EAI Endorsed Transactions
on Mobile Communications and Applications
Research Article **ICST.ORG**

The Impact of Mobile Offloading on Energy Consumption and Capacity of Radio Access Networks – Case of Finland

Michail Katsigiannis[1,]*

[1]Department of Communications and Networking, School of Electrical Engineering, Aalto University, Helsinki, Finland

Abstract

The Finnish Mobile Operators face two main challenges: (i) mobile data subscriptions penetration and traffic are experiencing rapid growth; and (ii) government intervenes in the market to attain contradictory goals related to extensive high-speed mobile networks and energy consumption reduction. The mobile operators have to increase the capacity in their networks, taking energy efficiency into account. The reduction of energy consumption in mobile networks results to the reducing carbon emissions, and possibly to cost savings. The purpose of this study is to investigate the wide-to-local area offloading in urban regions in Finland and examine the impact of such a network on the wide area access network in terms of energy and capacity. The results show that the capacity relief ranges from 9.7 to 38.7 %, depending on the penetration of local area service, but the energy savings in macro cellular network are negligible.

Keywords: Mobile network offloading; mobile data traffic; energy consumption; techno-economics; urban region; Finland

Received on 24 December 2014, accepted on 24 June 2015, published on 11 August 2015

doi: 10.4108/eai.11-8-2015.150090

1. Introduction

The Finnish Mobile Operators face two main challenges: (i) mobile data subscriptions penetration and traffic are experiencing rapid growth and (ii) government intervenes in the market to attain specific goals. For example, government imposes the broadband plan which sets the target of 100 Mbps internet access by 2015 [1]. Also, European Commission proposes a further development and extension of broadband coverage aiming to 30 Mbps download rate for all and at least 50% of European households subscribing to internet connections above 100 Mbps by 2020 [2]. Mobile networks will play an important role to the achievement of these goals. The aforementioned challenges push mobile operators to invest in network coverage and capacity expansion. However, the installation of additional radio equipment will increase the energy consumption in mobile networks.

Besides the goals about broadband strategy, European Commission has set a target for 20% reduction of Internet and Communications Technology (ICT) industry carbon footprint by 2015 [3]. Within ICT, the mobile communications industry constitutes a major sector. According to the International Telecommunication Union (ITU), mobile communications contributes an estimated 9 % of the global ICT greenhouse gas emissions [4]. While the broadband plan requires extensive deployment of high-speed mobile networks which will increase the energy consumption, the energy efficiency plan requires the reduction of energy consumption. These contradictory plans are also followed by the Finland’s Second National Energy Efficiency Action Plan [5] which highlights the energy efficient buildings. The building insulation will allow a building to use less heating and cooling energy. However, the external wall structure of such buildings will likely cause additional attenuation to the signal, when it propagates from outdoor to indoor environment. This creates a problem in mobile communications since around 80% of mobile data traffic is generated indoor and carried by outdoor macro cellular networks [6]. Thus, the deployment of indoor small cells seems to be an attractive solution for mobile operators

*Corresponding Author. Email:michail.katsigiannis@aalto.fi

to improve coverage, capacity and quality. Such a deployment option will require to be installed an enormous number of small cells in buildings. As a result, additional energy will be consumed, which will be part of end customers' energy bills.

Consequently, several network deployment strategies have to be investigated by mobile operators to meet the requirements for broadband and energy efficiency plans. The mobile operators have to increase the capacity in their networks, taking energy efficiency into account. Small cells can be deployed in indoor environments, complementing the macro cells creating a Heterogeneous Network (HetNet) with higher cell density in urban regions [7-8]. Small cells will increase the network capacity to serve areas with high traffic and improve cell-edge throughput and coverage. To some degree, also the outdoor-placed base stations can be a solution. However, the indoor deployment of access points is foreseen as a necessity in guaranteeing sufficient coverage, low latency, and improved power efficiency and battery life of terminal [9-11]. Also, they offload the macro network. Mobile network offloading, also called as wide-to-local area offloading, is the use of complementary network technologies to deliver data traffic originally planned for transmission over cellular networks [12]. Mobile network offloading as a deployment strategy, especially in densely populated areas, might provide a good solution to mobile operators to release capacity from the macro network [13-14]. According to Cisco, by 2016, more than half of all traffic from mobile-connected devices will be offloaded to the fixed network by means of Wi-Fi devices and femtocells [15].

The cost of small cells which complement the macro cells in areas with high demand is analysed by [16]. In addition, the wide deployment of indoor networks requires many devices (small cells) which will increase the energy consumption in the end customers' buildings. The energy consumption is becoming an increasingly important cost factor for mobile network operation and has to be also included to the cost structure [17]. Therefore, reducing energy consumption may result in cost savings to mobile operators and eventually to the end consumers.

The main research question is defined as follows: "Should mobile operators exploit indoor radio networks to cope with the challenges of energy consumption growth and traffic growth in their macro radio access networks?". The purpose of this study is to model a wide-to-local area offloading network in indoor places including homes, offices and public places for urban regions in Finland. Also, the study aims to investigate the impact of such a network to wide area access network in terms of energy and capacity. The goal is to assist mobile operators to make a decision on undertaking indoor network deployment investments.

This study is important for several reasons. It contributes firstly to the understanding how mobile offloading has an impact on the current network infrastructure and costs. Its contribution is also important in practice from managerial point of view, since the study investigates real cases for Finnish mobile operators. It provides information to operators to decide if wide-to-local area offloading is worthy to be implemented.

The paper is outlined as follows: Section 2 describes the model. Section 3 covers the results and the paper concludes in Section 4.

2. Offloading Model

The modeling logic is illustrated in Fig. 1. It is an improved version of the models presented in [18-19] and it runs in parallel with the short-run presented in [20]. More specifically, the offloading model calculates the indoor traffic, which has an impact on the average load factor of macro cells. The latter is used as an input to the short-run model to calculate the energy consumption of the macro cellular network. Therefore the offloading model is an extension of the short-run model to conduct research on mobile offloading topic. The model focuses on a single mobile network operator in Finnish mobile communication market for urban regions. The inputs of the model for offloading network are grouped to i) market and service, ii) technology and iii) cost in the second half of 2013. Also general market and service related parameters (mobile data users and market share) are needed. The model uses the market and service related inputs for offloading from the aforementioned studies, adjusted to all urban regions. Such inputs are the number of venue types, their size area, and the hours spent by the people who visit these venues. Also the Local Area (LA) service penetration is included. Regarding to the technology-related input parameters, the technical architecture is defined by network technologies and entities description [21], and assumptions about the cell range, capacity and number of active connections per indoor base station (access point AP). The main cost parameters include the list and the price of the radio access network equipment and sites, the network implementation actions and operational expenditures. The inputs are presented in parallelograms in Fig. 1 and the numerical values of the most important of them are given in Tables A.1-4 in Appendix. The main output of the network offloading model is the indoor network cost, including the operating cost of the urban macro network (from the short-run model).

Network offloading or wide-to-local area offloading is enabled by the deployment of indoor networks to venues such as homes, offices and public places mainly in urban regions where the data traffic is higher. This business scenario does not require any changes in the current macro radio access network. It requires only installation of some equipment in the core network (e.g., femto gateway, management system etc.). Therefore, no changes occur in infrastructure for the wide area radio access network. The indoor network is expected to have an impact on the wide area network such as macro network

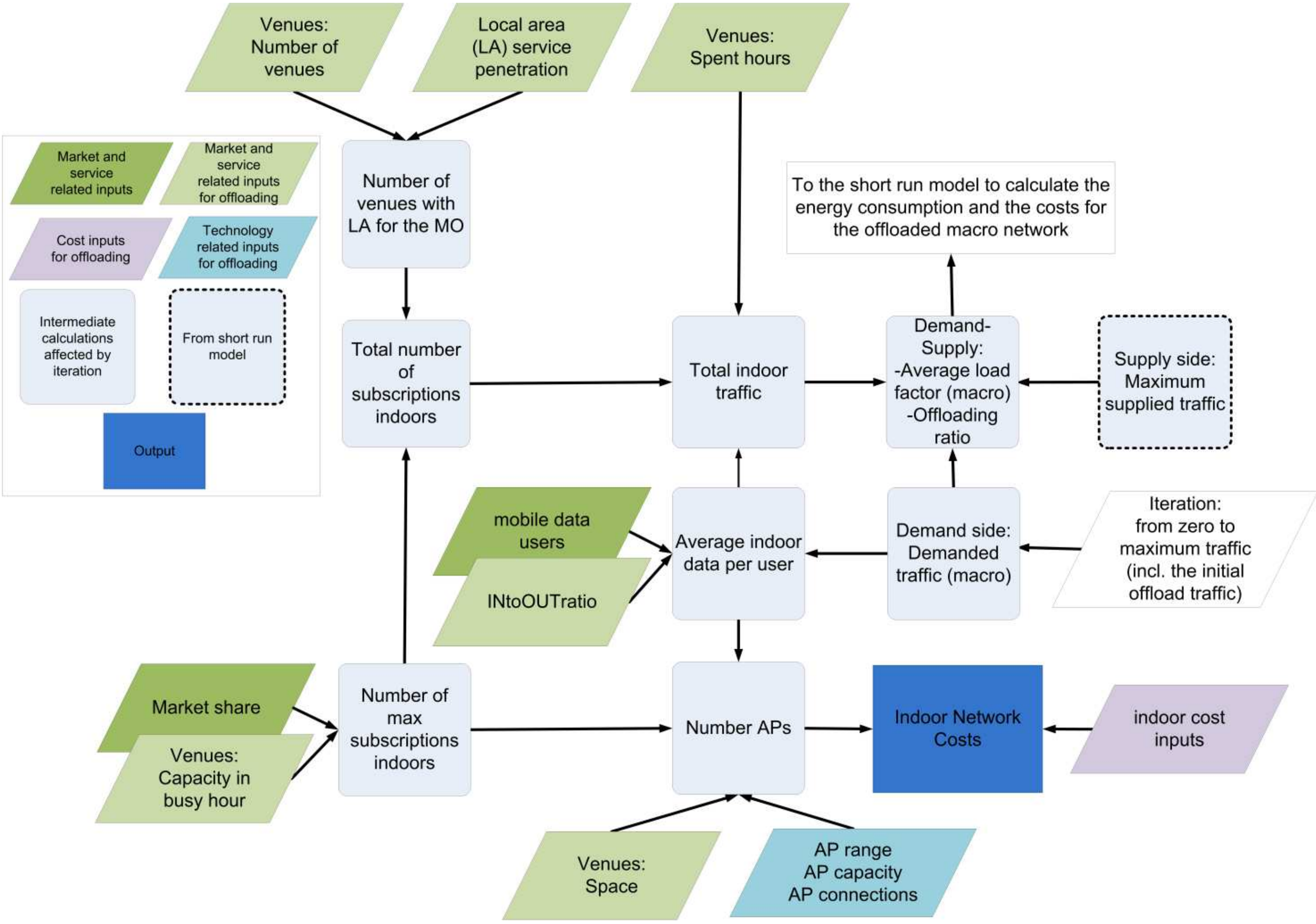

Figure 1. Wide-to-local area offloading model

capacity relief and energy consumption reduction. In addition, the wide-to-local area offloading can be considered as an alternative network deployment to delay the investments on the macro cellular network.

For this analysis it is assumed that the mobile operator, who operates also a fixed network, deploys access points (femtocells) at 2.6 GHz utilizing its own existing fixed network. The mobile operator has already a base of customers who use fixed broadband connections and share these with Wi-Fi access points. The mobile operators could switch all the Wi-Fi access points to femtocells by shipping the new devices to customers who simply replace them. In venues where the femtocells are installed, there are also mobile data subscribers which can use the new network for their indoor generated data traffic. It is assumed that the access to femtocells is configured as follows: Close Group Subscription (CGS) mode at homes, and Open Group Subscription (OGS) mode at other places [12].

2.1. Demand - Supply mismatch

The outputs of the model require some intermediate calculations. The demand and supply mismatch needs to define the average load factor in a site which is used for energy consumption calculation.

Supplied traffic

The supplied traffic S (1) is the capacity of the macro cellular network in downlink and it is calculated by multiplying the number of base stations with the average site capacity (average site capacity is equal to the number of sectors times the average cell capacity i.e., $\overline{R_{cell}}N_s$). The number of the base stations, N_{BS} per technology is calculated by the average site coverage, the land area and the percentage of the territory coverage. The BW is the bandwidth per cell and the SE is the spectrum efficiency of the technology.

$$S^{tech} = \overline{R_{cell}} N_s N_{BS} \quad (1)$$

where R_{cell} = BW * SE

The maximum supplied traffic is an input, calculated in the short-run model. It is the actual maximum network capacity in downlink measured in traffic per month (e.g., terabytes per month): the maximum supplied traffic is compared with the demanded downlink data traffic in a month in order to calculate the average load factor of the site. The supplied traffic of the indoor network does not influence the energy consumption of the macro network and therefore it is not used in calculations.

Having knowledge of the network capacity per region in the short-run model, the share of the total network capacity for each region (urban, suburban, rural) is calculated and used for the estimation of the demanded downlink traffic per region. Assuming that a mobile operator has deployed the network so as to carry the demanded traffic, the current macro network capacity for each region can be an indicator for the share of the demanded traffic in each region, i.e., the capacity share of urban region (c) is equal to the demanded data traffic share per region.

Demanded traffic

The demanded downlink data traffic D is given by (2). The total mobile traffic volume (V) for the whole country is usually the only known information regarding the mobile data traffic. The market share (m) of a mobile operator gives an approximation about the demanded traffic volume carried in an operator's network. The calculated capacity share per region (c) shares this traffic volume to urban region and the uplink to downlink ratio $r_{UL/DL}$ separates the traffic to uplink and downlink. Furthermore, the demanded downlink traffic is not evenly distributed over time and space (geographical area). Therefore, the traffic characteristics such as the traffic distribution over a 24-hour period (share of daily traffic in busy hour T_{Dtime}) and the traffic distribution among sites (share of traffic conveyed by some share of cells TD_{space}) are taken into account

$$D = \frac{Vmc}{(1+r_{UL/DL})30} \frac{T_{Dtime}}{T_{Dspace}} \quad (2)$$

The calculated demanded traffic D is further decomposed to indoor- (D_{IN}) and outdoor- (D_{OUT}) generated traffic (3)-(4). The traffic decomposition is determined by the outdoor generated traffic factor r_{out}.

$$D_{OUT} = Dr_{out} \quad (3)$$

$$D_{IN} = D - D_{OUT} \quad (4)$$

The demanded traffic is the value for the end of the iteration, while its indoor part is used for the calculation of the average indoor data per user. The urban indoor traffic is alternatively calculated from the average indoor data per user, the number of subscribers indoors, and the time they spend indoors. The number of subscribers indoors is strongly related to the local area service penetration i.e., the number of venues in which indoor network is installed. Also, the number of access points is calculated based on the number of subscribers, the space of the buildings and the technical characteristics of the access point such as throughput, the number of simultaneous open connections, and the coverage range.

Thus, the mismatch between the supplied and demanded traffic, taking into account the indoor traffic determines the average load factor L_{off} for the macro cells (5) which is used in the energy consumption calculations. The load in the urban macro cells drops because of the offload effect, since the cells serve only D_{OUT}.

$$L_{off} = \frac{D_{OUT}}{S} \quad (5)$$

The offloading ratio is an important performance indicator for the offloading network. The offloading ratio is defined as the ratio of the traffic carried by the indoor network to the current macro traffic level (6) .

$$r_{off} = \frac{D_{IN}}{D} \quad (6)$$

By substituting the average load factor L_{off}, the power consumption model presented in [20] now calculates the power consumption of the macro site, taking into account the offloading. The mathematical model is presented again for L_{off} in (7).

$$P_{off} = PL_{off} + p_o P(1 - L_{off}) \quad (7)$$

P is the maximum power consumption a site can consume and p_o is the percentage of maximum power consumption which is consumed when sites are at idle mode or other state which is not related to user data traffic transmission. Finally, the number of base station and the average power consumption will provide the energy consumption of the network.

3. Results

Table 1 shows the main simulation results highlighting the impact of indoor network deployment on the macro cellular network for three different values of Local Area service penetration. By deploying the indoor network with penetration 0.25 %, the urban macro network (at maximum demanded traffic i.e., 5989 TB/month) is relieved by 580 TB/month or 9.68% (offloading ratio). That means that the deployment of the offloading network is a quick solution to increase the current maximum network capacity (6569 TB/month) and delay investing on macro capacity expansion.

At the initial maximum demanded traffic level (i.e., 5989 TB/month), the impact of the offloading network on the operating cost of the macro network is the reduction of energy cost. The energy consumption of the urban macro network reduces from 2.09 to 2.07 GWh/month and its operating cost reduces by thousand euros. The energy cost savings are negligible but the monetization of the additional traffic will provide extra revenues. The question is if these revenues, the little energy cost savings and a reasonable charge for the local area service can cover the cost of the indoor network deployment. The operating cost to be covered for the offloading network is 258,030 €/month. (Only the maintenance cost of access points, the electricity cost is assumed to be shifted to customers). In addition, the investment cost for the indoor network (installation and equipment including the access points), has to be paid back. This investment cost is 26,129,000 € and it is roughly 2 times more than the annual operating cost of current urban macro network. Assuming that the users (or the venue owners) who have subscribed for LA service pay this cost (for a year, locked-in customers), then the average cost per LA user is 4 €/month (or the cost per LA venue owner is 8.64 €). Finally, the capital cost of deploying the indoor network is high and comparable to the macro cellular network investment and the operating cost is also getting high while the scale of the indoor network increases. When the cost of deploying an indoor network with a specific offloading capacity of the macro network, is becoming less than the cost of investing on macro network capacity expansion for the same capacity, then the offloading scenario is definitely a preferable option. For example, for the case of 25% LA service penetration, a mobile operator needs to spend around 27 million euros for infrastructure and 0.25 million euros per month for operating such an indoor network. Of course, the indoor network capacity is extremely high, but the macro network's capacity is relieved by 580 TB/month and the operating cost reduces insignificantly. Roughly, if the investments for the macro network capacity expansion of 580 TB/month cost more than 27 million euros then the offloading network is a preferable solution. It is important to take into account that new local area services could bring more revenues to mobile operators.

4. Discussion and conclusions

The mobile data traffic growth especially in urban regions pushes mobile operators to devise new network deployment strategies. Mobile network offloading is a scenario which gains popularity both in industry and academia. This study models and investigates the impact of deploying an indoor network on the macro cellular network's conditions. It is shown that the impact of the indoor network is mainly the capacity relief and the reduction of its energy consumption. The capacity relief ranges from 9.7 to 38.7 %, depending on the penetration of local area service in venues. This relief gives the possibility to operators to delay the macro investments. Also, the energy cost savings for the macro cellular network are negligible. This is reflected by the operating cost of the macro network which reduces insignificantly.

The offloading indoor network is a quick but uncertain solution. The penetration of such service and the user-deployed feature of the indoor network create uncertainty to mobile operators. Wide-to-local area offloading might be a good option for mobile operators in the far future when the traffic will be extremely high. But still wide-to-local area offloading has risks and benefits to mobile operators. On the one hand, there is a relief (offload) in capacity for the macro cellular network, but on the other hand the mobile operators may lose the opportunity to gain more revenues from monetizing the missing traffic.

Table 1. Wide-to-local area offloading results

LA penetration	25%	50%	100%
Maximum demanded traffic which is able to be carried by the current macro network without offloading (TB/month)	5989		
Maximum demanded traffic which is able to be carried by the current macro network with offloading (TB/month)	6569	7149	8309
Total indoor demanded traffic carried by the indoor network (TB/month)	580	1160	2320
Offloading ratio (%)	9.68	19.36	38.72
Energy consumption of the current macro network (GWh/month) [a]	2.09		
Energy consumption of the current macro network with offloading network (GWh/month) [a]	2.07	2.05	2.02
Macro network operating cost (€ '000 /month) [a]	1,054		
Macro network operating cost with offloading (€ '000 /month) [a]	1,053	1,052	1,051
Operating cost of offloading network (€/month)	258,030	516,051	1,032,091
Equipment cost of offloading network (€ '000)	26,129	51,957	103,610
Number of AP	258,030	516051	1,032,091
APs per km^2	221	442	884

Appendix A. Market, technology and cost inputs

Table A.1: Basic demographics for urban region

Land (km^2)	1166
Population	1757959
Population density	1507
Population percentage (%)	0.39
Territory percentage (%)	32.22

Table A.2: Demographics for offices, households and public places

Venue types		People[a]	Space (m2)	Venues	Hours spent by people in a day at venues
Offices per size	0…4	1.3	31.4	93345	8
	5…9	7.9	189.1	7949	8
	10…19	16.3	388.7	4176	8
	20…49	36.9	875.8	2346	8
	50…99	84.3	1999.9	638	8
	100…199	168.4	3993.5	296	8
	200…	547.4	12977	183	8
Households		2.04	79.4	881119	8
Public places	Large hotels	200	4500	50	3
	Small hotels	50	1125	450	3
	Restaurants	40	200	2917	1
	Cafe and bars	40	200	2083	1
	Shopping malls	4000	20000	11	1
	Retail shops	40	200	12003	0.1
	Transportation	600	3000	33	0.1

[a] Employees for offices, people for homes, visitors for public places in busy hour

Table A.3: Market, traffic characteristic and access point design parameters (2H/2013)

Mobile data traffic volume (TB, countrywide)	114927
MNO's market share (%)	40
Traffic distribution among sites	0.3[a]
Traffic distribution for busy hour (over 24-hour period)	0.1
Uplink to downlink ratio	0.1
Local Area (LA) service penetration in venues	25-100%
Indoor to outdoor ratio	9
Range (in km for 2600 MHz)	0.1
Throughput (Mbps)	172
Max active connections	15

a. 15% of traffic is carried by the 50% of the sites

Table A.4: Cost Classification – CAPEX, IMPEX, OPEX

Category	Equipment or action	comment	cost
CAPEX	Access point	-	100
	HeNB Gateway and authentication server (close subscriber group server list) and management system	-	300000
IMPEX	AP installation and setup	€/AP	0.1
OPEX	network maintenance	€/AP/month	1

Table A.5: Indoor network dimensioning

Venue types		Subs	Venues with LA	Max subs	Access points
Offices per size	0…4	0.5	23336	12070	23337
	5…9	3.1	1987	6182	1988
	10…19	6.3	1044	6677	1045
	20…49	14.4	587	8453	587
	50…99	32.9	160	5248	479
	100…199	65.7	74	4875	372
	200…	213.5	46	9810	690
Households		0.8	220280	175255	220280
Public places	Large hotels	78	13	3901	76
	Small hotels	19.5	113	8777	226
	Restaurants	15.6	729	45513	1459
	Cafe and bars	15.6	521	32509	1042
	Shopping malls	1560	3	18205	304
	Retail shops	15.6	3001	187253	6002
	Transportation	234	8	7802	134

[a] Average number of employees for offices, people for homes, visitors for public places who are subscribers in busy hour

References

[1] Finnish Ministry of Transport and Communications (2008, May 8). "Making broadband available to everyone. The national plan of action to improve the infrastructure of the information society". Publications of the Ministry of Transport and Communications, 50/2008, [online]. Available at: http://www.lvm.fi/web/en/publication/-/view/821179

[2] European Commission. Digital Agenda for Europe. Pillar IV. Fast and ultra-fast Internet access, [online]. Available at: http://ec.europa.eu/digital-agenda/our-goals/pillar-iv-fast-and-ultra-fast-internet-access

[3] European Commission (2009, March 12). Commission pushes ICT use for a greener Europe. Press release from European Commission, IP/09/393, [online]. Available at: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/393&format=HTML&age=1&language=EN&guiLanguage=en

[4] International Telecommunications Union (2008). "ITU and climate change". Report, [online]. Available at: http://www.itu.int/dms_pub/itu-s/opb/gen/S-GEN-CLIM-2008-11-PDF-E.pdf

[5] Finnish Government (2011). "Finland's Second National Energy Efficiency Action Plan". Report, [online]. Available at: http://www.buildup.eu/publications/20807

[6] Chowdhury, M.M.R., Noll, J (2010). Collaborative Radio: Towards Sustainable Business in the Evolution of 4G. In Proceedings of Wireless and Mobile Communications (ICWMC), Valencia, 20-25 September, 538-543.

[7] Markendahl, J., Mäkitalo, O., Werding, J. (2008). Analysis of Cost Structure and Business Model options for Wireless Access Provisioning using Femtocell solutions. In Proceedings of International Telecommunications Society (ITS), Rome,18-20 September.

[8] Ericsson (2012). Heterogeneous networks, white paper, [online]. Available at:

http://www.ericsson.com/us/ourportfolio/telecom-operators/heterogeneous-networks
[9] Nokia Networks (2014). Deployment Strategies for Heterogeneous Networks, white paper, [online]. Available at: http://networks.nokia.com/file/20326/deployment-strategies-for-heterogeneous-networks
[10] Damnjanovic, A., Montojo, J., Yongbin Wei, Tingfang Ji, Tao Luo, Vajapeyam, M., Taesang Yoo, Osok Song, Malladi, D (2011). A survey on 3GPP heterogeneous networks. IEEE Wireless Communications, 18(3):10-21.
[11] Parkvall, S., Furuskar, A., Dahlman, E. (2011). Evolution of LTE toward IMT-advanced. IEEE Communications Magazine, 49(2):84-91.
[12] Nokia Networks (2014). Indoor Deployment Strategies, white paper, [online]. Available at: http://networks.nokia.com/file/32531/indoor-deployment-strategies
[13] Han, B., Hui, P., Kumar, V.S.A., Marathe, M.V., Jianhua Shao; Srinivasan, A. (2012)."Mobile Data Offloading through Opportunistic Communications and Social Participation," IEEE Transactions on Mobile Computing, 11(5):821-834.
[14] Calin, D., Claussen, H., Uzunalioglu, H. (2010). On femto deployment architectures and macrocell offloading benefits in joint macro-femto deployments. IEEE Communications Magazine, 48(1):26-32.
[15] Han, B., Hui, P, Srinivasan, A. (2010). Mobile data offloading in metropolitan area networks. ACM SIGMOBILE Mobile Computing and Communications Review, 14(4):28-30.
[16] Cisco. (2014). Cisco visual networking index: Global mobile data traffic forecast update, 2013-2018, report. [online]. Available at: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf
[17] Weisi, G., O'Farrell, T. (2012) Capacity-Energy-Cost Tradeoff in Small Cell Networks, In Proceedings of IEEE Vehicular Technology Conference (VTC Spring), Yokohama, 6-9 May, 1-5.
[18] Katsigiannis, M. (2012). Mobile network offloading: Deployment and energy aspects. International Journal of Interdisciplinary Telecommunications and Networking, 4 (3):40-53.
[19] Katsigiannis, M., Smura, T., Casey T., Sorri, A. (2013). Techno-economic modeling of value network configurations for public wireless local area access. NETNOMICS: Economic Research and Electronic Networking, 14 (1-2): 27-46.
[20] Katsigiannis, M., Smura, T. (2015). A cost model for radio access data networks. INFO. 17 (1):39-53.
[21] 3GPP (2009). Technical Specification Group Services and System Aspects, Architecture aspects of Home NodeB and Home eNodeB, 3rd Generation Partnership Project, TR 23.830, Release 9.