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**Complementing macrocell deficits with either smallcells or Wi-Fi
-willingness to choose based on the cost-capacity analysis**

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Abstract

Nowadays, the increasing mobile data traffic adds extra pressure on the almost congested mobile networks. In order to meet the new demand, mobile operators have to improve their networks but as revenues are not expected to rise, they have to add extra capacity in a cost-efficient way. The solution might come from shifting the mobile data traffic towards indoor alternative networks, an approach known as mobile data offloading.

Among indoor solutions two technologies stepped forward, Wi-Fi and smallcells. This paper analyses the two technologies as complementing solutions for macrocell layer in the mobile data offloading context. The main discussed questions are whether the two solutions are interchangeable and what are the risks and pitfalls when choosing one of the two technologies. In order to answer the research questions, based on a proposed real life deployment scenario, a capacity-cost calculation has been driven. Thus, a newly built office building lacking indoor mobile coverage has been considered. Based on the calculated offered capacity, the deployment costs for a comprehensive solution using either of the two technologies have been estimated. The cost of provisioning for different solutions is based on the fact that either of these solutions needs to be built from scratch and no former type of coverage exists.

Regarding the interchangeability question, based on the conducted analysis, we claim that the answer is both “Yes” and “No”. “Yes” since the total cost of ownership for each technology is one order of magnitude lower compared to the traditional macrocell deployment. “No”, since deploying a smallcell network is four times more expensive than the Wi-Fi case when the same capacity is required. Thus, we can conclude that Wi-Fi and smallcells are two complementary rather than competing technologies. The goal is to offer a solution where the end-customer cannot tell whether he is connected on Wi-Fi or cellular. Integrating the two technologies into one single offered solution comes as the next normal step, more an evolution rather than a revolution.

1. Introduction

At the end of 2009 the mobile industry faced the inevitable; the aggregated mobile data traffic exceeded the voice traffic in the mobile networks (Ericsson AB, 2010). However, this was not an unexpected event but rather a historic milestone representing the start of a new era, the “smart-era”. In the last years the development of the mobile world has been an ongoing process that took off in 2007 when Apple launched its first iPhone. Since that moment the average customer’s data transfer behavior changed. Mobile data traffic started to increase and with the introduction of unlimited data plans, data traffic is growing at an astonishing pace. According to Cisco the average smartphone data usage grew by 81% in 2012, reaching 342Mb/month (Cisco, 2012). And this growth is not at its end. Adding the fact that by 2016 it is estimated that 25% of the mobile users will poses more than one mobile-connected device it is no surprise that the mobile data traffic demand exploded, being expected to rise 18 fold by 2016 (Cisco, 2012).

What should be good news for the mobile operators might become a nightmare as the increasing data traffic will lead to highly congested networks. For this reason the mobile operators will have to add more capacity to sustain their customers’ demands by expanding the capacity of their network infrastructure. However, this comes with huge costs due to expensive network deployments and since the average revenue per user (ARPU) is not expected to rise, the operators face a new challenge: the fact that MBB generates 70-80% of the traffic while bringing only 5-10% of the revenues might trigger what is called the “scissor effect”.

Another interesting aspect in today’s mobile networks is where the user data traffic will be generated from. It is estimated that by 2016, 70% of the mobile data traffic will be generated indoors while other raising the number up to 95%¹. This brings another problem for the mobile operators: modern offices are built of steel and energy-efficient glass, adding an additional pathloss component of 20-40dB attenuation for signals coming from outdoors (Tolstrup, 2008). So using the traditional approach for adding capacity by deploying more expensive macro base-stations will not be feasible either technically or economically.

So, assuring indoor coverage and the capacity needed for increasing MBB consumption while still remaining profitable, the mobile operators have to change business perspective and to find alternative ways to develop their networks without high CAPEX investments.

1.1 Indoor solutions

In order to face this new demand, mobile operators have shifted their business models towards using different possible indoor solutions. One way would be using a Distributed Antenna System, commonly known as DAS (The DAS Forum, 2013). Such a system implies using several antenna nodes inside one building in order to achieve increased coverage and have been widely deployed offering a “five bars” experience but without solving the future capacity demands.

¹ Simon Sauders – Chairman FemtoForum

The optimal solution might be represented by data offloading. Mobile data offloading refers to a new approach where the mobile generated traffic is carried out using an alternative network (DSL or cable broadband connection) rather than the conventional radio network. Currently Cisco estimates that 33% of the handset and tablet global traffic has been offloaded into the fixed network in 2011 (Cisco, 2012).

Two technologies stepped forward when discussing about mobile data offloading, smallcells and Wi-Fi. While Wi-Fi represents a well-known protocol widely deployed for data services, smallcells represent the newcomer technology in the industry but gaining rapidly a privileged position due to its capabilities. Smallcells, defined as low-power, short range and self-contained base stations, were initially used only in residential homes but rapidly extended to larger facilities like enterprises or metropolitan areas (Small Cell Forum, 2012). One can deploy a small-cell only by connecting a femto-Access Point (FAP) to Internet, the FAP being designed to be self-configurable without any user-intervention (Karonis, 2012). By operating in the interference-free licensed spectrum and offering seamless hand-over with the macro-layer there is no surprise that smallcells have been deployed on large scale in more than 25 countries with operators like Sprint reporting deployments of more than 1 million APs (Small Cell Forum, 2012). Smallcells have been intensively studied in the literature, authors like (Andrews, Claussen, Dohler, Rangan, & Reed, 2012) or (Calin, Claussen, & Uzunalioglu, 2010) analyzing the femtocell field both on technical and economic aspects, concluding that there are no obstacles in front of femtocell deployment on large scale. Most of the papers are focused on the interoperability between the macro and smallcell layer concerning capacity, coverage or interference issues, aspects discussed by (Juang, Ting, Lin, & Lin, 2010), (De La Roche, Valcarce, López-Pérez, & Zhang, 2010) or (Yavuz, Meshkati, Nanda, & Johnson, 2009).

On the other hand, working in the free unlicensed spectrum and being widely deployed around the world, Wi-Fi might be the solution the mobile world needs. Traditionally mobile operators' perception of Wi-Fi was that of a separate business or was linked to fixed broadband subscriptions offers. As an indication of its wide success, Wi-Fi is used in more than 200 million households and more than 750 000 hotspots are available worldwide (Cisco, 2012) hence mobile operators changed their view. Wi-Fi became a viable solution for solving the so called "data crunch" becoming more an opportunity rather than a threat (Popescu, 2013). Wi-Fi has been analyzed by (Dimatteo, Hui, & Han, 2011) or (Lee, Yi, Rhee, & Chong, 2013) concluding that this solution can be a viable choice in the mobile data offloading context. Furthermore (Johansson, 2007) makes an extended analysis related to heterogeneous networks covering also the Wi-Fi networks' case.

1.2 Paper objective and research questions

Taking into consideration the aforementioned “data tsunami” mobile networks face nowadays it is more and more clear that mobile data offloading might be the right solution. The question relies now on which is the right technology to complement the macrocell layer. Both Wi-Fi and smallcells present advantages that can recommend them as feasible solutions but which one is better?

This paper set out to analyze the potentials of smallcells and Wi-Fi in order to determine the proper complementing solution for macrocells’ deficits. Hence, the research questions are:

1. *Are smallcells and Wi-Fi networks interchangeable solutions?*
2. *What are the risks and pitfalls in front of choosing either smallcells or Wi-Fi for complementing macrocells?*

The paper outline is as follows. Chapter 2 presents the methodology, the used model assumptions and the framework for the analysis. Chapter 3 discusses the technical aspects of the conducted analysis where the required number of APs for each technology is calculated based on capacity and number of served users. Based on this, the following chapter presents the conducted cost analysis. The last two chapters provide the final discussion and the conclusions.

2. Methodology, assumptions and work flow

The starting point is discussing the interchangeability of smallcells and Wi-Fi as a cost efficient alternative to traditional macro base stations. In order to evaluate this aspect a quantitative research has been chosen as primary methodology based on information gathered through interviews with different experts in the industry. Among the conducted interviews we can mention representatives of mobile operators, equipment providers or third party actors involved in the mobile business. The interviews were conducted in a semi-structured way in order to offer the interviewees the possibility to express their own opinions while following a pre-defined set of questions.

For obtaining a clear estimate of the economic feasibility for each solution a newly built deployment scenario has been considered. Taking into consideration the fact that network congestion due to high data usage is most probable in highly dense areas, a newly built office building lacking mobile coverage is considered. This building, covering a total of 20000m² accommodates 1000 high mobile data consumers that are evenly distributed on its 4 floors. For estimating the total demand two monthly data consumption levels have been considered. The first level, 10GB/month/user, reflects the actual needs in the western countries while the second one, 50GB/month/user², being the predicted future demand. For obtaining a clear picture for the capacity requirements over the entire time period, it was assumed an annual mobile traffic growth of 30%, starting from 2013 reaching the predicted 50GB/month/user level in 2019.

² GB = gigabyte

The cost of provisioning for different solutions is based on the fact that either of these solutions needs to be built from scratch and no former type of coverage exists. Based on the calculated offered capacity, the deployment costs for a comprehensive solution using either of the two technologies are estimated.

For offering a clear picture over the total involved costs, Total Cost of Ownership (TCO) has been used. This takes into account the total expenses when running a network including acquisition price and yearly operating & maintenance costs. This model has been chosen due to the fact that it offers a framework to evaluate competing technologies when the eventual economic benefits are the same, the same monthly data subscription. The calculations have been done over a total period of 7 years and no depreciation rate has been taken into consideration since it is assumed that the life cycle is roughly the same for all three studied technologies and no equipment re-sale will be performed at the end of it.

3. Capacity calculation

3.1 User demand

For calculating the user demand a worst case scenario has been taken into consideration where the entire data amount is consumed only during working hours, 20 days/month and 8hours/day. According to this assumption the total required capacity per entire building results in 140Mb/s³ nowadays and 676Mb/s in the future. The entire demand is device independent (mobile phone, tablet or laptop). In consequence it is considered that every user is “on-line” at a certain moment of time. This leads to a total of 1000 concurrent mobile connections. On a per-floor basis the resultant required capacity is estimated at 35Mb/s and 169Mb/s.

3.2 Site planning

Macro base stations

For the macro base station case we will consider LTE technology having an average cell spectral efficiency of 1,69 bps per Hz (Rumney & Moray, 2013). Consequently, for different bandwidth allocation and considering three-sector sites the maximum offered capacity can reach up to 100Mbps for a total of 20MHz allocated spectrum as presented in Table I.

³ Mb = megabit, Mbps = megabits per second

Table I Macrocell offered capacity

Spectral efficiency	Allocated Bandwidth		
	5 MHz	10MHz	20MHz
1.69 bps/Hz	25Mbps	50Mbps	100Mbps

By using the total allocated spectrum, in order to meet the actual capacity requirements, 2 macro base stations will be needed. On the other hand, for the future predicted data demand, 7 LTE macro-base stations will be necessary.

Smallcells

When considering smallcells two different deployment approaches have been taken into consideration, either limited by the total capacity or by coverage (maximum number of concurrent served users and area coverage). All calculations have been done using 5MHz of spectrum reaching to a total capacity of 10Mbps offered by each 4G capable femto access point (FAP). Thus, in order to meet the capacity demand a minimum number of 14 FAPs will be required nowadays raising the number to 68 in the future.

In what concerns the covered area, the regular range of a femto-AP is considered around 20m (Chandrasekhar, Andrews, & Gatherer, 2008). With this assumption a minimum number of 4 FAPs will be required per floor with a total of 16 for the entire building.

When talking about maximum number of concurrent served users two different types of femto access points were considered, one with a maximum of 32users/FAP and one with 64users/FAP (Fujitsu, 2013), (ipaccess, 2012). According to these assumptions either 32 or 16 FAPs will be required.

Table II Number of total required FAPs for every limitation

Limitation		Year	
		now	future
Capacity		14	68
Area		16	16
Nr. of users	32users/FAP	32	32
	64users/FAP	16	16

Wi-Fi

In the case of Wi-Fi deployment two different IEEE 802.11 standards have been considered: IEEE802.11g and IEEE802.11n. Distance dependent throughput estimations have been used for network dimensioning where, as a rule of thumb, the actual throughput being considered as half of the data rate (Gast, 2005). The estimated throughput for each AP depending on the distance is depicted in Table III (Broadcom, 2003), (Juniper, 2012).

Table III Throughput per AP for different Wi-Fi protocols

Distance (meters)	802.11g only (Mbps)	802.11g Mixed (Mbps)	802.11n -2.4 GHz (Mbps)	802.11n -5 GHz (Mbps)
3	24.7	14.7	100	180
15	24.7	14.7	90	150
30	19.8	12.7	60	110
35	12.4	9.1	50	80

Furthermore, for the capacity calculation, only the downlink has been taken into consideration due to the fact that the vast majority of data consumption is used for download. The total number of required APs is presented in Table IV. A third case, where mixed 802.11a/b/g capable devices were taken into consideration due to the large variety of mobile devices users can operate. In this case APs use protection mechanisms that will lower the throughput.

A limiting factor is represented by the co-channel interference especially in the future demand case where 15-20 APs are required per floor in order to meet the capacity demand. For those cases, Wi-Fi deployment will be rather impossible. A feasible solution is represented by the 802.11n protocol. In this case an area coverage limitation appears in the low demand situation. For meeting the capacity requirements one single AP per floor would be sufficient but a minimum number of 2 APs/floor would be needed in order to cover the entire floor.

Table IV Total number of required 802.11 APs

Year	802.11g only (Mbps)	802.11a/b/g Mixed (Mbps)	802.11n -2.4 GHz (Mbps)	802.11n -5 GHz (Mbps)
Total required APs now	12	16	8	8
Total required APs in future	56	80	16	12

According to our capacity needs presented in Table V and taking also into consideration the area coverage and number of served users, the total number of APs required for each chosen technology is presented in Table VI.

Table V Total required capacity per year

Year	2013	2014	2015	2016	2017	2018	2019
Total required capacity [Mbps]	140	182	236.6	307.58	399.854	519.8102	675.7533

Table VI Total number of required APs per technology per year

	2013	2014	2015	2016	2017	2018	2019
Macro Base Stations	2	2	3	4	4	6	7
Smallcells 32 users	32	32	32	32	40	52	68
Smallcells 64 users	16	20	24	32	40	52	68
IEEE 802.11n	8	8	8	8	8	16	16

4. Cost analysis

The cost analysis is based on comparing the total cost for each deployment (macro base stations, smallcells and Wi-Fi) in order to meet the same capacity demand. It is considered that no previous form of mobile coverage is present in or around the building, each deployment being built from scratch. For obtaining a holistic picture over the price implications both capital expenditures (CAPEX) and operational expenditures (OPEX) will be considered. The total obtained cost includes radio equipment costs, macro base station sites, installation costs, site leases and operation and maintenance expenditures. Furthermore, a 5% per year price erosion is considered for all required new equipments. For the macro base stations case the estimated CAPEX and OPEX are shown in Table VII.

Table VII CAPEX and OPEX for macro base stations sites

CAPEX	Macro site + transmission	Cost K€	
		10 (actual)	7,4 (future)
OPEX	Radio equipment	10	7,4
	Site lease	10	
	Leased lines	10	
	O&M	10	
	Power	5	

According to Table VII for one three-sectors macro base station site the CAPEX is estimated to 110k€ for the actual demand while the OPEX is around 35k€ per year. According to the considered price erosion rate, for the future demand, the radio equipment's price is reduced to approximately 7400€ but without significant differences due to high buildout costs.

In case of Wi-Fi and smallcells the estimated costs per AP are roughly the same. More specifically, the deployment cost for one AP is considered around 1000€ containing the cost for the access point, installation & transmission and the share of the AP controller and management system (Markendahl & Makitalo, 2010). In all three deployment scenarios the backbone costs are not included being considered already built out. For calculating the CAPEX it has been taken into consideration the total number of new APs required every year in order to meet the traffic growth. Using those numbers and the estimated costs per AP presented above, it is

straightforward to compute the total CAPEX investments over the entire considered period of time. The figures are presented in Table VIII.

Table VIII Total CAPEX investments per year and technology [k€]

	2013	2014	2015	2016	2017	2018	2019
New Macro Base Stations	220	0	109.02	108.57	0	215.47	107.35
Reuse Macro Base Stations	20	0	9.02	8.57	0	15.47	7.35
Smallcells 32 users	32	0	0	0	7.40	10.91	14.30
Smallcells 64 users	16	3.92	3.84	7.54	7.40	10.91	14.30
IEEE 802.11n	8	0	0	0	0	7.27	0

While for macro base stations' case the annual operating expenditures were estimated to 35k€/year, for both smallcells and Wi-Fi the annual operating and maintenance costs were evaluated to 500€/year/AP containing mostly the broadband connection subscription. A clear picture of the entire cost estimation is presented in Table IX showing the total cost of ownership for each technology over a 7 years time period. TCO was chosen due to its capabilities to offer a clear picture over the total costs including acquisition and yearly maintenance for the entire studied period.

Table IX Total cost of ownership for every technology per year[k€]

	2013	2014	2015	2016	2017	2018	2019
New Macro Base Stations	290	360	574.02	822.59	962.59	1388.07	1740.42
Reuse Macro Base Stations	90	160	274.02	422.59	562.59	788.07	1040.42
Smallcells 32 users	48	64	80	96	123.40	160.32	208.62
Smallcells 64 users	24	37.92	53.76	77.30	104.71	141.62	189.93
IEEE 802.11n	12	16	20	24	28	43.27	51.27

5. Discussion

Following the obtained figures in Table IX it is clear that in order to overcome the capacity needs, deploying new macro base stations is not a cost efficient solution. The macro solution is one order of magnitude more costly than the other solutions and this significant difference appears mainly due to high sites' costs in the considered urban areas. Another determinant factor in the price difference is represented by the operating and maintenance costs. Still, even if the rate between macro's and smallcells' or Wi-Fi's OPEX is 70:1, the total cost difference is attenuated by the smaller number of required macro base stations comparing to the other indoor solutions.

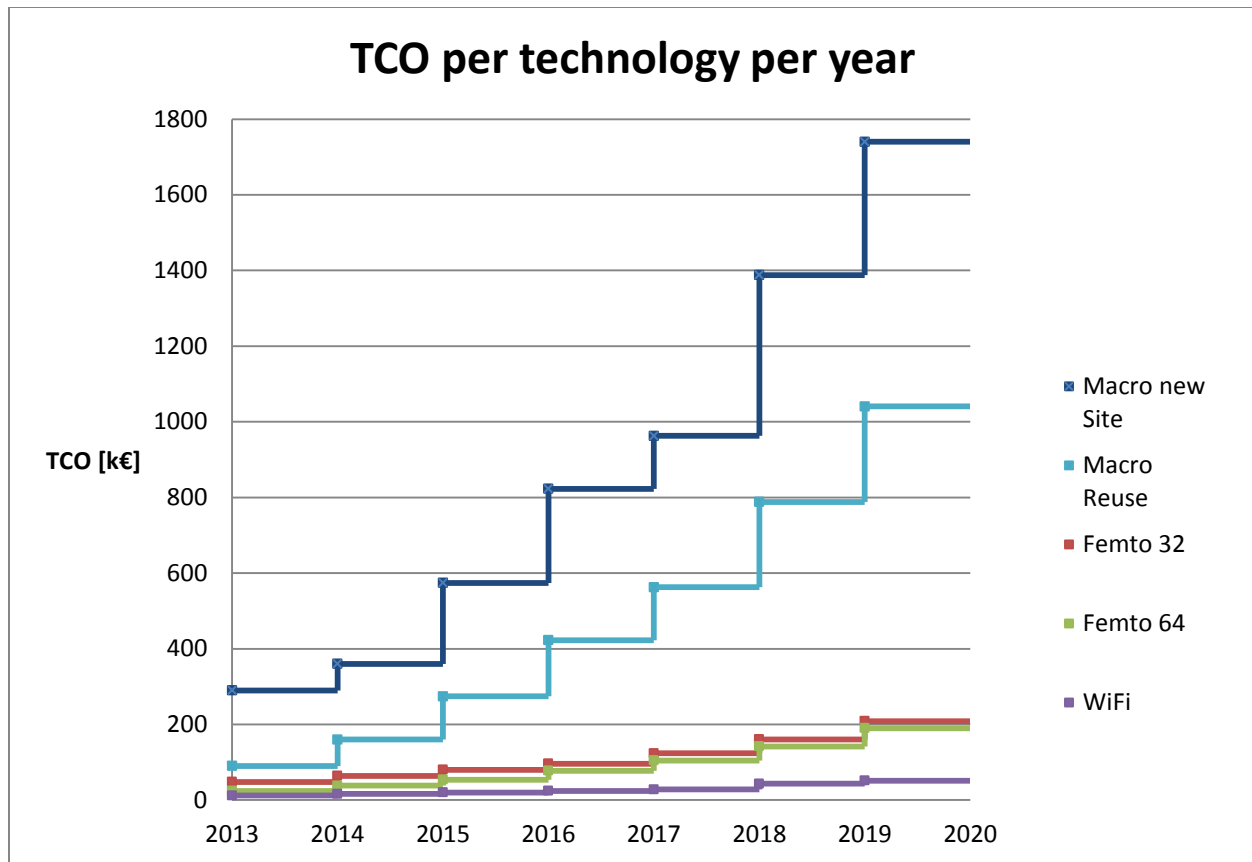


Figure 1 TCO per technology per year [k€]

One first thing that can be observed in Figure 1 is the “step-like behavior” the TCO has over the studied period. This comes as a result of the discrete increase of the total data demand for each year. According to this assumption, the total data demand is constant during a period of one year, resulting in a fixed number of required APs or base stations.

Following Figure 1 we can affirm that the two studied indoor solutions, Wi-Fi and smallcells, can be considered reliable for assuring indoor mobile data traffic from a cost-effective perspective. Even in the fortunate situation when already existing sites can be reused, the total cost for indoor technologies is one order of magnitude lower. When talking about the most cost effective solution, IEEE 802.11n technology is the solution to choose. And this might not be a surprise since it’s low cost per AP and great data transmission capabilities.

But deploying only Wi-Fi APs comes with a crucial disadvantage. Traditionally assuring voice services has been more important than data services and this is also the situation in our considered office scenario. Even if IEEE 802.11n is capable to offer great data transmission rates at low prices, its Voice-over-IP capabilities is rather less reliable compared to the cellular voice service. And this is the case where smallcells, offering both mobile voice and data services while still remaining cost-efficient, outperforms.

An interesting aspect that can be observed following figure 1 is the linear increase the total cost has every year for each technology. This behavior is caused by the linear increase of the total data demand. An exception is represented by the macro case where due to the fact that no extra base stations are required for 2014 and 2017, the TCO's increase in those cases is represented only by the operational expenditures. Furthermore, due to the fact that 2 macro base stations are required for 2018, the annual CAPEX is increased significantly hence rising the TCO in a more aggressive way.

When it comes to smallcells, as mentioned before, the deployment is driven by two factors, number of users and capacity demand. Thus, in the first 3 years when the number of deployed APs is driven by the number of served users, the total number of required smallcells differs for the two considered cases, 32users/smallcell and 64 users/smallcell. Starting from 2016, the number of required APs is driven by the capacity demand, resulting in an equal number of smallcells for the two cases. This fact can be observed also in the presented figure, where the two cases slightly differ for the first years, tending to equalize by the end of the studied period of time.

Another important aspect to discuss in the comparison represents the used spectrum. Due to the free unlicensed spectrum, Wi-Fi networks can be a straightforward inexpensive solution when extra data capacity is required. On the other hand, smallcells using the operator's licensed spectrum, comes with a set of advantages in what concerns the connectivity with the end-user mobile devices, this being achieved automatically, with zero end-user intervention. On the other hand, two new Wi-Fi standards promise to offer the same seamless offloading experience. IEEE 802.11u protocol and HotSpot 2.0 initiative are aiming to change the way mobile devices authenticate and connect to the Wi-Fi AP, achieving an automated process, invisible to the end-user.

Since both Wi-Fi and smallcells are technologies suitable for data offloading, a third solution may represent the case where femtocells and Wi-Fi are integrated in one device called Integrated Femto Wi-Fi (IFW) utilizing both technologies' advantages. This can be done on two different levels of integration. The first one, the co-existence level, represents the case where both solutions will operate independently, the integration being achieved only by joining the two APs corresponding to each technology into one single device. The second level should involve active cooperation where traffic shaping policies should make possible offloading the mobile data in a balanced way. This should be achieved based on the congestion level each network presents.

Traditionally, in the enterprise case, the Wi-Fi network was owned and operated by the internal IT department whereas the mobile indoor cellular network was in the mobile operators' responsibility. But when integrating the two services into one single device the ecosystem might be modified. And this process might be accelerated by a new trend where enterprises' IT departments are trying to shift the large capital investments to monthly OPEX fees. When talking

about offering IFW services the mobile operators and 3rd party companies are the two actors that have the incentives to invest and deploy such indoor networks. Until now, the relationship between MNOs and enterprise customers was limited to minutes and mobile devices. But this is changing and as Spider Cloud's CMO, Ronny Haraldsvik mentioned "IT directors want a stronger relationship with their communication partners". By deploying an IFW network, MNOs can solve their indoor coverage problems, a major churn factor, and in the same time enhance their market position by offering Wi-Fi-as-a-Service.

The general trend of transferring CAPEX to OPEX might represent a business opportunity for 3rd party actors too. The business case for this type of actors is represented by ensuring indoor mobile coverage and capacity as a service, allowing mobile operators and IT departments to externalize expensive and time consuming investments towards experienced actors in the field. But for offering IFW services one has to have access to MNOs' licensed spectrum. And this is a valuable asset that MNOs would not easily give away the control due to both economic and technic reasons. The solution for this problem comes from the recent allocation of unlicensed spectrum in the 1800MHz band in countries like Sweden, UK and Netherlands. The possibility to use free unlicensed spectrum for operating indoor smallcells represents the trigger 3rd party actors were waiting for.

6. Conclusions

Traffic demand is rising at an astonishing pace and mobile operators have to keep up with this. But in order to be able to offer the required capacity and keep their customers happy they have to develop their networks. The problem is that the traditional way of adding capacity by deploying more macro base station is not a cost-efficient solution. The alternative approach, where coverage and capacity is provided indoors, proved to be a feasible solution, both technical and economical. Among the existent indoor solutions, this paper studied smallcells and Wi-Fi and their economic implications when assuring the actual and future capacity demands.

The main question discussed in this paper, whether Wi-Fi and smallcells are interchangeable solutions from a cost perspective, can be answered by both "Yes" and "No". "Yes" from a cost perspective when compared to the macro case, both solutions having the total cost of ownership an order of magnitude lower than macrocells. "No" since, deploying a smallcell network is four times more expensive than the Wi-Fi case when the same capacity is required.

The second question refers to the eventual risks and pitfalls one might take when choosing one of the two solutions when complementing the macrocell network. Wi-Fi was designed mainly for data traffic and due to its high transmission rates at low prices, 802.11n technology might be a perfect choice for mobile data offloading. But beside the technical issues, Wi-Fi still offering lower security and QoS levels than the mobile networks, MNOs might not want to shift the entire mobile data traffic towards Wi-Fi APs. If this happens, the operators

might lose the control over the traffic and customer base, becoming irrelevant in the ecosystem. On the other hand, using the operators' licensed spectrum, thus offering a seamless connection between the mobile device and the AP, represents the main advantage smallcells have. But due to the limited number of users one smallcell can serve, a larger number of APs are required to meet the demands. This might lead to frequency interference problems which can cause issues in the macrocell network too when spectrum is reused.

Wi-Fi and smallcells are two complementary rather than competing solutions. Nowadays one cannot focus on only one radio access technology. The goal is to offer a solution where the end-customer cannot tell whether he is connected on Wi-Fi or cellular. Integrating the two solutions comes as the next normal step, more an evolution rather than a revolution. Furthermore, the first actor that will be able to offer indoor services with no CAPEX but based on predictable OPEX will have the biggest advantage and the chance to consolidate its position in the market.

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