A Novel Joint Handover and Base Station Sleep mode Algorithm in HetNet

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***Abstract*—The demand for wireless resources is increasing in high pace. Heterogeneous network (HetNet), which consists of cells with different coverage, e.g., macro cell base stations (BSs) and small cell BSs, is a key solution to address this increased demand. This paper presents a handover (HO) algorithm for BS sleep-wake mode, which reduces the energy consumption in HetNet. In the first phase of the HO algorithm, parameters such as the distance of user equipments (UEs) with their respective BSs, velocities of UEs and their received power strength (RSS) are employed to determine the necessity of HO. This phase, i.e., HO necessity estimation phase (HONEP), helps reducing the unnecessary HOs and consequently save more energy. After HONEP, in the second phase UEs select the new BS based on the average distance of UEs and BSs to which they approach, RSS and average traffic load of BSs which is advertised through beacon signals. A game-theoretic sleep-awake algorithm is executed in parallel to HO algorithm in BSs. System power consumption and BSs' average traffic load are evaluated by computer simulation. The effect of users mobility on system performance is discussed accordingly.**

***Index Terms*—HetNet, handover, base station sleep mode algorithm, game theory, energy efficiency, mobility**

I. Introduction

The demand for wireless resource is increasing in high pace. Video streaming and social media [1] contribute to this increase to a great extent. Consequently, traffic load and energy consumption in wireless cellular system is increasing accordingly and this urges the necessity of designing more energy and spectral efficient systems.

Heterogeneous networks (HetNets), consisting of macro cell base stations (MBSs) and small cell base stations (SBSs), are proven to be highly effective in increasing the wireless resources [2]–[4]. The consumption energy in HetNets reduces when combined with ON/OFF switching algorithms which adapt to network traffic conditions. In [3] a centralized sleep mode algorithm is proposed. It is shown that this algorithms can improve the energy efficiency in HetNets. However, the main drawback of centralized approaches is that the consumption energy increases due to an increased information exchange between BSs. On the other hand, connecting all BSs to data processing centers, e.g. cloud radio access network (cloud-RAN), through high capacity backbone links, is an expensive solution and probably not yet suitable for some geographic areas. Sleep mode algorithms which rely on self-distribution control, do not need any information exchange through back haul communication. In such algorithm, each BS decides independently to turn ON or OFF depending on it's traffic load and consumption power.

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In this paper, we use the similar ON/OFF switching algorithm as in [1], in which a non-cooperative, *mixed strategy*, game is used to decide the ON, OFF or extended power status of each BS. In strategic form games [5], each player, here BS, selects it's strategy (action) only to maximize it's utility, i.e., a function which evaluates each player's outcome. In non-cooperative games, players decide their strategies independently without negotiating with other players. To the best of our knowledge there has been no study on mobility in HetNets which employ ON/OFF switching algorithms. In this paper, we propose a handover (HO) algorithm for UEs, combined with an ON/OFF switching algorithm for BSs in a HetNet scenario. The HO algorithm comprises of two different phases, i.e., HO necessity estimation phase (HONEP) and HO execution phase (HOEP). In first phase, several parameters such as, UE's velocity and the RSS and distance from its associated BS are checked. If certain conditions are met, then the algorithm goes into the second phase and decides about the best target BS. First phase is essential in order to reduce the number of unnecessary HOs and save energy. In the second phase UEs select the new BS based on the average distance of UEs and BSs to which they approach, RSS and average traffic load of BSs which are advertised periodically through beacon signals.

The rest of this paper is organized as follows. In Section II, system model is described along with power consumption, load, and utility function models. Section III discusses our proposed algorithm, Section IV provides the simulation results and the evaluation of our algorithm. Sections V indicates the acknowledgment and finally, Section IV concludes the paper.

II. System Model

In this paper, we focus on the downlink transmission in HetNet, assuming one MBS and a variable set of SBSs, $\mathcal{S} = \{1, ..., S\}$, distributed uniformly within the MBS. MBS is on the center of a hexagonal shaped macro cell. Fig. 1 shows an example realization of such HetNet scenario. Each BS

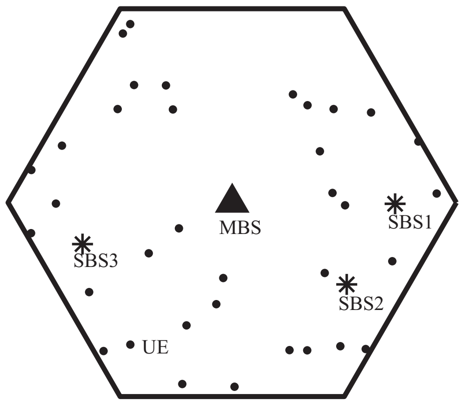

Fig. 1. HetNet topology

chooses it's strategy (transmission power level), using Table I. Transmission power of sth BS is given according to:

$$P_s(t) = \xi_s(t) \cdot P_{sMAX}^{TX}, \tag{1}$$

where $\xi_s(t)$ is the transmission power level and P_{sMAX}^{TX} is the maximum transmission power of sth BS.

A. Consumption power

When a BS is in OFF mode, the BS consumes power only for detecting UEs. The consumption power of sth BS in OFF mode at time t is given by [6]:

$$P_s^{All}(t) = \frac{P_{radio} + P_{base}}{\chi} = P_s^{Idle}, \tag{2}$$

with

$$\chi = (1 - \chi_{DC})(1 - \chi_{main})(1 - \chi_{cool}), \tag{3}$$

where P_{radio} and P_{base} are consumption power in radio frequency and baseband unit. χ_{DC}, χ_{main} and χ_{cool} are losses in DC-DC conversion, main supply, and cooling units.

Consumption power of sth BS in ON mode at time t is given by [6]:

$$P_s^{All}(t) = \frac{P_s(t)}{\eta\chi(1 - \chi_{feed})} + P_s^{Back} + P_s^{Idle}, \tag{4}$$

where η and P_s^{Back} are respectively, the power amplifier's efficiency and consumption power in backbone network. χ_{feed} models the loss in the feeder.

TABLE I
TRANSMISSION POWER LEVELS

Identification Number of Strategy i	Transmission Power Level $\xi_s(t)$
1	0
2	1/3
3	2/3
4	1

Algorithm 1 : Sleep mode algorithm at BS [1].

Input: $\hat{u}_{s,i}(t)$, $\hat{r}_{s,i}(t)$, $p_{s,i}(t)$
Output: $a_s(t+1)$
Initialization: $\mathcal{S} = \{1, ..., S\}$;
while do
  $t-1 \rightarrow t$,
  BS's strategy selection: $a_s(t) = f\left(p_{s,i}(t-1)\right)$
  Calculation of traffic load estimation $\hat{\nu}_s(t)$ and transmission to all UEs
  Calculation of traffic load $\nu_s(t)$, power consumption $P_s^{All}(t)$ and utility $u_s(t)$
  if $\nu_s(t) > 1$ **then**
    Select connected UEs
  end if
  Update of utility estimation $\hat{u}_{s,i}(t)$,regret $\hat{r}_{s,i}(t)$ and probability distribution $p_{s,i}(t)$
end while

B. Traffic load

Signal to interference plus Noise Ratio (SINR) of UE at point z is given by:

$$\varsigma_s(z) = \frac{P_s(t) g_s(z)}{\sum\limits_{\forall s' \in \mathcal{S}/s} P_{s'}(t) g_{s'}(z) + N}, \tag{5}$$

where $g_s(z)$ is UE's channel gain at point z and connected to sth BS. N is the noise variance.

Data rate of UE at point z is given by:

$$D_s(z) = w \log_2(1 + \varsigma_s(z)), \tag{6}$$

where w is the channel bandwidth.

Traffic load density of UE at point z is given by [7]:

$$\vartheta_s(z) = \frac{\kappa_s(z) v_s(z)}{D_s(z)}, \tag{7}$$

where $\kappa_s(z)$ is the packet arrival rate and $v_s(z)$ is the average packet size of UE at point s.

Traffic load is given by:

$$\nu_s(t) = \sum_{z \in \mathfrak{L}_s} \vartheta_s(z), \tag{8}$$

where $\mathfrak{L}_s$ is the coverage area of sth BS.

C. Utility

Utility of sth BS is formed by its consumption power $P_s^{All}(t)$ and traffic load $\nu_s(t)$ according to:

$$u_s(t) = -(\phi \cdot P_s^{All}(t) / P_{sMAX}^{TX} + \varphi \cdot \nu_s(t)), \tag{9}$$

where ϕ and φ ($\phi > 0, \varphi > 0$) are weighting factors of consumption power and traffic load. These figures define the influence of consumption power and load.

III. Algorithm

We use the sleep mode algorithm in [1] as shown in Algorithm 1. The proposed UE association algorithm is shown in Algorithm 2.

Algorithm 2 : Association algorithm at UE.

Input: $\hat{\nu}_s(t)$ and $P_s^{RX}(t)$
Output: $s(z,t)$
if UE isn't currently connected to any BS **then**
  UE chooses a new BS, $s(z,t)$, based on $\hat{\nu}_s(t)$ and $P_s^{RX}(t)$
else
  Decide whether to HO or not
  if HO is necessary **then**
    UE chooses a new BS, $s(z,t)$, based on $\hat{\nu}_s(t)$ and $P_s^{RX}(t)$
  else
    UE doesn't change its BS
  end if
end if

A. BS's strategy selection

Each BS has a set of strategies $\mathcal{A}_s = \{a_{(s,1)}, ..., a_{(s,A)}\}$ and $a_s(t)$ is the strategy chosen by sth BS at time t. A probability is associated with the strategy set of each BS and is updated at each iteration. BS's next strategy is decided by probability distributions $p_{s,i}(t-1) \quad \forall i = 1,2,3,4$ according to:

$$a_s(t) = f(p_{s,i}(t-1)), \tag{10}$$

where f is the conversion function from probability distribution to strategy and is elaborated in Algorithm 3. As previously described, each strategy defines the transmission power level, $\xi_s(t)$, of BSs. Please note that MBS selects its strategy only from $i=1$ and $i=4$.

Algorithm 3 : Strategy selection at BS.

Input: $p_{s,j}(t-1)$ $(j = 1,2,3,4)$
Output: i
Select r $(0 < r < 1)$ randomly
if $p_{s,1}(t-1) > r$ **then**
  $i = 1$
else
  if $\sum_{j=1}^{2} p_{s,j}(t-1) > r$ **then**
    $i = 2$
  else
    if $\sum_{j=1}^{3} p_{s,j}(t-1) > r$ **then**
      $i = 3$
    else
      $i = 4$
    end if
  end if
end if

B. Traffic load estimation

Each BS estimates its traffic load, $\hat{\nu}_s(t)$, according to:

$$\hat{\nu}_s(t) = \hat{\nu}_s(t-1) + n(t)\cdot(\nu_s(t-1) - \hat{\nu}_s(t-1)), \tag{11}$$

where $n(t)$ is the learning rate and is selected in a way to make sure that the changes in traffic load estimation is slower than the UE association speed. If traffic load estimation changes rapidly, UEs change connected BS frequently, in which case it may result in destabilization of the algorithm. $\hat{\nu}_s(t)$ is then transmitted via periodic beacons to all UEs.

C. HO Algorithm

Fig. 2 shows the geo-relational model of UE and its connected BS. In this figure, $v(t)(\geq 0)$ is the velocity of UE and $v_b(t)(-\infty < v_b(t) < +\infty)$ is its velocity component in the direction of the connected BS. $d(t)$ is the UE's distance to its connected BS. Each UE receives the traffic load estimation $\hat{\nu}_s(t)$ and received power $P_s^{RX}(t)$ from all BSs through beacon signals and decides about HO based on this information. Algorithm 4 shows the proposed HO algorithm at UE.

Algorithm 4 : HO algorithm at UE.

if UE is connected to MBS **then**
  Always search for a new BS using (12)
else
  (UE is connected to SBS)
  if $d(t) > r_{SBS}$ (r_{SBS}: small cell radius) **then**
    search for a new BS using (12)
  else
    if $v_b(t) < 0$, $d(t) \leq d^{TH}$ (d^{TH}: distance threshold) and $P_s^{RX}(t) \leq P^{TH}$ (P^{TH}: power threshold) **then**
      search for a new BS using (12)
    else
      Do not change current connected BS
    end if
  end if
end if

For new UEs or whenever HO is needed, each UE at point z selects the BS to connect to, $s(z,t)$, based on the following criterion:

$$s(z,t) = \arg\max_{s\in\mathcal{S}} \{(\hat{\nu}_s(t) + \varsigma_s)^{-\varpi} \cdot P_s^{RX}(t) \cdot (d_s(t))^{-\lambda}\}, \tag{12}$$

with

$$\varsigma_s = 1 - \nu_s^{PRF}, \tag{13}$$

where ς_s and ν_s^{PRF} are offset and preferred load of sth BS. ϖ $(\varpi > 0)$ and λ $(\lambda > 0)$ are coefficients which define the influence of traffic load estimation, $\hat{\nu}_s(t)$, and the distance between UE and sth BS, $d_s(t)$.

D. Load Compensation

If traffic load of sth BS is larger than 1, it has to drop some of its connected UEs, such that the overall load again becomes equal or less than 1. Please note that this phenomena causes increase in network dropping probability and our proposed UE association and HO algorithm try to improve the network dropping probability by incorporating BSs' load information into the decision process.

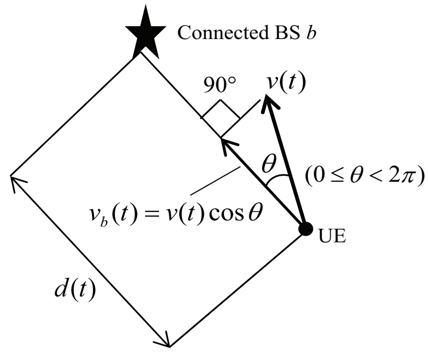

Fig. 2. Geo-relational model of UE and its connected BS

E. Computation of probability distribution

For ith strategy of sth BS, utility estimation, $\hat{u}_{s,i}(t)$, regret estimation, $\hat{r}_{s,i}(t)$, and probability distribution, $p_{s,i}(t)$, are updated according to [1]:

$$\begin{aligned} \hat{u}_{s,i}(t+1) &= \hat{u}_{s,i}(t) + \iota_b(t+1) \cdot \mathbf{1}(t) \cdot (u_s(t) - \hat{u}_{s,i}(t)), \\ \hat{r}_{s,i}(t+1) &= \hat{r}_{s,i}(t) + \tau_s(t+1) \cdot (\hat{u}_{s,i}(t) - u_s(t) - \hat{r}_{s,i}(t)), \\ p_{s,i}(t+1) &= p_{s,i}(t) + \varrho_s(t+1) \cdot (G_{s,i}(\hat{r}_{s,i}(t)) - p_{s,i}(t)), \end{aligned} \quad (14)$$

with

$$\mathbf{1}(t) = \begin{cases} 1 & (if \quad a_s(t+1) = a_s(t)) \\ 0 & (if \quad a_s(t+1) \neq a_s(t)), \end{cases} \quad (15)$$

and

$$G_{s,i}(\hat{r}_{s,i}(t)) = \frac{\exp(\varepsilon_s \hat{r}_{s,i}(t))}{\sum_{i' \in \mathcal{A}_s} \exp(\varepsilon_s \hat{r}_{s,i'}(t))}, \quad (16)$$

where $G_{s,i}(\hat{r}_{s,i}(t))$ is the Boltzmann distribution and ε_s is the temperature parameter. $\iota_s(t)$, $\tau_s(t)$ and $\varrho_s(t)$ are learning rates which follow a form like $1/t^c$ (c: power parameter) and should meet the following criterion.

$$\begin{aligned} &\lim_{t\to\infty} \sum_{m=1}^{t} \iota_s(m) = +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \tau_s(m) = +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s(m) = +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \iota_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \tau_s^2(m) < +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \frac{\tau_s(t)}{\iota_s(t)} = 0, \qquad \lim_{t\to\infty} \frac{\varrho_s(t)}{\tau_s(t)} = 0. \end{aligned} \quad (17)$$

IV. Computer Simulation

Simulation parameters are summarized in Table II. We compare our proposed joint HO and ON/OFF switching algorithm with a benchmark in which all BS are always ON at all time.

Fig. 3 shows total number of HOs *vs* different average velocities for 60 UEs and two different SBS numbers, i.e., 3 and 7. Total number of HOs indicates the number of alterations of connected BS by UEs. As expected for higher velocities, the total number of HOs is higher, which indirectly indicates a higher number of control signalling and as a result higher energy consumption. However, the proposed algorithm shows about 50% less number of HOs, compared to the benchmark.

TABLE II
Simulation Parameters

Parameter	Value
Network	
Total time	10000s
Time interval of 1 iteration	1s
Noise Variance N	-174dBm/Hz
Arrival Rate $\kappa_s(z)$	180kbps
MBS	
Maximum Transmission Power P_{sMAX}^{TX}	46dBm
Minimum MBS-SBS Distance	75m
Cell radius r_{MBS}	250m
SBS	
Maximum Transmission Power P_{sMAX}^{TX}	30dBm
Minimum SBS-SBS Distance	40m
Cell radius r_{SBS}	40m
Path loss (d:Distance of BS and user (m)) (unit: dB)	
MBS - UE	15.3+37.6log$_{10}$(d) [1]
SBS - UE	27.9+36.7log$_{10}$(d) [1]
Threshold Parameters	
Power Threshold P^{TH}	-90dBm [8]
Distance Threshold d^{TH}	20m
Learning Parameters	
Boltzmann Temperature ε_s	10
Weighting Coefficients for Power Consumption and Traffic Load, ϕ, φ	10, 5
Weighting Exponent of Traffic Load and Distance, ϖ ,λ	1, 0.5
Learning Rate Exponents c for ι_s, τ_s, ϱ_s	0.6,0.7,0.8

Fig. 4 shows the average traffic load per BS *vs* different number of UEs under the average velocity of 4km/h. We observe that the proposed approach has a better performance than the benchmark. In benchmark algorithm all BSs transmit with maximum power which results in an increased total amount of interference experienced by UEs. Please note that total load is related to each UE's SINR and received interference based on Eqs. 5 to 8. However, for higher number of UEs, i.e., 80, the average load of both algorithms is almost identical. This is mainly due to interference saturation. As we can see, this saturation point can be further improved by increasing the number of SBSs (in this case from 3 SBSs to 7). Average BSs' traffic load is inversely related to average BSs' throughput. As a result, higher load indicates a lower throughput.

Fig. 5, shows the total consumption power in HetNet *vs* different number of UEs at an average velocity of 4km/h. We notice a steep ascend in gradient from 40 to 60 UEs, when 7 SBSs are employed. This is because SBSs increase their transmit power in order to reduce their traffic load. We can also observe that, as the number of BSs increase, the performance gap between the proposed algorithm and the benchmark increase. This shows the effectiveness of our proposed algorithm in dense SBS deployments.

In Fig. 6, total number of HOs *vs* different number of UEs is shown at an average velocity of 4km/h. We observe that the proposed algorithm has a higher number of HOs compared to the benchmark up to 60 number of UEs. However, for more than 60 UEs the total number of HOs in the proposed algorithm is less than the benchmark. This is because the effect of ON/OFF switching is more apparent on total number

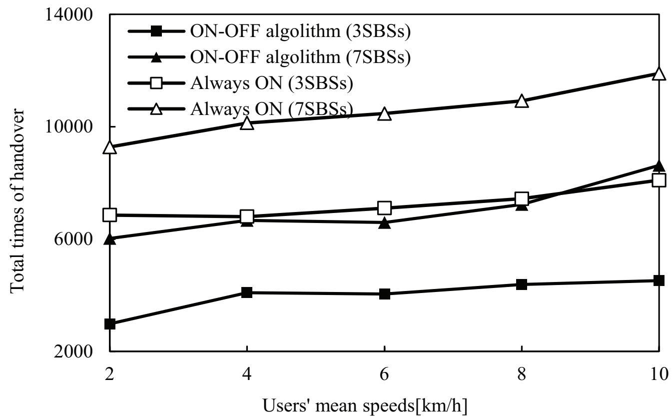

Fig. 3. Total number of HOs *vs* different average velocities for 60 UEs and two different SBS numbers, i.e., 3 and 7

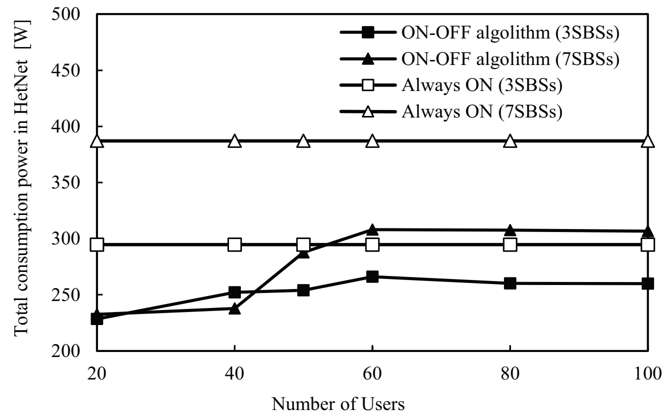

Fig. 5. The total consumption power in HetNet *vs* different number of UEs at an average velocity of 4km/h

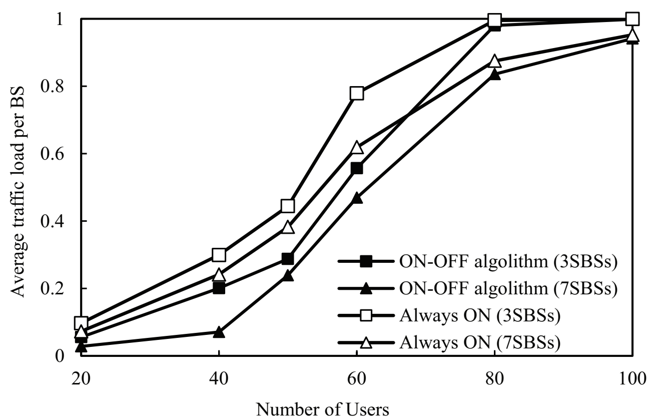

Fig. 4. The average traffic load per BS *vs* different number of UEs under the average velocity of 4km/h

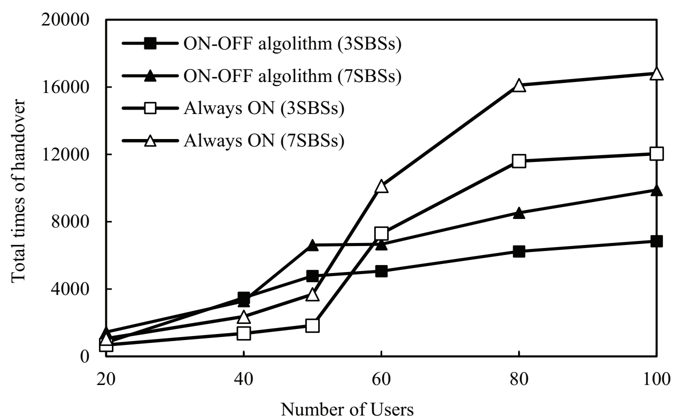

Fig. 6. Total number of HOs *vs* different number of UEs is shown at an average velocity of 4km/h

of HOs, when the UEs' density increase. This again proves the effectiveness of the proposed algorithm for higher UE densities.

V. ACKNOWLEDGMENT

We would like to thank authors in [1] for constructive discussions and continuing support.

VI. CONCLUSION

In this paper, a joint distributed HO and BS sleep mode algorithm was proposed within the context of HetNet. The HO algorithm first estimates the necessity of HO based on parameters such as received signal strength of the current connected BS and UE's velocity. If a HO seemed inevitable, at the next step UE selects the BS to be connected based on its relative distance to the BS, received power strength and BS's traffic load. Simulation result shows that the algorithm works well both in terms of energy efficiency and spectral efficiency. It was also noticed that the proposed algorithm yields significant improvement compared to the conventional algorithms in dense SBS deployment and higher UE densities.

REFERENCES

[1] S. Samarakoon, M. Bennis, W. Saad, and M. Latva-aho, "Opportunistic sleep mode strategies in wireless small cell networks," in *IEEE International Conference on Communications 2014 - Mobile and Wireless Networking Symposium (ICC'14-MWS)*, June 2014, pp. 2707–2712.

[2] K. M. S. Huq, S. Mumtaz, M. Alam, J. Rodriguez, and R. L. Aguiar, "Frequency allocation for hetnet comp: Energy efficiency analysis," in *Wireless Communication Systems (ISWCS 2013)*, August 2013, pp. 1–5.

[3] S.Zhou, A.J.Goldsmith, and Z.Niu, "On optimal relay placement and sleep control to improve energy efficiency in cellular networks," in *IEEE International Conference on Communications*, June 2011, pp. 1–6.

[4] H. Zhang, C. Jiang, N. C. Beaulieu, X. Chu, X. Wen, and M. Tao, "Resource allocation in spectrum-sharing ofdma femtocells with heterogeneous services," *IEEE TransactionsCommunications*, vol. 62, no. 7, pp. 2366–2377, June 2014.

[5] A. Okada, *Game Theory*. Yuhikaku, 1996.

[6] G. Koudouridis and H. Li, "Distributed power on-off optimisation for heterogeneous networks - a comparison of autonomous and cooperative optimisation," in *2012 IEEE 17th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, Sept 2012, pp. 312–317.

[7] H. Kim, G. de Veciana, X. Yang, and M. Venkatachalam, "Distributed α-optimal user association and cell load balancing in wireless networks," *IEEE/ACM Transactions on Networking*, vol. 20, no. 1, pp. 177–190, Feb 2012.

[8] G. F. Pedersen, "Mobile phone antenna performance," in *Aalborg University*, November 2013, p. 14.