-farming of the allocated spectrum bands.

For cultural, economic or strategic reasons, it is unlikely that MNOs will see Wi-Fi as a replacement technology for licensed spectrum and networks. As a replacement, Wi-Fi is disruptive for MNO's as it challenges its legacy business models, alters core assets of their balance sheets such as commercial margins, investments in core and access networks, as well as the spectrum licences.

Another challenge exists around the fact that the current Wi-Fi business model has largely been built around a 'free usage' proposition: the price a user is prepared to pay for accessing a Wi-Fi network is almost nil as it is widely available for free, thereby challenging any attempts from an MNO to charge for Wi-Fi traffic. In a defensive strategy, MNO's could enter the Wi-Fi business and roll out networks in those specific venue categories to ring-fence the "Free Wi-Fi" model. This latter scenario is more likely in Emerging Markets where the only broadband backhaul networks belong to the MNO's.

The presence of multiple Wi-Fi providers at the same venue leads to duplication of physical Wi-Fi AP's, competing for physical access to suitable AP vantage points. The Network Provider / Service Provider model is likely to evolve and become streamlined with one WISP servicing one venue. Some MNO's may be more inclined to use 3rd party Wi-Fi networks, often shared between the MNO's (Virgin Wi-Fi in the London Tube). Some players are developing roaming platforms (BT, Boingo, IPass), routing authentication and traffic from the Wi-Fi host network back to the home core of the users. These NetCo/Serve Co or Roaming agreements are in their early days.

The Wi-Fi roadmap is complex with on average a new evolution every 2 years or so; IEEE 802.11 n is already being replaced by IEE 802.11 ac and seamless authentication (EAP-SIM, HOTSPOT 2.0) and traffic management mechanisms (ANDSF) are being rolled out now. The usual lifecycle of network CapEx is 5 to 7 years whereas Wi-Fi APs would require replacing every 3 years. MNO's are concerned with the long-term protection on their investments and the immaturity of Wi-Fi (see also Section 4). MNOs would need to take into account the different technology life-cycles for Wi-Fi.

MNOs may be reluctant to embrace Wi-Fi for applications beyond coverage extension

For the reasons above as well as the risk of damaging their reputation for delivering high quality network experience, MNO's may be slow or reluctant to embrace Wi-Fi for any application beyond coverage extension as it goes against their strategic interests. Other players such as MSO's or Apple/Google/Microsoft see an opportunity in Wi-Fi as a way to reach out and attract users with their content offerings.

In the long run, all the telecommunication players are looking at providing ubiquitous services and controlling the end-to-end user experience. MNO's or MVNOs are likely to set up wholesale agreements with Wi-Fi Network Providers combining their cellular network services with Wi-Fi services to extend the reach and coverage, but not the capacity of the cellular network.

The structure of the wholesale agreement between MNO's and MSO's may deter MNOs from using Wi-Fi as a coverage or capacity solution. Wholesale agreements being discussed today include wholesale Price per GByte, monthly Subscriber Active Fee, monthly Fee per SSID activated per Access Point and any combinations of those. Successful wholesale deals in Europe are generally based on a fixed fee per Wi-Fi AP or per SSID; MNO's are reluctant to sign deals based on a wholesale rate per GB.

6. Conclusion

The appeal of Wi-Fi today is rooted in venue specific coverage, high quality broadband, and low cost. This model is proving to be highly successful with up to 70% of traffic on smart-phones being carried over Wi-Fi. Notwithstanding this high level of Wi-Fi traffic, cellular traffic is also growing rapidly and we do not see compelling evidence that Wi-Fi traffic is replacing cellular traffic in a significant way. Instead, demand is growing for both forms of connectivity. Furthermore, there is evidence that where good access to both 4G and Wi-Fi are available, traffic over both carriers increases i.e. usage on one stimulates usage on the other creating synergy between the two and a better overall experience for the end user. We believe that going forward, this model will continue to be successful, with Wi-Fi and cellular each delivering complementary parts of user's coverage needs. This will be further enhanced by innovative business models and technical advances of the Wi-Fi technology.

In this context, the main question addressed in this paper is whether Wi-Fi can or will alleviate capacity congestion on cellular networks. We considered first the offload potential from venue specific, coverage-led implementations of Wi-Fi, the predominant form of Wi-Fi today and probably the future; and secondly, the potential suitability of Wi-Fi as the base technology for purpose-built capacity solutions in areas of cellular congestion.

In locations where the cellular network is congested, Wi-Fi traffic replacing cellular traffic is limited and patchy

Existing Wi-Fi coverage-led networks. Cellular congestion occurs in many urban and suburban areas of the network, not just city centres. While opportunities for Wi-Fi offload exist in these critical areas, the amount of offload is small. The main reason is that Wi-Fi traffic is complementary but there are other constraints as well. Outside city centres, Wi-Fi availability and the opportunity for cellular off-load are significantly reduced, even in developed markets. The effect is even more pronounced in emerging markets where Wi-Fi availability is often prevented due to an absence of fixed broadband for backhaul.

Wi-Fi is a second choice to HSPA/LTE as the preferred technology for deploying and operating small cells for capacity

Wi-Fi as a capacity solution. Advances are being made with extending the functionality of Wi-Fi to match that of cellular which should in principle enable Wi-Fi based small cell solutions to be realised. However, there remain significant drawbacks to using Wi-Fi when compared with native cellular technology, which make small cells based on HSPA or LTE a more effective and attractive proposition for many MNOs. Notwithstanding these drawbacks, there will be circumstances where MNOs are unable to deploy their own small cell solutions when carrier-grade Wi-Fi small networks could provide a sensible solution.

We envisage that Wi-Fi will continue to grow rapidly delivering appealing, venue specific, coverage-led solutions. Cellular and Wi-Fi forms of access are complementary and the symbiotic existence drives greater demand of each. Both require new spectrum allocations for the future.

Appendices

Appendix A: **Incremental nature of Wi-Fi traffic**

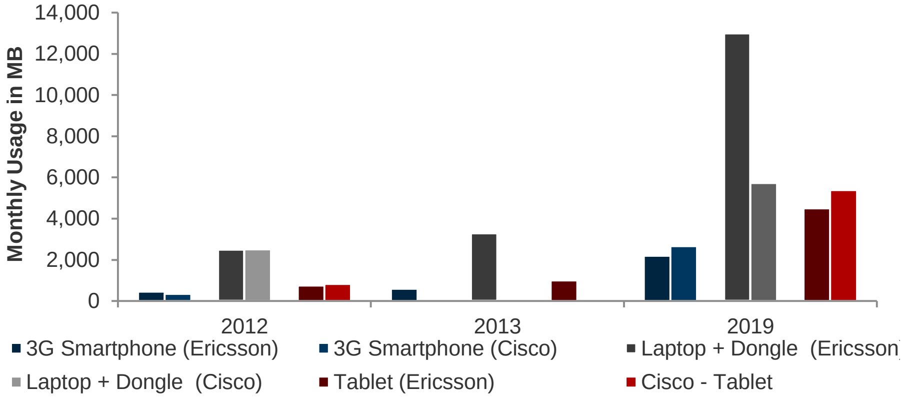
According to a survey conducted by Informa[9] of six markets, Japan, South Korea, US, Canada, UK and Germany, average monthly Wi-Fi traffic jumped 35.67% in the eight months from August 2012 to March 2013, compared with a 1.17% increase for cellular traffic collected from Android smartphones. Across these same markets, Wi-Fi on average accounted for 73% of total traffic on Android smartphones in April, up from 67% in August.

At first reading, this outcome contradicts earlier reports from EE in August 2013[10], based on a customer survey, showing evidence of the erosion of the Wi-Fi traffic when LTE is launched. However, closer inspection suggests that against customer intentions, the behavior of smartphone users in the most advanced LTE markets is entering a new phase as LTE networks mature together with Wi-Fi networks.

South Korea is by far the most mature LTE market in terms of penetration with an LTE penetration of a staggering 50%. Wi-Fi use as a share of total traffic on LTE devices is actually on the rise, having grown from 62.1% in August to 69.9% in April, outpacing the growth in Wi-Fi traffic on 3G devices over the same period. Wi-Fi's share of data use on 3G devices remains higher, however, at 79.9% in April, up from 73.4% in August.

According to Cisco[11], in 2012, typical 4G phone usage is 1.3 GB per month compared to 350 MB for a 3G phone. Using the analysis above, if you apply the 70% offload figure, the share of the monthly traffic transported on a Wi-Fi network would be roughly 750 MB on a 3G handset and 2.8 GB on a 4G handset.

Exhibit 4: Traffic forecasts according to Cisco and Ericsson



Source: VNI Mobile Forecast Highlights, 2012 - 2017 - Cisco Systems - Ericsson Mobility Report – Ericsson

If the Wi-Fi traffic were only driven by capacity offload, the Wi-Fi traffic coming from a 3G handset and a 4G handset would be expected to be roughly the same in absolute terms. However, the analysis shows that almost twice as much traffic is carried over Wi-Fi when using a 4G handset. The best way to look at this data is to assume that 70% of the time is spent by 3G or 4G users in areas where Wi-Fi networks are available, and cellular networks are either limited in coverage or congested.

According to Localytics[12], there is also a noticeable asymmetry in traffic being offloaded by Apple 4G smartphones compared to iPad 4G tablets. Whilst the offloaded traffic on an iphone 5 is close to 50%, the traffic offloaded on an iPad 4 is closer to

9 Understanding the Role of Managed Public Wi-Fi. Informa
10 4GEE Mobile Living Index. EE. August 2013.
11 VNI Mobile Forecast Highlights, 2012 – 2017. Cisco. 2012
12 iPad Connectivity Report. Localytics. March 2012

70%. As tablets usage would primarily be used in indoor venues, and due to the form factor are based on a static experience, the difference in traffic patterns reinforces the argument that Wi-Fi usage is driven by availability of the network rather than a deliberate decision to choose one Wi-Fi bearer over a cellular one.

Confirming the coverage orientation of Wi-Fi traffic, a recent paper from Deutsche Telecom[13] showed that by comparing total traffic before and after introduction of Wi-Fi in user trials, cellular traffic was unaffected by the introduction of free Wi-Fi access

The venues where Wi-Fi networks are available are unlikely to be intensively covered by the mobile operators in the near future for the reasons explained earlier. Whilst the composite traffic from a smart device will keep on growing, the proportion of Wi-Fi offload should remain at around 60%-70%.

On the other hand, the challenge for companies rolling out Wi-Fi networks interested in covering outdoor areas to a level on a par with that of cellular networks remains the monetisation of such networks outside “real estate” venues.

In Coleago’s opinion, the status quo is likely to remain at the level seen today i.e. an equilibrium determined by:

- the cost for the MNO of covering indoor venues
- the lack of source of funding for a Wi-Fi SP to cover outdoor areas.

The traffic analysis above confirms that there is little evidence that Wi-Fi is currently delivering real capacity relief for the cellular networks. It also provides little indication of any dramatic change of such a trend in the near future.

13 Wi-Fi Offloading.- Fairy tale or Swiss Army Knife? DT. Wi-Fi Offload Summit. January 2014.

Appendix B: **Spectrum, traffic distribution and site numbers**

The principal motivations for MNOs to acquire new spectrum are

- new bands to support new technologies such as LTE
- low frequency bands to improve the depth of coverage and reduce costs
- increased capacity per site, reducing the no. of extra sites needed for capacity

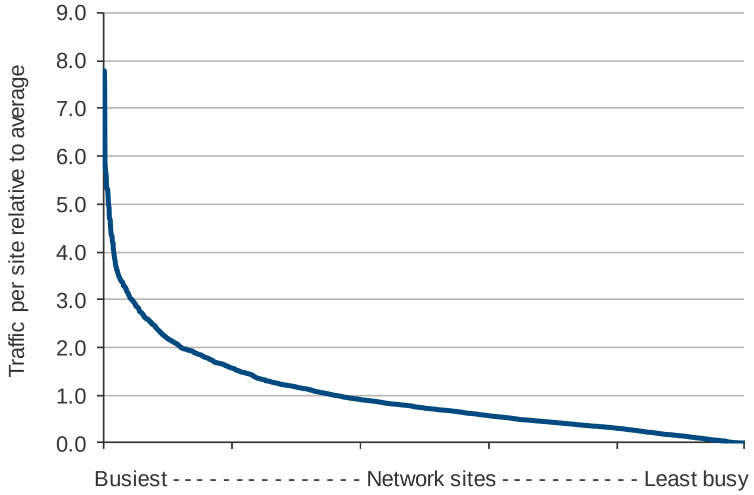
If MNOs fail to acquire new spectrum, they will have to acquire many more sites to increase site density and capacity (see Appendix C.1). Two factors that have a major bearing on the numbers of extra sites needed are

- Traffic distribution, which is heavily skewed across cellular sites.
- Geographic distribution. The sites on which the highest traffic levels are encountered are widely distributed, occurring not just in city centres but also in many urban and sub-urban areas

Exhibit 5 shows a typical distribution curve of traffic per site across the whole network. It demonstrates how traffic is heavily concentrated on a small percentage of sites. As traffic grows, the regular macro sites in these areas become overloaded and capacity enhancement measures have to be implemented (see Appendix C.1). If the level of overload is high, the network faces a double hit

- the costs of capacity enhancement at each individual site go up significantly
- the number of sites needing expansion rises exponentially.

Exhibit 5: Distribution of traffic per site across network



Source: Coleago

In these circumstances, the MNO has a number of potential options

- Invest in network capacity expansion, acquiring new sites in the process
- Acquire new spectrum
- Offload to Wi-Fi

Of these, acquiring new spectrum is by far the most effective option.

Appendix C: Wi-Fi and cellular capacity solutions

C.1. Hierarchy of capacity solutions

As traffic grows, MNOs add capacity in the most cost effective manner available. Operators have a range of capacity enhancement measures at their disposal. In approximate order of cost, the most common ones are

1. Additional radio carriers
2. More advanced technology e.g. HSPA → HSPA+ or LTE
3. Implement more advanced antenna solutions e.g. 2x2 → 4x2, 4x4 MIMO
4. Higher-order sectorisation e.g. 3 → 4 to 6 cells per site
5. One or more "capacity sites" located near traffic hot-spot. This could be a "street-works" site which is lower cost and lower height than a full macro.
6. Small cell layer. Based on Wi-Fi or Cellular technology. Alternative to capacity sites. Probably gives the greatest capacity uplift but is costly and relatively immature.

By far the simplest and least cost option is the addition of extra radio carriers using the existing technology already deployed. This option is only open of course if the operator has more spectrum available.

Not all of these solutions will necessarily be deployed. For example, adding more antennas to masts for high order MIMO or sectorisation can be impractical.

Other solutions are progressively more costly. The solution that probably gives the greatest uplift in capacity is small cells. This technology is still relatively untested and has some way to go before it is widely deployed in practice. It faces a number of challenges including obtaining rights of access to street furniture and backhaul. Nonetheless, the benefits are potentially very great and should lead to successful implementations in due course.

Small cells in principle could be implemented with either Wi-Fi or cellular technology. In Europe at least, most operators appear to be favouring 3G or 4G as the preferred technology. Whichever is used, the small cell clusters must be integrated with the main network.

C.2. Cell range

The cell ranges of LTE and Wi-Fi are both limited by the uplink. Their system parameters are designed to meet the target cell sizes and, as a wide area system, cellular has a far greater range target to meet than Wi-Fi. Accordingly, LTE has a link budget supporting a much greater path loss.

Most Wi-Fi traffic is today carried over the 2.4 GHz band which is rapidly becoming congested in public and private places. Additional traffic will need to migrate to the 5 GHz band. Propagation in this band however is poorer than the lower bands making it more suited to very short-range applications (this can be partly offset by MIMO). This makes the band less suitable for outdoor Wi-Fi.

The link budget advantage of LTE and UMTS supports the use of bigger cells for the small cell layer. This has to be balanced against the requirement that the cells must be small enough to be replicated multiple times in order to re-use the available spectrum and increase capacity. The advantage of the higher link budget of LTE (and UMTS) is that it allows great flexibility of design to meet optimum trade-offs between

- Cell size and coverage area
- Depth of in-building coverage
- Spectrum re-use and capacity increase
- Minimisation of no. of small cells and cost

Wi-Fi is more constrained in this respect. This would be significant in busy areas of cellular network where cell sizes are larger, such as in some urban and sub-urban districts. In residential districts, the traffic is more evenly distributed and the small cells will need to cover a relatively large area. With Wi-Fi, this will demand many more cells.

C.3. Mobility and interworking

To achieve seamless service for the user and to optimise the traffic distribution across different cells and frequency bands, important requirements for the capacity layer are full mobility between cells (Wi-Fi to Wi-Fi and Wi-Fi to cellular) and full interworking with the cellular layers of the network. Network architectures and technical functions such as Mobile IP, VCC, DSC (see Appendix C) are available that go some way to supporting these capabilities but thus far, have rarely been deployed. What is known is that they would introduce significantly more complexity into the network which would not be the case were native, standardised cellular solutions used.

C.4. Functionalities for Wi-Fi/Cellular integration

Cellular networks are multi-standard (GSM, UMTS, HSPA, LTE, LTE-A), multi-band (range of frequency bands), and multi-layer (macro, micro, small-cell). The standards have been designed to support full inter-operability and seamlessness between these access types. However, as an unlicensed technology, Wi-Fi has in the past been treated as a separate, “Untrusted” technology because of the lack of information and control of the Wi-Fi access by the cellular core network.

Wi-Fi however is becoming increasingly recognised as a form of mobile access that complements cellular. The user desires a seamless and convenient service from all forms of these HetNets (Heterogeneous Networks), ensuring that the device is connected to the optimum network, delivering the best user experience, with the minimum manual intervention from the user. The level of network integration that this implies demands a fully coordinated set of standards including architectures, network and device functionalities and APIs. Wi-Fi is a simpler and more basic system than cellular and with fewer functional capabilities when compared with cellular. A range of developments designed to fill the gaps has recently been taking place.

Concerted efforts are being made by standards bodies (IEEE, 3GPP) and other representative organisations (WFA, WBA, GSMA) to develop and define missing capabilities. Innovative solutions are also being developed and implemented by individual enterprises such as Cisco, Aptilo, Accuris, Birdstep, DeviceSpace, and others. 4G Americas[14] conducted a review of the status of recently developed functions and proposes a range of new enhancements. The most important functions developed belong to the following areas.

- Wi-Fi network discovery and automatic SIM-based authentication
- Intelligent Network Selection and traffic steering following client-based policies
- Mobility ensuring that Internet sessions remain uninterrupted when roaming between Wi-Fi and cellular
- Wi-Fi based location that naturally extends MNO capabilities

14 Integration of Cellular and Wi-Fi networks. 4G Americas. Sept 2013.

Exhibit 6 highlights recent developments and programs.

Exhibit 6: Recently developed Wi-Fi and Cellular network integration functions

Category	Standards body / organisation	Standard / program	Capability
Authentication and network discovery			
	WFA	Hotspot 2.0 / Passpoint	Facilitating and automating secure and trusted Wi-Fi connectivity Wi-Fi network discovery
	IEEE	802.11u	Building block of HotSpot 2.0
	WBA	NGH (Next generation hotspot)	
	IETF	EAP-AKA; EAP-SIM	Secure authentication protocols
Network selection and traffic steering			
	3GPP	ANDSF	Client-based, policy driven control of network selection and traffic steering Being aligned with HotSpot2.0 functions
Mobility	3GPP	SaMOG	Mobility between 3GPP and Wi-Fi networks
Network integration	3GPP	Trusted WLAN access	Architecture giving Trusted WLAN access to 3GPP core (EPC). Based on SaMOG

Source: Various

These are important steps towards the full interworking needed to integrate Wi-Fi capacity networks and cellular networks. Many of these are vital for Wi-Fi as a capacity solution for cellular since the Wi-Fi access needs to be integrated and managed as a seamless extension of the cellular network. The process of enhancing the Wi-Fi capabilities continues.

What is now significant is that both cellular and Wi-Fi players are now pushing for these new capabilities to be developed. The drivers come from the industry. If this momentum is maintained over the 5 to 10 year time-frame relevant to new spectrum, the prospects are good that the standards needed for effective Wi-Fi / cellular interworking will be available. How ubiquitously they will be supported on devices remains to be seen.

