Achieving Energy Efficiency through the Opportunistic Exploitation of Resources of Infrastructures Comprising Cells of Various Sizes

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Abstract

One of the main challenges of the arising wireless world is to support a wide set of QoS-demanding services. However, the solutions that will be considered should not only take into consideration the optimization of the network performance, but should also be energy efficient both for the operator and the end-user. This paper presents the concept of Opportunistic Networks (ONs) as an energy efficient method to exploit wireless networks. The cases studied in this work comprise a macro base station and femtocells. The proposed solution will offload a proportion of the traffic of the base station to the femtocells, through the creation of an ON. Therefore, the base station will consume less energy since terminals will be rerouted to the femtocells. In addition, the femto-terminals will operate to lower power levels leading to battery savings. Results from simulations are provided to confirm the proposed solution.

Keywords: opportunistic networks, capacity extension, future internet, femtocells, energy consumption.

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1 Introduction

The wireless world is at the centre stage due to the need of people for mobility in conjunction with a wide set of applications. However, current networks were not designed for the usage level that faces today. Therefore, there is need to enhance networks to handle the increased traffic and offer adequate services in terms of quality of service (QoS), security and mobility. Until recently the provided solutions were not taking into account energy aspects. Nonetheless, in recent years research has turned to solutions that provide efficiency with respect to economic, societal and energy criteria.

A common problem that network operators face is that at any moment their network may experience capacity problems due to a plethora of reasons: an increase in the amount of customers, e.g. due to a mass event, a displacement of users, a malfunction in the infrastructure, etc. As a result, congestion issues arise. However, the solution that will be adopted should not only take into consideration network optimization, but should also exploit green technology that will result in capital and operational expenditure (CAPEX and OPEX respectively) savings.

In order to confront this problematic situation, this work will focus on the use of Opportunistic Networks (ONs) that seems to be a promising solution for the problem of the capacity extension of congested infrastructure (e.g. base stations (BSs)). ONs are operator-governed, coordinated extensions of the infrastructure and are created dynamically for a limited time [1]. The life cycle of an ON consists of four phases: suitability determination, creation, maintenance and termination. At the suitability determination phase, the suitability of an ON at a specific time and area is determined. The final configuration of an ON is done in the creation phase. The selection of aspects such as involved nodes, used spectrum for the ON are done based on context information and more accurate estimations of the radio environment. At the maintenance phase monitoring will be done to ensure that the ON is still valid and efficient for what it was created for. According to the monitoring information reconfiguration or termination functionalities can be triggered. Reconfiguration will ensure the most efficient operation of the ON. When the ON operation is no longer necessary or suitable, the ON will be terminated [2].

The proposed solution to relieve the congested infrastructure is to exploit the opportunity that femtocells offer, e.g. extra capacity, and create an ON in order to offload a proportion of the traffic to alternate Wireless Access Networks (WANs) that are not problematic. However, optimization of the

network performance is not the only target, but energy efficiency constitutes the prominent target.

In our work a network is considered that consists of a macro BS, terminals that are served via the macro BS and femtocells that are distributed within the coverage area of the macro BS. This paper will focus on the benefits that derive from the exploitation of femtocells that lead to energy savings both for the infrastructure and the end-user side.

The rest of the paper is structured as follows: Section 2 provides state of the art work related to our problem. Section 3 provides an overview of the capacity extension through femtocells concept. Section 4 illustrates the mathematical formulation that was used for the problem. Simulation methodology and results are provided in Section 5 and, finally, the paper concludes with Section 6.

2 Related Work

This section provides a discussion of state-of-the-art work related to the examined problem.

Mobile data offloading is the use of complementary networks for the delivery of data that was originally targeted for cellular networks [3]. The main Radio Access Technology (RAT) used for the data offloading is Wi-Fi. The main advantage of Wi-Fi is that it operates at the unlicensed spectrum and therefore causes no interference to cellular networks. In addition, in most urban areas Wi-Fi is ubiquitous available deployed by operators or by single users. In [4] the authors evaluate the potential costs and gains for providing Wi-Fi offloading in a metropolitan area by using large scale real mobility traces for empirical emulation.

Virtual carrier is a method to exploit the cooperation of licenced (e.g. UMTS, LTE) and unlicensed (Wi-Fi) spectrum to improve network capacity. The levels of synergy vary, depending on whether a multiprotocol client connects to distinct 3G/4G and Wi-Fi Access Points (APs) or to integrated 3G/4G/Wi-Fi devices that can implement cooperative utilization of the available spectrum. In this case, an additional/virtual carrier is available to increase network performance [5]. In [6] the authors provide further information for multiradio interworking between Worldwide Interoperability for Microwave Access (WiMAX) and Wi-Fi.

The authors in [7] propose a distributed solution for designing the radio resource allocation of downlink transmissions in femtocell networks. The network to which the algorithm is evaluated consists also of a macro BS and

several femtocells deployed within its area. Furthermore, the authors in propose an optimal power allocation strategy based on modelling the interferer's activity as a two-state Markov chain. In the single femto-user access is shown how to maximize the expected value of femto-user rate, averaged over the interference statistical model. Then, the approach is extended to the multiuser case, adopting a game-theoretic formulation to devise decentralized access strategies, particularly suitable in view of potential massive deployment of femtocells. Moreover, in [9] the authors propose a distributed resource allocation strategy for the access of opportunistic users in cognitive networks. The solution is based on a social forage swarming model, where the search for the most appropriate slots is modelled as the motion of a swarm of agents in the resource domain, looking for "forage", representing a function inversely proportional to the interference level.

In addition, in [10] the authors suggest a distributed inter-cell power allocation algorithm where each cell computes by an iterative process its minimum power budget to meet its local QoS constraints. Their results show how their work permits to reduce both transmission power and harmful effects of in-band interference, while meeting QoS constraints of users in each cell. Moreover, the authors in [11] focus on a power control mechanism and propose a novel approach for dynamic adaptation of femtocells' transmitting power. The basic idea is to adapt the transmitting power of femtocells according to current traffic load and signal quality between user equipments and the femtocell in order to fully utilize radio resources allocated to the femtocell.

Furthermore, in [12] the EARTH energy efficiency evaluation framework (E^3F) evaluates the performance of a Radio Access Network (RAN) at system level using multi-cell system information. Also, it introduces a BS power model that is used to monitor the network energy consumption. In addition, relevant performance metrics related to the energy consumption of the network are defined and used as a complement to the classical key performance indicators. Moreover, the authors in [13] present new concepts to save energy in small-cell wireless communication BSs. The power consumption of these BSs is dominated by three components: the digital baseband engine, the analogue RF transceiver and the power amplifier. For these components, energy adaptation solutions are identified and quantified in function of the signal load.

3 Scenario Overview

As mentioned in the previous sections, an operator may face at any moment congestion in the infrastructure. In order to overcome this problematic situation our approach proposes the use of ONs for the infrastructure capacity extension through femtocells. Femtocells are fully featured but low power BSs that operate in licenced spectrum in order to connect mobile terminals to the network of an operator through residential broadband connections [14]. Therefore, the signal strength improves significantly resulting to better QoS. Moreover, there are different ways for a user to access a femtocell. The Closed Subscriber Group (CSG) model, where only a limited number of users have access to femtocell's resources. These users are defined by the femtocell owner. The Open Subscriber Group (OSG) where all operator's customers have access to the femtocell. The Hybrid Subscriber Group (HSG) where a limited amount of femtocell's resources are available to all users, while the rest are operated in a CSG manner [15].

In the capacity extension problem, as soon as a BS experiences congestion issues the Network Management Entity (NME) is notified in order to trigger the solution procedure. If neighbour femtocells exist, the suitability determination phase will define the terminals that are able to be redirected to femtocells, i.e. terminals with low mobility level. These terminals will be rerouted to femtocells relieving the congested BS, while the remaining to the BS terminals will be able to experience higher QoS. In addition, due to the fact that a proportion of terminals will be assigned to the femtocells, the BS will no longer be connected to them leading to a reduction in its energy consumption and savings in OPEX. Furthermore, the terminals that are served by the femtocells need lower transmission power to communicate with them and as a result their battery lifetime is expected to increase.

The benefits that derive from the concept of the capacity extension through femtocells are depicted in Figure 1.

4 Mathematical Formulation

For the solution we propose, a network that comprises a macro BS, femtocells and terminals is considered. The target is to estimate the energy consumption of the BS in relation with the connections with the terminals that it serves. For this purpose the Okumura–Hata propagation model for suburban areas is introduced [16] in order to enable us to calculate the transmission power that is needed for the communication between the BS and its terminals. Moreover, it

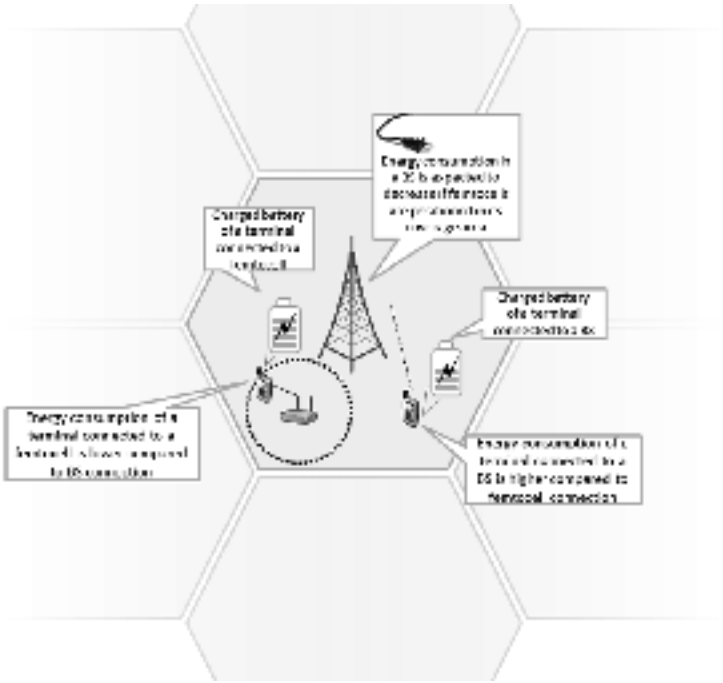

Figure 1 The benefits of the capacity extension through femtocells.

is assumed that not all terminals are transmitting data simultaneously. Therefore, if T is the set of terminals, $IT \subseteq T$ will denote the set of idle terminals and $AT \subseteq T$ will denote the set of active terminals, i.e. the set of terminals that are transmitting data. Apparently $IT \cup AT = T$. The transmission power of the BS for a specific time t can be estimated as follows:

$$P(t) = \sum_{i \in IT} P_i + \sum_{a \in AT} P_a, \tag{1}$$

where P_i is the power needed to communicate with an idle terminal and P_a is the power needed to communicate with an active terminal. P_a can be estimated via the Okumura-Hata propagation model, while P_i is assumed to be a small proportion of the transmission power that the BS would need to communicate with the terminal if it was active.

The energy consumption of the BS until a specific time t_0 can be calculated as

$$C(t_0) = \sum_{t \leq t_0} P(t) \cdot t, \tag{2}$$

Table 1 Simulation parameters.

Parameter name	Parameter value
BS antenna height	20 m
Terminal's antenna height	1.6 m
Frequency of transmission	2000 MHz
Terminal's sensitivity	–120 dBm

where t is the amount of time for which the BS was transmitting at power level $P(t)$.

Finally, the propagation model that was used for the femtocells is the one described in [17].

5 Simulation Results

5.1 Methodology

In order to evaluate the operation of the proposed concept, 3 test cases are considered for estimating the power consumption of the macro BS. The values of the parameters that were considered during the simulations are depicted in Table 1.

All test cases were simulated by using a customized version of the Opportunistic Network Environment (ONE) simulator [18] in a system with Intel Pentium D CPU at 2.80 GHz and 2.5 GB of RAM.

The topology that is used for the evaluation of the proposed solution consists of a macro BS, 30 femtocells that are located in a uniform distribution within the area of the BS and 50 terminals that move randomly within the area of the BS with an average velocity of 1 m/s.

5.2 Test Cases and Results

Test case 1 illustrates the impact of enabling femtocells to the network, to the power consumption of the macro BS, while test case 2 aims at showing how the number of users affects the power consumption of a macro BS. Finally, test case 3 depicts the impact of the use of femtocells to the battery lifetime of a terminal.

These test cases are indicative scenarios that highlight the benefits that derive from the concept of the capacity expansion through femtocells.

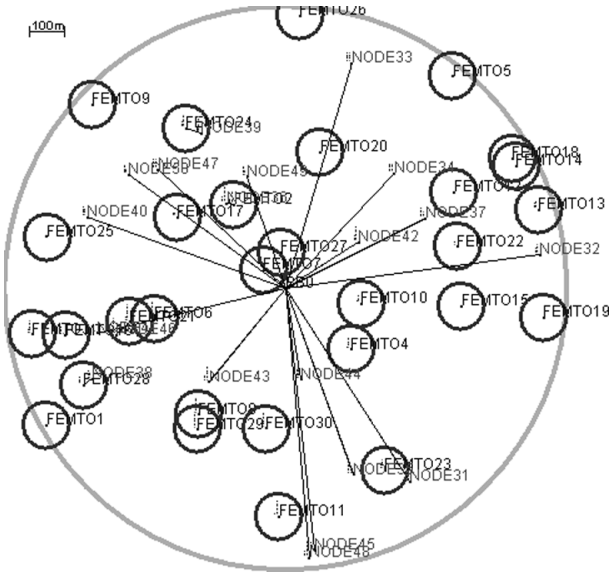

Figure 2 A macro BS with femtocells within its coverage.

5.2.1 Test Case 1

In this test case, the impact of the number of femtocells on the power consumption of the BS will be examined. Therefore, a macro BS area is considered as shown in Figure 2. The outer circle depicts the coverage of the macro BS, while the smaller circles indicate the coverage of the femtocells. Firstly, the case where the BS operates without nearby femtocells will be studied and then 10 femtocells will be enabled each time. The simulation time was 2000 secs.

Figure 3 depicts a snapshot from the case where all terminals are connected to the BS and all femtocells are disabled, while Figure 4 illustrates the total energy consumption of the BS. The horizontal axis depicts the simulation time, the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected to the BS. As it can be observed, the number of terminals that are connected to the BS is constantly 50 due to the fact that there are no nearby femtocells to acquire terminals.

Figure 5 illustrates the progress of the transmission power of the BS. The horizontal axis depicts the simulation time and the vertical axis on the left depicts the transmission power of the BS. The black line depicts the moving average of the transmission power of the BS. As it can be observed, when

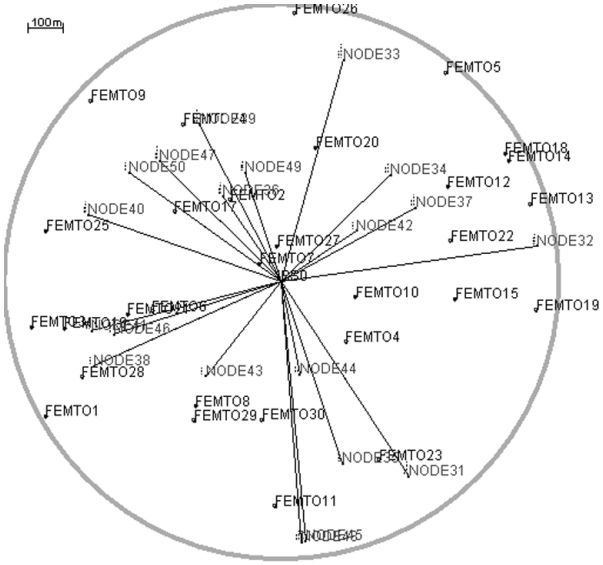

Figure 3 A macro BS without femtocells.

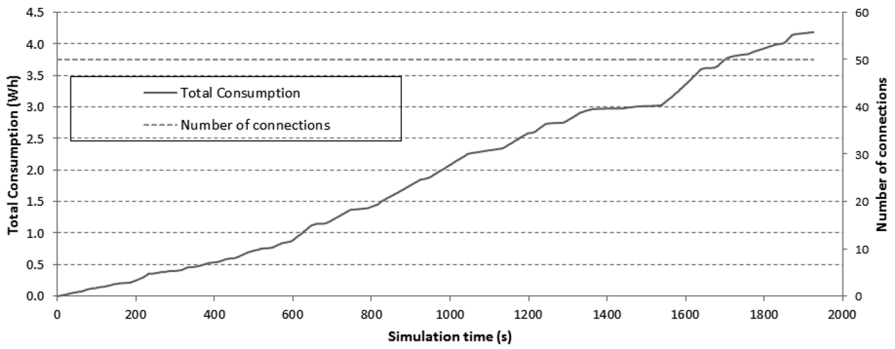

Figure 4 Total energy consumption of a BS without femtocells.

more terminals are transmitting data, the transmission power is high, while when most terminals are idle, the transmission power is very low.

Figure 6 depicts a snapshot from the case of the macro BS with 10 nearby femtocells, while Figure 7 illustrates the total energy consumption of the BS with 10 nearby femtocells. The horizontal axis depicts the simulation time, the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected

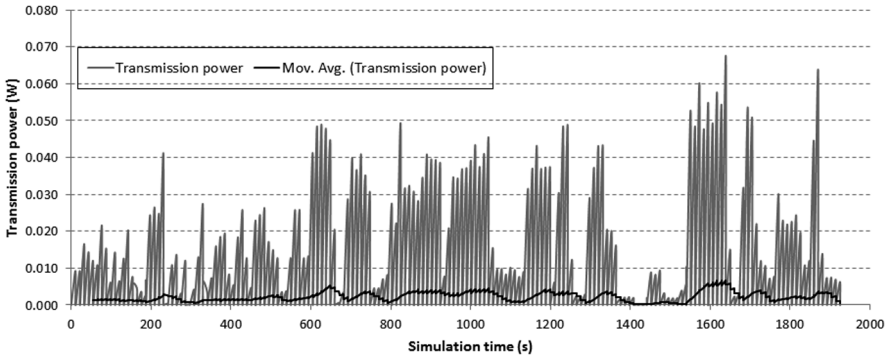

Figure 5 Transmission power of the BS without femtocells.

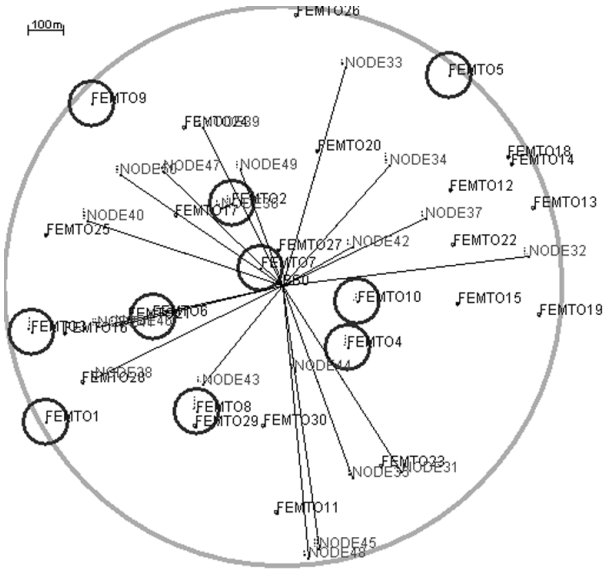

Figure 6 A macro BS with 10 nearby femtocells.

to the BS. Apparently, the energy consumption of the BS decreased due to the fact that the femtocells acquired a proportion of the traffic of the macro BS. In addition, as it can be observed the number of terminals that are connected with the BS has reduced since a proportion of the terminal is served by the femtocells.

Figure 8 illustrates the progress of the transmission power of the BS. The horizontal axis depicts the simulation time and the vertical axis on the left

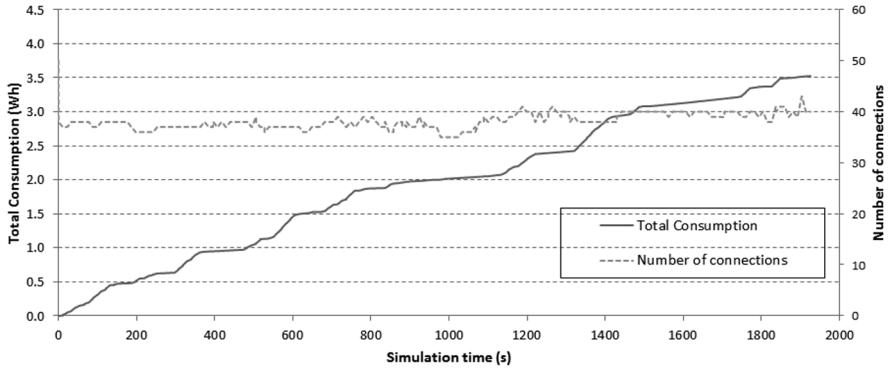

Figure 7 Total energy consumption of the BS with 10 nearby femtocells.

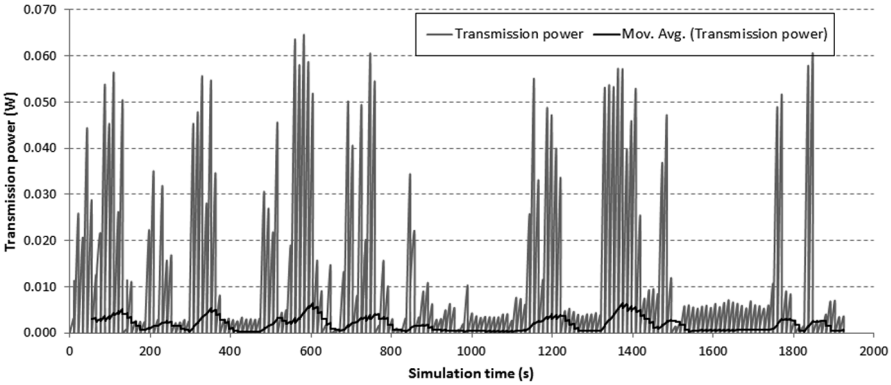

Figure 8 Transmission power of the BS with 10 nearby femtocells.

depicts the transmission power of the BS. The black line depicts the moving average of the transmission power of the BS.

Figure 9 depicts a snapshot from the case where 20 femtocells are within the area of the macro BS, while Figure 10 illustrates the total energy consumption of the BS. The horizontal axis depicts the simulation time, the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected to the BS. Apparently, the energy consumption of the BS has decreased even more due to the fact that more femtocells acquired traffic from the macro BS. In addition, as it can be observed the number of terminals that are connected with the BS has reduced more.

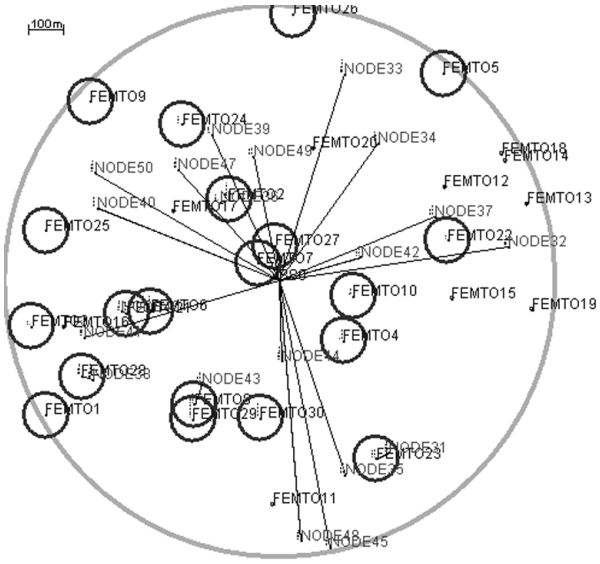

Figure 9 A macro BS with 20 nearby femtocells.

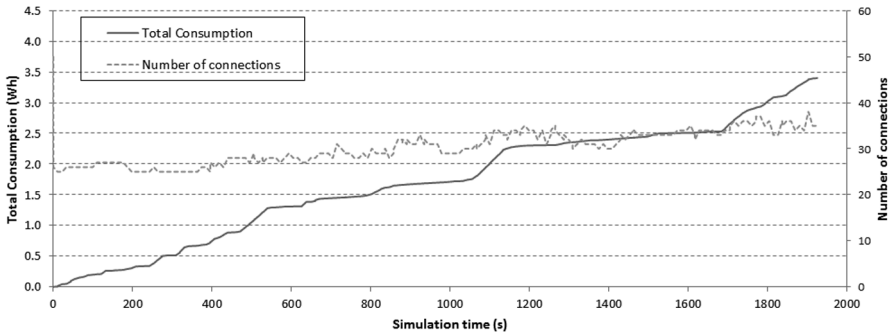

Figure 10 Total energy consumption of the BS with 20 nearby femtocells.

Figure 11 illustrates the progress of the transmission power of the BS. The horizontal axis depicts the simulation time and the vertical axis on the left depicts the transmission power of the BS. The black line depicts the moving average of the transmission power of the BS.

A snapshot of the case of a macro BS with 30 nearby femtocells is depicted in Figure 2. Figure 12 illustrates the total energy consumption of the BS with 30 nearby femtocells. The horizontal axis depicts the simulation time,

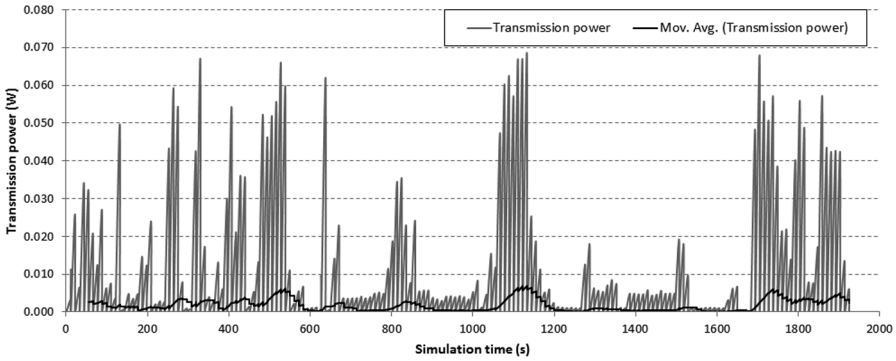

Figure 11 Transmission power of the BS with 20 nearby femtocells.

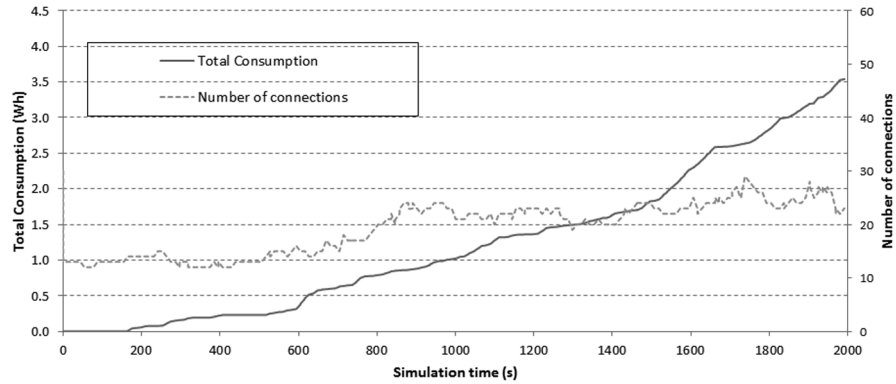

Figure 12 Total energy consumption of the BS with 30 nearby femtocells.

the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected to the BS. In this case, the energy consumption of the BS has not decreased that much in comparison with the case of the 20 nearby femtocells, since most users have been already rerouted to the femtocells.

Figure 13 illustrates the progress of the transmission power of the BS. The horizontal axis depicts the simulation time and the vertical axis on the left depicts the transmission power of the BS. The black line depicts the moving average of the transmission power of the BS.

Finally, Figure 14 illustrates a comparison of the energy consumption of the BS for the aforementioned cases. The vertical axis indicates the BS total energy consumption, while the horizontal axis depicts the network type,

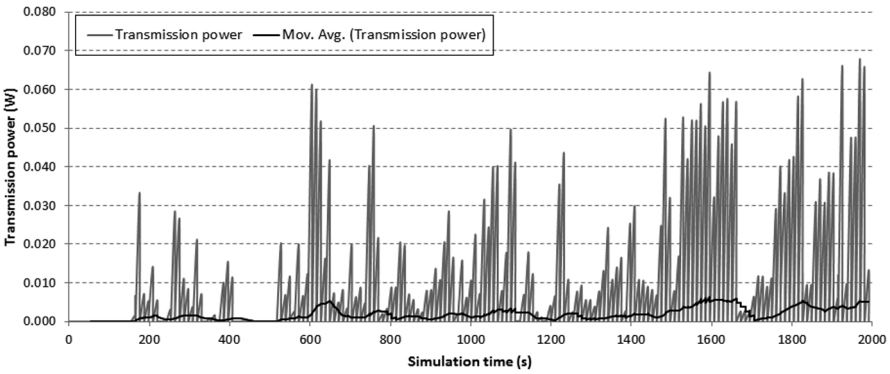

Figure 13 Transmission power of the BS with 30 nearby femtocells.

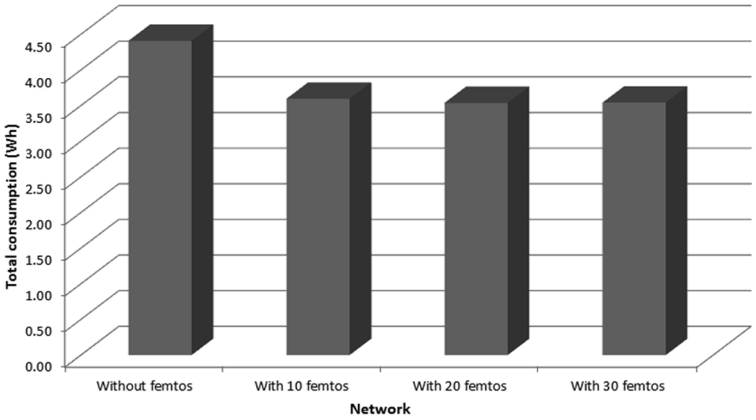

Figure 14 Energy consumption comparison for a BS with 0, 10, 20 and 30 nearby femtocells.

i.e. a network without femtocells and with 10, 20 and 30 femtocells. More specifically, when 10 femtocells were enabled to the network the energy consumption of the BS decreased by 18.54%. When 20 femtocells were enabled in the network, the energy consumption of the BS was reduced by 19.72% in comparison with the case were there were no femtocells. Finally, when 30 femtocells were enabled, the energy consumption of the BS was reduced by 20.01% percent. Therefore, as femtocells are deployed to the network, the energy consumption of the BS decreases. However, after a point where most of the traffic has been rerouted to the femtocells, the addition of more femtocells is not that much beneficial.

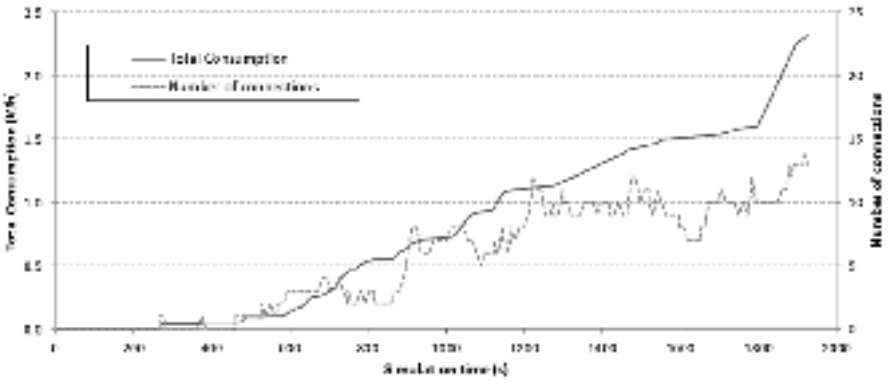

Figure 15 Total energy consumption of the BS with 30 terminals.

5.2.2 Test Case 2

In this test case, the impact of the number of terminals on the power consumption of the BS will be examined. A macro BS area with 30 femtocells is considered as in the previous case. The number of terminals for which the BS energy consumption will be studied is 30, 40 and 50 terminals.

Figure 15 illustrates the total energy consumption of the BS with 30 terminals. The horizontal axis depicts the simulation time, the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected to the BS. In this case, the energy consumption of the BS is very low since most users are served through the femtocells as can be observed also from the number of terminals that are connected to the BS.

Figure 16 illustrates the total energy consumption of the BS with 40 terminals. The horizontal axis depicts the simulation time, the vertical axis on the left depicts the energy consumption of the BS and the vertical axis on the right depicts the number of terminals that are connected to the BS. In this case, the energy consumption of the BS has increased as it was expected since more terminals were added to the network. Moreover, it can be observed that the number of the connected terminals to the BS has also increased.

The total energy consumption of the BS for the network that comprises 50 terminals is illustrated in Figure 12 of test case 1. As it can be seen, the energy consumption of the BS is even higher since 10 additional terminals were included in the network. In addition, the number of terminals that are connected with the BS was increased respectively.

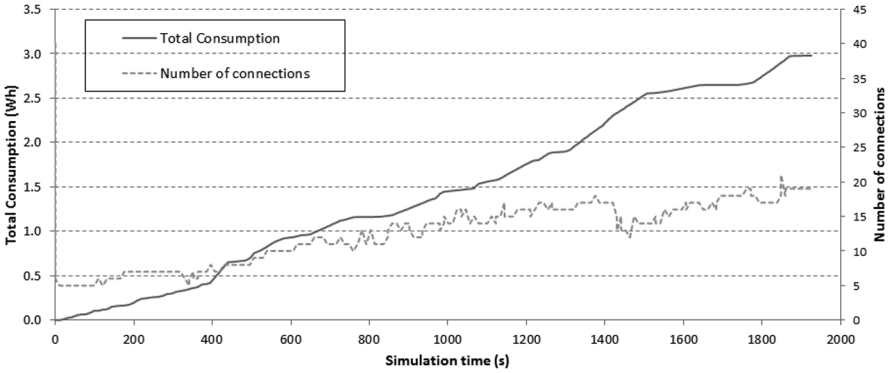

Figure 16 Total energy consumption of the BS with 40 terminals.

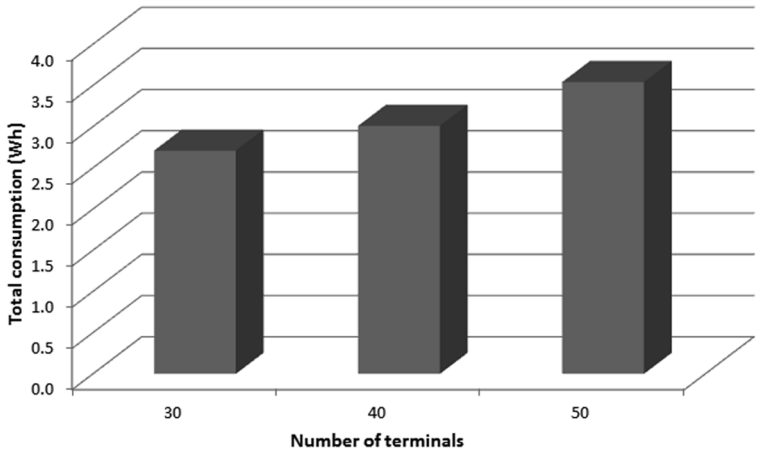

Figure 17 Total energy consuption of the BS for a network with 30, 40 and 50 terminals.

Finally, Figure 17 illustrates a comparison of the total energy consumption of the BS for the above-mentioned cases. More specifically, for the case of the network with 30 terminals, the consumption of the BS was 2.71 Wh. When 10 more terminals were added to the network, the BS consumption increased by 10% and reached 3.01 Wh. Finally, when terminals increased to 50, the BS consumption increased by 15% in comparison with the case of 40 terminals. As a result, as it was expected the energy consumption of the BS tends to increase when the number of terminals also increases.

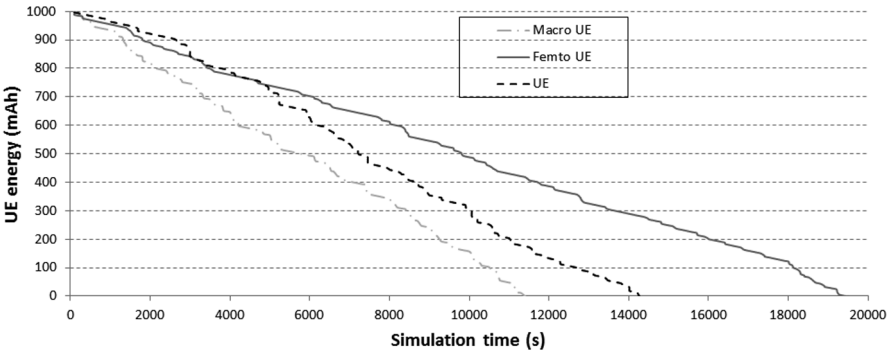

Figure 18 Progress of the energy level of macro-terminals, femto-terminals and terminals that connect both to macro BSs and femtocells.

5.2.3 Test Case 3

In this test case, the battery consumption of terminals will be examined. More specifically a terminal that is served exclusively through the macro BS (macro User Equipment (UE)), a terminal that is served only through a femtocell (femto UE) and a terminal that is moving and can be served from the BS and a femtocell (UE), but not simultaneously will be studied.

Figure 18 depicts the progress of the energy level of a macro UE vs. the progress of the energy level of a femto UE vs. the progress of the energy level of a UE. It is assumed that the energy of a terminal decreases as time progresses and that also decreases when data are transmitted. In addition, it is assumed that the terminals send data every 30 secs. Apparently, the energy of the femto UE decreases at a lower rate since the terminal needs less transmission power to communicate with the femtocell, while the energy of the macro-terminal decreases in a high rate due to the high transmission power. On the other hand, the progress of the energy level of the moving terminal is in the middle of the progress of the femto-UE and the macro-UE as it was expected since when it is within the coverage of an available femtocell, i.e. in terms of capacity and accessibility, it connects to the femtocell, otherwise it connects to the BS. More specifically, as it can be observed in Figure 19, the battery lifetime, i.e. the time needed for the energy level of a terminal to reach 0, of a femto-UE is 19506, while for a macro UE the lifetime is 11400 and for the moving UE is 14263. Hence, the lifetime of a macro-UE is 41.56% lower than the one of a femto-UE and 25.12% lower than the one of the moving UE.

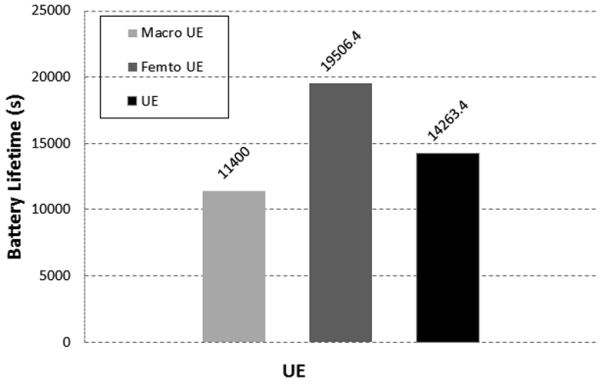

Figure 19 Battery lifetime of macro-terminals, femto-terminals and terminals that connect both to macro BSs and femtocells.

6 Conclusion

This paper considers ONs as a promising solution to the problem of capacity expansion of congested infrastructure. In particular, it focuses on the benefits that derive from the use of femtocells at the energy consumption of a macro BS and the battery lifetime of terminals through 3 indicative test cases. Simulation results depicted that the BS energy consumption is decreasing while the number of femtocells increases. The reason is that the more femtocells, the more traffic is acquired by the BS and therefore the number of terminals that connect to the BS is low.

In addition it was illustrated that the BS energy consumption increases while the number of terminals increases in the network. The reason is that the more terminals in the network, the more connections will be made with the BS. As a result the BS needs higher transmission power to serve the terminals.

Furthermore, the battery lifetime of a macro-terminal, a femto-terminal and a moving terminal was studied. Simulations illustrated that the battery lifetime of a femto-terminal is significantly higher than the one of the macro-terminal.

As a result, capacity extension through femtocells proved to be an energy efficient solution that provides benefits not only to the operator than is able to make savings in OPEX, but also to the end-user that can experience higher QoS levels and higher battery lifetime.

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References

[1] V. Stavroulaki, K. Tsagkaris, M. Logothetis, A. Georgakopoulos, P. Demestichas, J. Gebert, and M. Filo. Opportunistic networks: An approach for exploiting cognitive radio networking technologies in the Future Internet. *IEEE Vehicular Technology Magazine*, 52–59, September 2011.

[2] A. Georgakopoulos, K. Tsagkaris, V. Stavroulaki, and P. Demestichas. Efficient opportunistic network creation in the context of Future Internet. In J. Domingue et al. (Eds.), *The Future Internet: Achievements and Technological Promises*, Lecture Notes in Computer Science, Vol. 6656. Springer, pp. 293–306, 2011.

[3] B. Han, P. Hui, V. Anil Kumar, M. Marathe, J. Shao, and A. Srinivasan. Mobile data offloading through opportunistic communications and social participation. *IEEE Transactions on Mobile Computing*, 2011.

[4] S. Dimatteo, P. Hui, B. Han, and V. Li. Cellular traffic offloading through WiFi networks. In *Proceedings of 8th IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2011)*, Valencia, Spain, October 2011.

[5] S. Yeh, S. Talwar, G. Wu, N. Himayat, and K. Johnsson. Capacity and coverage enhancement in heterogeneous networks. *IEEE Wireless Communications*, 18(3), June 2011.

[6] N. Himayat et al. Heterogeneous networking for future wireless broadband networks. IEEE C80216-10_0003r1, January 2010.

[7] A. Agustin, J. Vidal, and O. Muñoz. Interference pricing for self-organisation in OFDMA femtocell networks. In *Proceedings of European Workshop on Broadband Femtocell Networks, Future Network and Mobile Summit*, Warsaw, Poland, pp. 1–8, June 2011.

[8] S. Barbarossa, A. Carfagna, S. Sardellitti, M. Omilipo, and L. Pescosolido. Optimal radio access in femtocell networks based on markov modeling of interferers' activity. In *Proceedings of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Prague, pp. 3212–3215, May 2011.

[9] P. di Lorenzo and S. Barbarossa. Distributed resource allocation in cognitive radio systems based on social foraging swarms. In *Proceedings of IEEE 11th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, June 2010.

[10] C. Abgrall, E.C. Strinati, and J.C. Belfiore. Distributed power allocation for interference limited networks. In *Proceedings of IEEE 21st International Symposium on Personal In-*

door and Mobile Radio Communications (PIMRC), Istanbul, pp. 1342–1347, September 2010.
[11] P. Mach and Z. Becvar. QoS-guaranteed power control mechanism based on the frame utilization for femtocells. *EURASIP Journal on Wireless Communications and Networking*, 2011.
[12] P. Skillermark, M. Olsson, Y. Jading, G. Auer, V. Giannini, M.J. Gonzalez, and C. Desset. System level energy efficiency analysis in cellular networks. In *Proceedings of Future Network & Mobile Summit 2011*, Warsaw, Poland. IIMC International Information Management Corporation, June 2011.
[13] B. Debaillie, A. Giry, M.J. Gonzalez, L. Dussopt, M. Li, D. Ferling, and V. Giannini. Opportunities for energy savings in pico/femto-cell base-stations. In *Proceedings of Future Network & Mobile Summit 2011*, Warsaw, Poland. IIMC International Information Management Corporation, June 2011.
[14] ThinkFemtocell, available online at http://www.thinkfemtocell.com/.
[15] G. de la Roche, A. Valcarce, D. Lopez-Perez, and J. Zhang. Access control mechanisms for femtocells. *IEEE Communications Magazine*, 48(1):33–39, January 2010.
[16] M. Hata. Empirical formula for propagation loss in land mobile radio services. *IEEE Transactions on Vehicular Technology*, VT-29(3): 317–325, August 1980.
[17] Z. Jako and G. Jeney. Downlink femtocell interference in WCDMA networks. In *Proceedings of Energy-Aware Communications, 17th International Workshop (EUNICE 2011)*, Springer, September 2011.
[18] A. Keranen, J. Ott, and T. Karkkainen. The ONE simulator for DTN protocol evaluation. In *Proceedings of SIMUTools'09: 2nd International Conference on Simulation Tools and Techniques*, Rome, March 2009.

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