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Toward capacity-efficient, cost-efficient and power-efficient deployment strategy for indoor mobile broadband

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TOWARD CAPACITY-EFFICIENT, COST-EFFICIENT AND POWER-EFFICIENT DEPLOYMENT STRATEGY FOR INDOOR MOBILE BROADBAND

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Abstract

Mobile operators nowadays tend to deploy dense heterogeneous layers of 3G and 4G networks in outdoor and indoor environments by adding more macrocells and smallcells (e.g. microcells, picocells and femtocells) in response to the increasing subscriber demand for coverage and capacity. The main driver and enabler behind this tendency is the phenomenon that around 80% of power consumption in mobile communication networks stems from the radio base stations. This situation makes mobile operators opt for the use low-power radio base stations to provide better coverage, capacity and a more environment-friendly operation. The use of low-power radio base stations leads to reduction of energy consumption in mobile communication networks power.

The aim of this study is to conduct a comparative study between homogenous macrocell deployment and indoor smallcell deployments as alternative solutions for provision of the required indoor coverage and capacity. Moreover, the study highlights the importance of backhaul solutions being critical components in the smallcell network deployment. Furthermore, the scope of the study is extended to cover the investigation of the value of the heterogeneous (i.e. hybrid macrocell-femtocell) deployment scenario as a cost and power-efficient solution versus the homogenous macrocell deployment scenario in view of the variations in the mobile network traffic during the day.

The main findings indicate that the CapEx and OpEx of the backhaul solution represent the major part of the total deployment cost in the indoor smallcell deployment scenario (i.e. femtocell case) compared to those of the macrocell deployment scenario. Nonetheless, the perceived saving in the total cost of ownership (TCO) resulting from the use of indoor smallcell (i.e. femtocell) remains a satisfactory and convenient motivation considering the traffic variation across the day, traffic distribution between indoor and outdoor locations and the keenness to use the spectrum resources more efficiently.

Keywords—*Backhaul; Cost; Capacity; Femtocell; fiber optic; HSPA; LTE; Microwave; Macrocell; Power Consumption, Deployment Strategies.*

1 Introduction

The demand for mobile broadband access has increased dramatically in recent years in terms of number of mobile connections and volume of traffic. As of year 2010 around 80% of the generated data traffic originates from indoor environments as per Cisco forecasts. The growth of data traffic is anticipated to continue exponentially due to the emerging IP-based applications and to the technological advances in the end-user devices (e.g. smartphones and tablets). This growth entails considerable investments in network infrastructure and the associated essential resources such as the frequency spectrum. In addition to that, the reduction of energy consumption in mobile communication networks has recently become a significant concern and an extremely pressing challenge for mobile operators and policy makers in the light of the increasing public and political awareness of climate change and environmental issues. Recent statistics indicate that mobile communication networks consume around 0.5% of the global energy and around 80% of the power consumption in the mobile networks stems from the radio access network; namely radio base stations (Tombaz, et al., 2011). This explains why low-power and low-cost smallcell are gaining more and more attention as cost-efficient and energy-efficient solutions for the provision coverage and capacity requirements in indoor and spotty locations.

In fact, mobile operators nowadays tend to deploy dense heterogeneous layers of 3G and 4G networks in outdoor environments by adding more macrocell and small outdoor cells (e.g. Microcell and Picocell) in response to the increasing subscriber demand for coverage and capacity (Nokia Siemens Networks, 2011). Such dense outdoor deployment should sustain the required service levels in indoor and outdoor environments; but this cannot always be realized at reasonable deployment costs and power consumptions. Moreover, the backhaul network capacity presents an extra challenge in the outdoor smallcell deployment because of the number radio base stations (RBSs) involved. Furthermore, the adoption of high spectral efficiency air interfaces such as HSPA+ and/or LTE increases the RBS capacity and puts more requirements on the backhaul network.

The ongoing research studies at this juncture focus on two apparently contradicting issues: the extent to which the number of radio base stations required can be reduced and the ability to cope, at the same time, with the increasing demand for capacity. These two issues can be approached by either optimizing the power consumption of the radio base station and/or by lowering the required number of radio base stations through upgraded deployment strategies, e.g. seeking the optimum ways for the provision of the required network capacity in places where it is really needed such the crowded business districts (Nokia Siemens Networks, 2011)(Markendahl & Mäkitalo, 2010).

Numerous scholarly works have been devoted for investigating the differences between macrocell deployment and smallcell deployment. The authors of (Tombaz, et al., 2011), for example, conducted a comparison between homogeneous macrocell-centric networks and the alternate heterogeneous network scenarios in terms of the total cost of ownership (TCO) and energy consumption. In a similar step (Frias & Pérez, 2012) evaluated the cost of providing LTE mobile broadband services in urban environments using two scenarios: a joint-deployment of femtocells and macrocells scenario and a homogenous deployment of macrocell scenario. The findings of (Frias & Pérez, 2012) work indicated that the achieved cost saving varies according to the available frequency bandwidth and the business model used, (closed subscriber group or open subscriber group). Moreover (Markendahl & Mäkitalo,

2010) compared the cost, capacity and performance of a macrocell network deployment versus those of femtocell network deployment in relation to different user demands (low and high demand) in a business district and with the indoor coverage in focus. The main findings of (Markendahl & Mäkitalo, 2010) study indicate that femtocell deployments have much lower cost only when new macrocell sites need to be deployed to meet the end user demand.

Unlike the preceding scholarly works, the approach followed in this study, when comparing homogenous macrocell deployment and indoor smallcell deployment (i.e. femtocell), centers on investigating the effects of traffic variation during the day taking into account different demand levels, radio access technologies (i.e. HSPA and LTE) and backhauling technologies. The effects of the traffic variation on capacity, deployment cost and power consumption is identified and analyzed in order to answer the following questions:-

- 1) *How would the backhaul solution affect the cost structure and power consumption structure in the context of the indoor mobile broadband?*
- 2) *How would the heterogeneous deployment scenario (i.e. hybrid macrocell-femtocell deployment) help operators to adapt and cope with the traffic demand variation throughout the day?*

2 Methodology

A quantitative research approach has been adopted in this study in order to investigate and answer the posed research questions. Two deployment scenarios for the provision of the required indoor coverage and capacity have been assumed for comparison and investigation; namely, the femtocell deployment scenario and the traditional macrocell scenario. The process of comparing and analyzing the two scenarios has taken into account different radio access techniques (e.g. HSPA and LTE) focusing on interplay between metrics such as the deployment cost, targeted network capacity and power consumptions resulting from the traffic variation during the day. This investigation has been extended as well to discuss the challenges of network dimensioning emanating from the traffic variation across the day. In this connection, a hybrid deployment scenario can be compared with a homogenous macrocell network deployment scenario.

3 Mobile Network Architecture: Heterogeneous RAN

The description of the mobile network architectures can vary in terms of terminology used in different mobile network generations and systems (2G, 3G or 4G). These different mobile systems or generations, which exist today, are characterized by various radio interfaces and access networks and in some cases they share the same core network. Without going into the details of any specific mobile network generation, the mobile network architecture can include three parts namely; Radio Access Network (RAN), core network and backhaul & transmission network as illustrated in figure-1.

3.1 Radio Access Network (RAN)

The RAN represents the last mile towards the mobile end users and it utilizes the electromagnetic radio spectrum as a medium to carry the subscriber traffic. The RAN has three main types of nodes, namely, the radio base station (RBS), that manages and allocates the radio resources among the end users (i.e. mobile devices), the End-Users Devices and the radio network controller (RNC) which is responsible for controlling the radio base stations

(RBS) that are connected to it. The RNC performs the management of the available radio resource as well as the management of some of the mobility functions as per the 3G standards and terminology.

The radio access network, as shown in figure 1, is traditionally rolled-out using outdoor macrocells, each with a cell radius normally ranging between 1 to 10 km depending on the used frequency band and the propagation environment (i.e. urban, sub-urban or rural areas). With data traffic typically doubling at least in the mobile network year-on-year, 3G operators are increasingly tuning up second and third 5MHz frequency carriers at more and more of their macrocells, thereby, approaching the limits of the spectrum available to them. Leading mobile operators who have rolled out an initial macrocell layer of LTE are already in the process of planning for the next level of capacity expansion. In spite of the various capacity-enhancing techniques that enable network operators to squeeze more out of the macrocell network, the data growth dense their networks and push them to take a step-change towards the use of 3G and 4G smallcell. The purpose of deploying smallcell is to increase the number of radio base stations available to each mobile subscriber as a capacity-efficient solution that brings the mobile broadband capacity closer to the mobile subscriber which results in its turn in a better quality data connection per mobile device.

The term “smallcell” refers to type of radio base stations that encompasses microcells, picocell/metrocell and femtocells. These smallcell transmit signals at power levels much lower than macrocells besides being physically much smaller as well. In addition, the Radio Base Station (RBS) products used in building out these new public access smallcell typically support the use of omnidirectional antennas (DASForum, 2013). The following subsections furnish further details on the different types of smallcell.

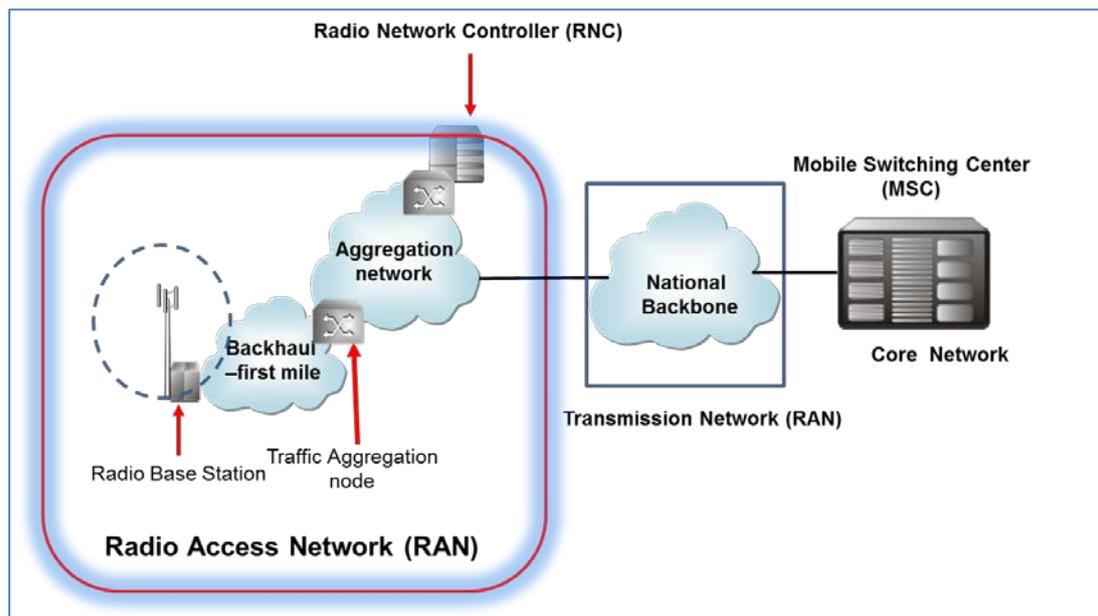


FIGURE 1: TOWARD HETEROGENEOUS MOBILE NETWORK ARCHITECTURE

3.1.1 Microcell and Picocell Solutions

Microcells and their smaller peers, picocells are generally deployed by mobile network operators to improve their networks coverage and capacity in high traffic public outdoor areas such as public transport terminals and stations. The term “microcell” is conventionally used to describe a single, outdoor, short-range radio transceiver. A microcell is physically larger than

picocells, and has greater coverage and capacity capabilities which allow the microcell to support more users than a picocell. For instance, a microcell solution can support up to 200 users within a cell radius not exceeding one kilometer while a picocell solution is typically intended for installations in enterprise environments and can support up to eighty users (DASForum, 2013).

3.1.2 Femtocell Solutions

Femtocell is defined by the Smallcell Forum as fixed, stand-alone, low-power, short-range cell site designed to improve wireless reception inside buildings. From a design point of view, a femtocell resembles a regular Wi-Fi Access Point. Femtocell Access point is normally linked to the mobile operator's core network via the existing Internet broadband connection in buildings. Compared to microcell and femtocell don't require special skills or technical expertise for installation. The typical femtocell access point (FAP) operate with lower transmission power compared microcells and picocells, and has less coverage area (DASForum, 2013).

3.1.3 Femtocell vs. Wi-Fi: Differences and Similarities

Wi-Fi technology is developed initially by the Institute of Electrical and Electronics Engineers (IEEE) as a type of wireless local area network (WLAN) that allows data traffic transfer between computers. Wi-Fi networks are designed to operate in unlicensed frequency bands namely 2.4 GHz and 5 GHz radio bands. Thanks to its flexibility and friendly use, the WiFi technology is now found in almost all laptops, notebooks smartphones, televisions sets, video games, digital cameras, and even in the global position system (GPS) devices and machine to machine (M2M) enabled solutions. Typical Wi-Fi hotspot can contain one or more access points (APs), each with an indoor coverage radius ranging between 20 and 200 meters.

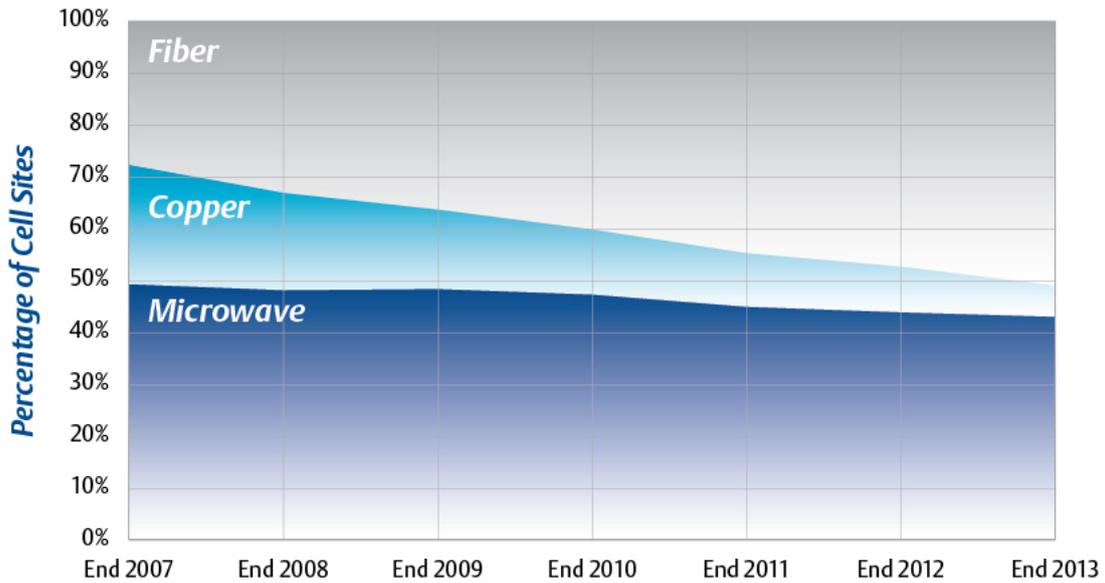
In other hand the femtocells are deployed using licensed cellular bands which enables mobile subscribers to move seamlessly between the femtocells sites and the outdoor cellular sites as both operate in the same frequency bands and use the same radio access technology (RAT) (Nokia Siemens Networks, 2011) (Inter Digital, Inc., June 2012). That is why the deployment of femtocells faces the same challenges experienced by the deployment macrocell and outdoor smallcell. The mobile network planning challenge remains to be whether to assign dedicated spectrum resource for femtocell deployment or not. If the same macrocell frequency band is used for femtocell deployment, co-existence and interference problems may arise (Smallcell-Forum, March 2011)

3.2 Core network

The core network is the brain and central component of the mobile network that carries out the switching and mobility management functions that allow mobile devices roaming on the network to communicate with each other and with the devices of other networks (whether circuit-switched, packet-switched or IP-based). As shown in Figure-2, the core network contain entities/nodes such as the Mobile Switching centers (MSC) that controls calls and data sessions originating from and terminating on the network i.e. the switching and routing traffic. Furthermore, among other functions, the core network performs the access authentication and billing functions where it determines the type of service and treatment to be provided to each user based on his stored user-profile.

3.3 Backhaul Network

As shown in Figure-2, the interconnectivity between the two main components of the mobile network architecture, that is the Radio Access Network and the core network, is provided via a transmission network which is capable of backhauling all types of traffic from the radio base stations (RBS) via the radio access controllers to the core network nodes with the desired QoS level. Nonetheless, the current technological advances in radio access interfaces (i.e. HSPA+ and/or LTE) and the shift towards more heterogeneous mobile networks have imposed rigorous standards for the design of backhaul networks. Hence, mobile network operators (MNOs) are gradually forced to replace their legacy backhaul connections with new backhauling solutions, such as shown in Figure-3, in order to meet the increasing demands for capacity and enhanced quality of service (QoS).



Source: Heavy Reading, Ethernet Backhaul Quarterly Market Tracker, August 2010.

FIGURE 2: CHANGES IN THE BACKHAUL SOLUTIONS ADOPTION

4 Deployment Scenario, Models and Assumptions

In order to compare the total deployment cost of different scenarios both the CapEx and OpEx have been taken into account. In this study, the net present value (NPV) analysis is performed considering the investments and recurring costs for 10 years, assuming that all investments are made in the first year, with a discount rate of 10% and that OpEx is increased by 10% each year. In the following sections a description of the used deployment scenarios, adopted power models and cost calculation structure are introduced along with the necessary assumptions.

4.1 Deployment Scenario

An urban area of 1Km*1Km that consists of 10 office buildings and five residential buildings has been chosen as base for the study in this paper as illustrated in Figure-3. Ten thousands mobile subscribers are assumed to be uniformly distributed in the ten five-floor office building; i.e. each floor accommodates 200 mobile subscribers. While four apartments, with symmetric shape and size, are assumed to exist per floor in each of the five ten-floor residential buildings. On average, a family composes of five members is assumed to be living

in each apartment. This deployment scenario is considered so as to resemble the typical situation in Western Europe with a focus on the situation in Sweden.

As can be seen from the scenario illustrated in Figure-3, two types of radio base stations (RBSs) are considered; namely outdoor macrocell and indoor smallcell (e.g. femtocell). The traffic from the radio base stations is transported through the backhaul network to the radio network controller (RNC). In this study, the elements in second aggregation mile (i.e. in the transmission network) and the RNC are considered to be a common infrastructure in both of the microwave and fibre optic deployment scenarios as shown in figure-3. Accordingly these elements have not been considered in the power consumption model and deployment cost calculations as will be described in the forthcoming sections.

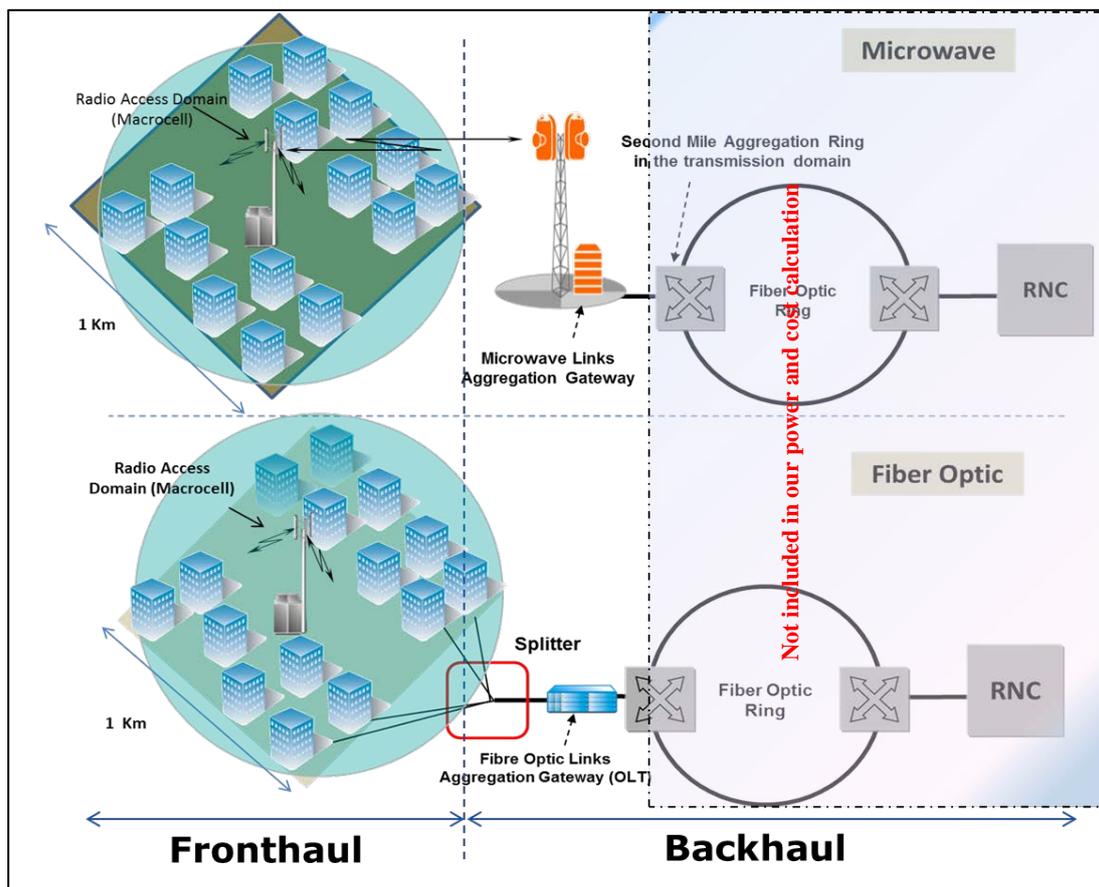


FIGURE 3: DEPLOYMENT SCENARIO

4.2 Subscribers Demand

To study the effect of the demand variation across the day, two traffic profiles are assumed during the day; namely traffic during the working hours (from 8:00 AM to 4:59 PM) and after the working hours (from 5:00 PM to 7:59 AM). It is also assumed that around 80% of the mobile traffic comes from indoor location as indicated by recent statistics (Paolini, 2011). Moreover, based on the data growth forecast published by Cisco and PTS (Swedish Regulator), we assumed 5GB/month/person and 20GB/month/person for present demand (year 2012) and future demand (year 2017) demand respectively (Cisco, 2012). Accordingly, the average data rate per mobile subscriber ranges between 20 Kbps and 100 Kbps, for present and future demand levels respectively.

4.3 Power Consumption Model in Mobile Network

In mobile communication networks, the power consumption of the radio access networks dominates. The power consumption in the radio access network is composed of three components, namely the power consumed in the radio base stations (RBSs), the power consumed in the backhaul network and Radio Network Controller (RNC). Each one of these three components contains two parts; fixed power consumption part independent from traffic load and dynamic power consumption part which vary according to the traffic load. However as mentioned before we will not consider the power consumption in the RNC since it is a common infrastructure element in all the studied deployment scenarios.

4.3.1 Power consumption of Radio Base Stations (RBS)

The power model developed within the scope of EARTH project is utilized in this study to estimate the power consumption of different types of radio base stations (RBS) (Auer, et al., October 2011). Hence,, the power consumption of Radio site (PRS) can be modeled as a linear function of the maximum transmitted power (P_{tx}) as shown in the equation (1) below (Tombaz, et al., 2011):-

$$\text{Power consumption per RBS} = \text{Number of RBS} * (PF_{BS} + \Delta P * P_{tx}) \quad (1)$$

Where P_{tx} represents the maximum transmitted power by the radio base station, ΔP represents a scaling factor based on measurement, PF represents a fixed power amount consumed independent from the traffic transmission. The typical value used to calculate the power consumption for different RBS types are given in Table I.

TABLE 1: POWER COSUMPTION PER RADIO BASE STATION

Parameters	P_F [W]	P_{tx} [W]	ΔP	Source
Macrocell	118.7	20	5.32	(Auer, et al., October 2011)
Femtocell	4.8	0.05	7.5	(Auer, et al., October 2011)

4.3.2 Power consumption of Backhauling Network

The backhauling network represents part of the transmission network and composes of backhaul links and aggregation nodes that are structured in a typical tree network topology. Three types of aggregation nodes are considered: (1) a LAN switch to aggregate the traffic from inside the office and residential buildings (number of femtocells) to the backhaul link, (2) an aggregation gateway for microwave links and (3) Optical Line Terminal (OLT) equipment as an aggregation node for fiber optic links as shown in figure-3. Accordingly the power consumption of the backhauling network can modeled as the power consumed per backhauling connection (which is either fiber optic cable or microwave link) and its associated aggregation nodes.

4.3.2.1 The power consumption in the backhaul link

The power consumption in the backhaul link can be modeled taking into account the fixed part of the power consumed independently from the traffic load and the dynamic part of the consumed power that depends on the traffic load as described by equation (2):-

$$\text{Power consumption per Backhaul connection} = P_F + P_{tx_BH} * (\%load) \quad (2)$$

Where P_{tx_BH} represents the maximum transmitted power per backhaul link, PF represents a fixed power amount consumed independently from the traffic load and $\%load$ the

proportional relation between the traffic backhauled from a radio site and the maximum capacity offered by a backhaul link. The assumptions used to calculate the power consumption of two types of backhaul links are shown in Table-2.

TABLE 2: POWER CONSUMPTION ASSUMPTION (BACKHAUL)

Backhaul Link Type	P_F [W]	P_{tx_Bh} [W]	Maximum Capacity	Source
Microwave Link	80	60	100 Mbps	(ericsson, 2012) (Deruyck, et al., 2012)
Fiber Optic Link	5	2.5	1 Gbps	(Grobe, et al., 2011) (Skubic, et al., January 2012)

4.3.2.2 Power Consumption of Aggregation Node

The power consumption (P_n) in the aggregation node can be estimated using equation (3):-

$$P_n = \alpha * P_{max} + (traffic\ load) * 1 - \alpha * P_{max} + P_p * Number\ of\ RBS + P_u * Number\ of\ UL \quad (3)$$

Where P_{max} represents the maximum power supplied to the aggregation node, While α is factor that represents the percentage consumed from P_{max} independent from traffic load. Moreover P_p and P_u represent the power consumed in a downlink port and uplink port in the aggregation node respectively and the *Number of UL* represents the number uplink ports in the aggregation node and the *traffic load* represents the traffic backhauled from the entire Radio base Stations (RBSs) as percentage of the maximum traffic capacity can be handled by the aggregation node. The values of the parameters in Table-3 are used to calculate the power consumed in different types of aggregation nodes (P_n).

TABLE 3: POWER CONSUMPTION (AGGREGATION NODE)

Aggregation Node	α	P_u [W]	P_p [W]	P_{max} [W]	Capacity Of Aggregation Node
Microwave Links Aggregation Gateway	0.1	2	1	53	2 Gbps
Fiber Optic Aggregation Node (OLT)	0.1	20	1	300	40 Gbps
LAN switch	0.1	2	1	57	1 Gbps

4.3.3 Cost Structure Modelling

The cost structure of the deployment of a mobile communication network consists primarily of a capital expenditure (CapEx) component and operation expenditure (OpEx) component. The (CapEx) component comprises all the cost incurred from the bidding process up to the commissioning of the network while the (OpEx) component involves all the cost incurred in keeping the network running. The CapEx component includes the investments in civil works, radio and transmission equipment, base stations sites, backhaul facilities, towers and masts, auxiliary systems, site acquisition, shelters, installation, commissioning, etc. The OpEx component, in its, customers acquisition and retention, system upgrades, staff training, fuel and power supply, site lease, operation and maintenance, etc.

In this study, the total deployment cost (CapEx and OpEx) of the radio access network is broken down into two parts: radio sites part and backhaul network part. The CapEx of the radio site build-out includes civil works, shelter, radio equipment, auxiliary systems and installation and commissioning as shown in Table-4. The dominant cost component in macrocell site build-out is the cost associated with the civil construction works and the cost of auxiliary systems (that include costs of tower/ masts, non-telecom equipment, power system, installation, site lease, etc.), while the dominant cost component in the femtocell site build-out

is the cost of the femtocell equipment itself. The CapEx of the backhaul network comprises the costs of the backhaul links, aggregation nodes, telecom auxiliary systems and civil works as well as the associated installation and commissioning costs. On other hand the operation expenditure (OpEx) relating to the radio sites and the backhaul network comprises the cost of annual operation and maintenance (O&M) activities, the cost of annual power consumption and the cost of the leased lines as shown in Table-4.

TABLE 4: COST (CAPEX AND OPEX) ASSUMPTIONS

Item	Cost (k€)	References
Femtocell Base Station+ Ethernet Cables	1	(Markendahl & Mäkitalo, 2010)
Macrocell Base Station (with 3 TRX)	25	(Frias & Pérez, 2012)
Cost of additional TRX	5	(Frias & Pérez, 2012)
Site Construction (Macrocell)	75	(Frias & Pérez, 2012) (Markendahl & Östen, 2010)
Microwave Link cost including	10	(Tzvika Naveh, Oct. 2009)
Microwave Aggregation Site	40	(radproductsonline.com, 2013)
Fiber Optic Link (ONU+ modem)	0.5	(Tzvika Naveh, Oct. 2009)
Fiber Optic WDM PON OLT (128 Ports)	100	(Grobe, et al., 2011)
Fiber Optic rollout cost per Km	3.8	(Frias & Pérez, 2012)
LAN Switch (24 ports)	1.8	(radproductsonline.com, 2013)
Annual Fiber Optic licensed line Fee	0.8	(Frias & Pérez, 2012)
Cost of KWH in Sweden	0.00007	(http://www.energy.eu/ , 2013)
O&M represent 10%(of CapEx) and installation 5%(of CapEx)		

5 Interplay: Demand for Network Capacity and Investment Cost

The number of required radio base stations to meet certain capacity in the radio access network is sensitive to the capacity of the radio base station (RBS) and the cell size (cell coverage area). The RBS capacity depends on the allocated bandwidth, the spectral efficiency of the utilized Radio Access Technology (RAT) and the transmit power. In its turn, the transmit power of radio base station (RBS) and mobile station (MSs) cannot be increased beyond pre-defined limits due to health and safety regulations. On the other hand, the RBS coverage or cell size depends on the required average data rate at cell edge; thus the cell size could be calculated by considering the relationship between data rate, distance (cell radius) and the used frequency band (i.e. high or low frequency bands).

5.1 Macrocell Deployment vs. Femtocell deployment

In this paper, the coverage area of a macrocell site is estimated based on the methodology introduced in (Markendahl & Mäkitalo, 2010), where Okumura–Hata propagation Model is

utilized to calculate the maximum cell radius for a macrocell. By using this methodology, the maximum cell radius of around 3.26 km and 1.48 km can be achieved when 900 MHz band and 2.6 GHz band are used respectively to meet the required coverage. It remains to state that in macrocell deployment, the use spectrum bandwidth per RBS and spectral efficiency are the most significant factors that affect the achieved capacity per radio base station (RBS) as illustrated in Figure 4, keeping in mind the fact that the transmit power shall not exceed a certain limit.

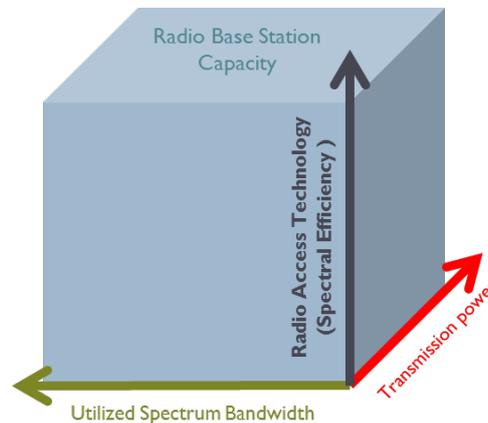


FIGURE 4: RADIO BASE STATION (RBS) CAPACITY

In the indoor deployment case, the majority of femtocell vendors provide Femtocell Access point (FAPs) that serve around 6 ~ 20 concurrent active mobile users; noting the fact that FAPs are coverage limited. For the purpose of this study, a minimum number of 10 FAPs per floor (i.e. 200 persons per floor) is assumed in the case of the office building and at least one FAP per flat is assumed in the case of the residential buildings (i.e. 4 FAPs per floor).

The total deployment cost has been calculated for each deployment scenario using the cost model introduced in section 4.3.3. As illustrated in Figure-4, deployment scenarios with fiber optic as backhaul solution are more costly compared to the cases when microwave solution is adopted. A closer look shows that the OpEx and CapEx of the backhaul solution represent major part from the femtocell deployment case as described in Figure-4, with around 45%, of total CapEx and around 15% of total OpEx. Moreover a less impact is noticed in macrocell deployment cases with around 15% of total CapEx and 7% of total OpEx.

Moreover, in the macrocell deployment scenario the consumed power by the backhaul solution represents around 8% of the total power consumption in worst case scenario (i.e. Microwave case) and around 2% in best case (i.e. fiber optic) as shown in Figure-6. While in the femtocell deployment, the backhaul solution contributes more considerably to the total power consumption with about 80% of the total power consumptions in worst case (i.e. microwave) and drops down to around 20% in the best case scenario (i.e. fiber optic). In summary the microwave backhaul consumes more power compared to fiber optic backhaul for same demand level in all the deployment scenarios.

In short, the obtained results in Figure-5 and Figure-6 indicate that the backhaul solutions contribute significantly to the power consumption and cost of the femtocell deployments compared to those of the macrocell deployments.

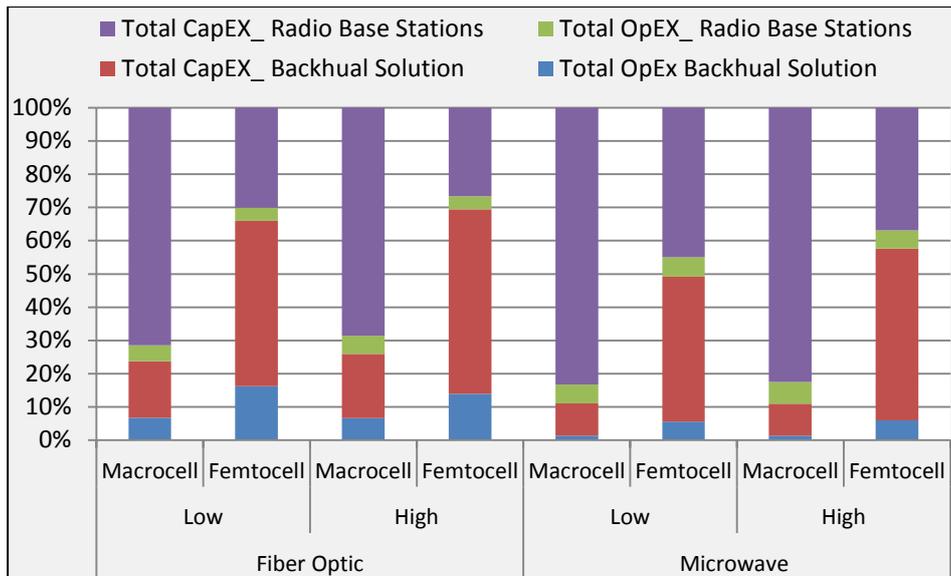


FIGURE 5: COST STURCTURE

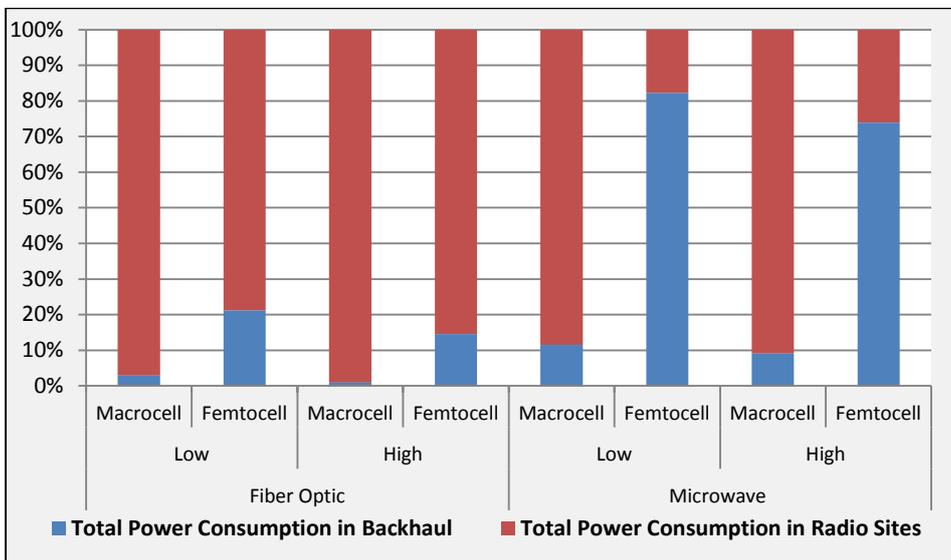


FIGURE 6: POWER STURCTURE

5.2 Traffic variation, Deployment Cost and Power Consumption

The 3G and 4G macrocells are usually designed to support voice and data with the highest possible availability in indoor and outdoor locations. Taking into consideration the fact that around 80% of the traffic comes from indoor locations and the traffic demand varies during the day (i.e. during working hours and nights); network deployment strategies adaptable to the demand, locations and varying traffic loads are crucial. One potential and attractive strategy is to complement the macrocell network with smallcell networks; thereby creating a hybrid or heterogeneous network that is capable of providing cost-efficient higher network capacity and better coverage when compared with a homogeneous mobile network. Figure-7 and Figure-8 show that significant savings in the costs of infrastructure and power consumption can be made by adopting the heterogeneous deployment strategy in lieu of the homogeneous strategy.

The main observations than can be drawn from Figure-7 and Figure-8 highlight the fact that the mobile network operators will dimension their network to handle the traffic demand

during the peak hours (during the working hours) and have less options to optimize the cost of provision the service during the night (i.e. in low traffic demand situation). Although the MNOs tend to turn off number of RBSs during night to save energy; such approach will not eliminate the required investment cost to buildout the macrocell site anyway (i.e. civil work and auxiliary system). However by adopting hybrid network deployment approach, MNOs could save around 70 % in the deployment cost compared homogenous macrocell deployment as shown in Figure-7.

Furthermore, in macrocell deployment strategy the coverage and service availability are the main concerns of the network operator. An outage at a single radio base station (in case of RBS is turned off) may constitute a major disruption or degradation to service availability; a matter that is to be avoided at all costs. However, when the macrocells tier of the network is complemented by smallcells tiers, an outage in an indoor smallcell will merely constitutes a tolerable reduction in the overall network capacity rather than a major degradation of the service availability. Over and above, mobile operators may operate their indoor small cells in office buildings during peak hours (i.e. working hours) only and switch them off during non-working hours (e.g. night hours and holidays). Such mode of operation can lead to considerable savings in the cost of power consumption as can be derived from the results shown in Figure-8.

On other hand, the use of more spectrum bandwidths per RBS in macrocell deployment scenarios means that operators can deploy less number of new sites or even re-use existing sites and hence exploit previous infrastructure investments; which reduce the power consumption and total deployment cost as shown in Figure-7 and Figure-8. This could be a key motivation for sharing spectrum resources between mobile network operators. On other hand the use of more bandwidth per site does not necessarily lead to less number of RBSs in the case of indoor smallcell deployment since number of indoor smallcell will be required to cover each floor anyway.

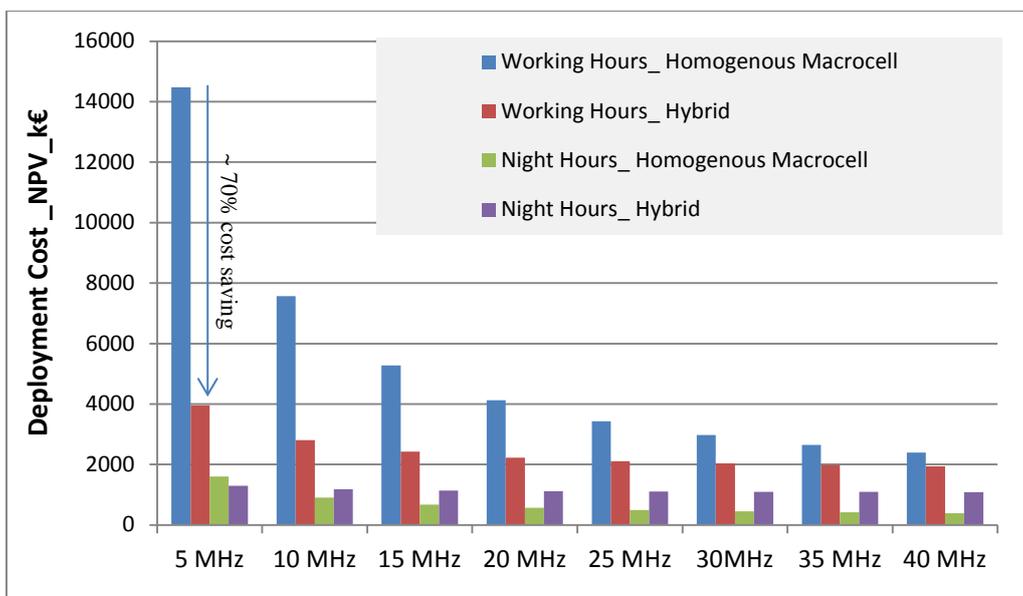


FIGURE 7: DEPLOYMENT COST: HOMOGENOUS MARCOCELL VS. HYBRID SCENARIO

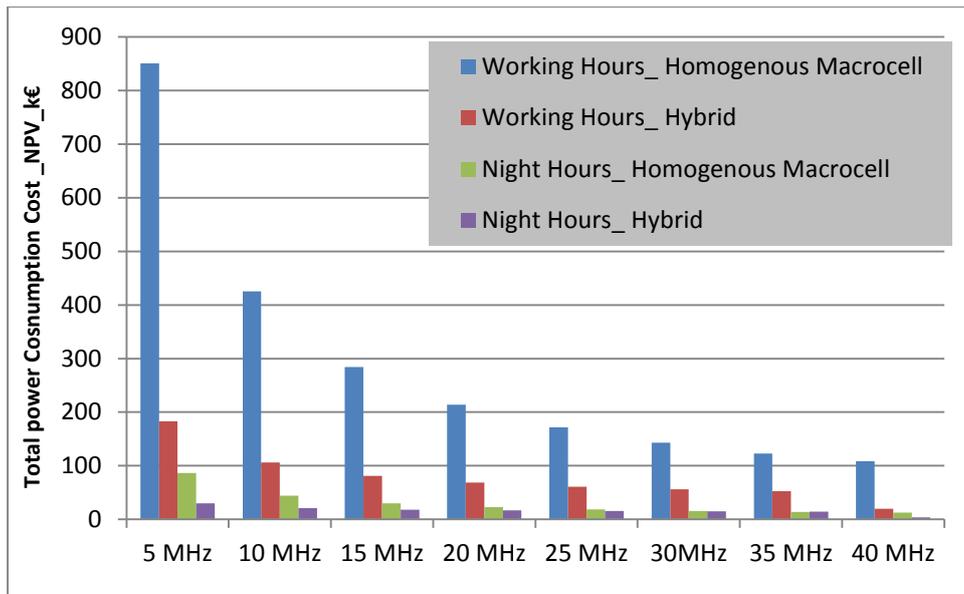


FIGURE 8: POWER COSUMPTION COST: MARCOCELL VS. HYBRID SCENARIO

6 Conclusion

Evidently the mobile communication industry has witnessed a rapid growth in the past decade. Mobile traffic, as well, is set to grow dramatically over the years to come with the mobile data traffic increasing most rapidly. Meeting the increasing data traffic and the associated demand for capacity by adding more radio base station sites leads to the increase of deployment cost and energy consumption. In this paper, different network deployment scenarios (i.e. macrocell and femtocell) and backhauling solutions have been investigated considering the interplay between capacity demand, power consumption and investment cost.

Although the main findings and results reached in this study are subject to the assumptions made and models used, they give general deductive conclusions as follows: the backhaul solutions contribute significantly to the power consumption and the deployment cost in the indoor smallcell deployment scenario (i.e. femtocell deployments) compared to those of macrocell deployment. However, rolling-out the smallcell (i.e. femtocells) on indoor locations like shopping malls and office buildings which properly have existing internet connectivity reduces the backhaul challenges compared to outdoor smallcell deployment (i.e. microcell and picocell). Moreover the indoor deployment of smallcell (i.e. femtocell) will relax the site acquisition and power supply challenges; especially when the facility owner has the same interest as the MNOs in provisioning the mobile service.

In summary, the carefully planned indoor deployment of low power radio base stations within the macrocell coverage such as femtocell could lead to more adaptable network architecture to the capacity demand at more reasonable deployment cost and power consumption and open opportunity for power saving mechanism (e.g. by turn off number of indoor smallcell in the low demand situation).

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