A Game Theoretic Framework for Energy Efficient Deployment and Operation of Heterogeneous LTE Networks

Elias Yaacoub[1], Ali Imran[1], Zaher Dawy[2], and Adnan Abu-Dayya[1]

[1]Qatar Mobility Innovations Center (QMIC), Qatar Science and Technology Park, Doha, Qatar.
Email: {eliasy, alii, adnan}@qmic.com
[2]Department of Electrical and Computer Engineering, American University of Beirut (AUB), Beirut, Lebanon.
E-mail: zaher.dawy@aub.edu.lb.

***Abstract*—In this paper, a game theoretical framework for energy efficient operation of heterogeneous LTE cellular networks is proposed. Within this framework, two game theoretic concepts are studied and analyzed. The first approach is a coalition-based method that assumes a group of base stations (BSs) in a network form a coalition. The second approach is based on the Nash bargaining solution and considers that BSs play a bargaining game where each BS attempts to maximize its own utility. These methods were implemented with utilities focusing either on traffic load and quality of service (QoS), or on the QoS versus the consumed power in the network. The tradeoffs between QoS and energy consumption are investigated, depending on the utility selected. Simulation results show that the results are utility dependent, and that the centralized coalition-based approach generally leads to better performance.**

***Index Terms*—LTE, heterogeneous networks, energy efficiency, green communications, coalitional game theory, Nash bargaining solution.**

I. Introduction

Energy efficiency is representing an increasing concern for cellular network operators. Although the main purpose is to minimize their electricity costs and maintain profitability, reducing negative effects on the environment is also an important objective [1].

A large portion of the energy dissipated in a cellular system is actually consumed at the base stations (BSs). Hence, putting certain BSs in sleep mode, or switching them off in light traffic conditions, is an efficient technique to save energy in wireless networks, e.g., see [2], [3]. In [4], the cell size is adjusted dynamically depending on the traffic load using a technique called "cell zooming" for the purpose of reducing energy consumption. The power ratio, corresponding to the ratio between the dynamic and the fixed power part of a BS power consumption model, is introduced in [5]. This ratio is used to propose a solution based on traffic load balancing.

Several enhancements incorporated in next generation cellular systems, e.g. LTE-Advanced (LTE-A), consist of reducing effective cell sizes by using combinations of microcells [6], distributed antenna systems [7], relays [8], and indoor femtocells [9]. In this paper, we use the term "small cells" to refer to a combination of these cells. Together with macrocells, they form a heterogenous network (HetNet), with HetNets expected to constitute a paradigm shift in state-of-the-art cellular networks [10]. The operation of such HetNets is optimized through the use of advanced interference coordination/mitigation techniques, heterogeneous fractional frequency reuse patterns, and cooperative multipoint transmission/reception techniques.

In this paper, a game theoretic framework based on utility maximization is proposed in order to ensure that green LTE/LTE-A HetNets operate with the least required number of BSs while maintaining a certain degree of quality of service (QoS). The paper is organized as follows. The system model is described in Section II. The proposed game theoretic techniques are presented in Section III. The utility metrics used in this paper are described in Section IV. Simulation results are presented and analyzed in Section V. Finally, in Section VI, conclusions are drawn and indications for future research are outlined.

II. System Model

We consider a geographical area of interest with uniform user distribution. The area is covered by a heterogeneous LTE network, consisting of macrocell BSs with a cell radius R_M, and small cell BSs with a smaller cell radius $R_S < R_M$. The game theoretic techniques presented in Section III will be used in conjunction with the utilities of Section IV in order to switch-off certain BSs and achieve energy efficiency in the network. The proposed methods can be applied to any combination of macrocells and small cells in the network.

In the downlink (DL) direction of LTE, orthogonal frequency division multiple access (OFDMA) is used, whereas single carrier frequency division multiple access (SCFDMA) is used in the uplink (UL) direction [11]. The LTE spectrum is subdivided into resource blocks (RB) where each RB consists of 12 adjacent subcarriers. The assignment of a single RB takes place every 1 ms, which this the duration of one transmission time interval (TTI), or the duration of two 0.5 ms slots in LTE [12].

The data rates depend on the channel gain of each user on each subcarrier. The channel model adopted in this paper includes pathloss, lognormal shadowing, and Rayleigh fading.

This work was made possible by NPRP grant # 4-353-2-130 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

Intercell interference is also taken into account in the calculation of the signal to interference plus noise ratio (SINR), and thus affects the data rates achieved and consequently the resource allocation process. The details of the channel model, uplink and downlink SINR, interference, and data rate calculations can be found in [13] and are not repeated here due to space limitations.

When a user k joins the network, it is associated with the best serving cell l^*, i.e the cell having the available UL and DL RBs that maximize the user's performance. Assuming one UL RB and one DL RB are allocated for each user, this corresponds to the RBs for which the UL and DL subcarriers, $i^{*(\mathrm{UL})}$ and $i^{*(\mathrm{DL})}$, satisfy (1) and (2), respectively:

$$(i^{*(\mathrm{UL})}, l^*) = \arg\max_{(i,l)} \left(1 - \sum_{k_l=1; k_l \neq k}^{K_l} \alpha_{k_l,i,l}^{(\mathrm{UL})}\right) R_{k,i,l}^{(\mathrm{UL})} \quad (1)$$

$$i^{*(\mathrm{DL})} = \arg\max_{i} \left(1 - \sum_{k_l=1; k_l \neq k}^{K_l} \alpha_{k_l,i,l^*}^{(\mathrm{DL})}\right) R_{k,i,l^*}^{(\mathrm{DL})} \quad (2)$$

where $R_{k,i,l}^{(\mathrm{UL})}$ and $R_{k,i,l}^{(\mathrm{DL})}$ represent the UL and DL achievable data rates, respectively, of user k over subcarrier i in cell l. The first term in the multiplications of (1) and (2) indicates that the search is on the RBs that are not yet allocated to other users, where $\alpha_{k_l,i,l}^{(\mathrm{UL})} = 1$ if UL subcarrier i is allocated to user k_l in cell l. Otherwise, $\alpha_{k_l,i,l}^{(\mathrm{UL})} = 0$. The same rules apply for DL subcarriers.

A user is considered to be successfully served if the following conditions are satisfied:

$$\begin{cases} R_{k_l}^{(\mathrm{UL})} \geq R_{\mathrm{Target},k_l}^{(\mathrm{UL})} \\ R_{k_l}^{(\mathrm{DL})} \geq R_{\mathrm{Target},k_l}^{(\mathrm{DL})} \end{cases} \quad (3)$$

where $R_{k_l}^{(\mathrm{UL})}$ and $R_{k_l}^{(\mathrm{DL})}$ are the respective UL and DL data rates of user k_l in cell l, aggregated over all its allocated UL and DL subcarriers, respectively. $R_{\mathrm{Target},k_l}^{(\mathrm{UL})}$ and $R_{\mathrm{Target},k_l}^{(\mathrm{DL})}$ are the UL and DL target data rates, respectively, representing the QoS constraints. They can vary depending on the service used by the user. Hence, a user is considered to be in outage if at least one of the conditions in (3) is not met.

III. Proposed Game Theoretic Techniques

This section describes the two game theoretic methods proposed in this paper and implemented with the utilities presented in Section IV. The first approach presented in Section III-A is a cooperative coalition-based method where a group of BSs in a network are considered to form a coalition. The second approach presented in Section III-B is based on BS competition where each BS aims to maximize its own utility.

A. BS Coalition Approach

BSs in a certain geographical area are assumed to cooperate together by forming a coalition. Hence, the objective would be to maximize the benefits of the coalition as a whole, not of individual BSs. Considering there are N_{BS} BSs in the coalition, each having its own payoff function or utility, such that the utility of BS l is denoted by U_l, then the objective is to maximize the total utility of the coalition as follows:

$$\max_{\alpha_{k_l,i,l}^{(\mathrm{DL})}, \alpha_{k_l,i,l}^{(\mathrm{UL})}, P_l^{(\mathrm{DL})}, P_{k_l}^{(\mathrm{UL})}} \left(\sum_{l=1}^{N_{\mathrm{BS}}} U_l\right) \quad (4)$$

Subject to:

$$P_{k_l}^{(\mathrm{UL})} \leq P_{k_l,\max}^{(\mathrm{UL})}; \forall k_l = 1, ..., K_l; \forall l = 1, ..., N_{\mathrm{BS}} \quad (5)$$

$$P_l^{(\mathrm{DL})} \leq P_{l,\max}^{(\mathrm{DL})}; \forall l = 1, ..., N_{\mathrm{BS}} \quad (6)$$

$$\sum_{k_l=1}^{K_l} \alpha_{k_l,i,l}^{(\mathrm{UL})} \leq 1; \forall i = 1, ..., N_{\mathrm{sub}}^{(\mathrm{UL})}; \forall l = 1, ..., N_{\mathrm{BS}} \quad (7)$$

$$\sum_{k_l=1}^{K_l} \alpha_{k_l,i,l}^{(\mathrm{DL})} \leq 1; \forall i = 1, ..., N_{\mathrm{sub}}^{(\mathrm{DL})}; \forall l = 1, ..., N_{\mathrm{BS}} \quad (8)$$

$$\sum_{l=1}^{N_{\mathrm{BS}}} \frac{N_{\mathrm{out},l}}{N_{\mathrm{served},l} + N_{\mathrm{out},l}} \leq P_{\mathrm{out,th}} \quad (9)$$

The constraints in (5) and (6) indicate that the transmit power cannot exceed the maximum power for the UL and DL, respectively. The constraints in (7) and (8) correspond to the exclusivity of subcarrier allocations in each cell for the UL and DL, respectively, since in each cell, a subcarrier can be allocated at most to a unique user at a given scheduling instant. Finally, the constraint in (9) is related to enforcing QoS, where $N_{\mathrm{out},l}$ corresponds to the number of users in outage in cell l, i.e., the users associated with cell l as their best serving cell according to (1) and (2), but that were not able to satisfy their QoS requirements in (3). $N_{\mathrm{served},l}$ indicates the number of users served successfully in cell l. Hence, this constraint indicates that the total outage rate in the network should not exceed a tolerated outage threshold $P_{\mathrm{out,th}}$.

To perform this sum-utility maximization, Algorithm 1 is implemented. In this algorithm, we introduce two indicator variables: I_j^{ON} indicates if a BS j is on or off, by setting its value to 1 or 0, respectively, whereas I_j^{attempt} is a tracking parameter that indicates whether an attempt has been made to switch BS j off in the current iteration or not. It is set to 1 if the attempt was made and to 0 otherwise. The loop at Lines 1-4 is an initialization phase. In the Loop at Lines 5-23, the algorithm finds the BS having the weakest individual utility, then checks if the reassignment of its users to other BSs and putting it in sleep mode leads to an enhancement for the coalition's utility. If an enhancement is reached, the BS is switched off. Otherwise it is kept on. Then the algorithm moves to the next BS, and so on. The iterations are repeated until no improvement can be made in the sum-utility, even if an attempt is made on all the BSs that remained "on" (which in this case will lead to $\prod_{j=1; I_j^{\mathrm{ON}}=1}^{N_{\mathrm{BS}}} I_j^{\mathrm{attempt}} = 1$ and allows to exit the loop at Line 5).

In this approach, the BS acts in the benefit of the coalition by allowing its utility to be set to zero if this leads to an increase in the utility of the coalition. This can be implemented

Algorithm 1 Utility Maximization Algorithm

for all BS j **do**
  $I_j^{\text{ON}} = 1$
  $I_j^{\text{attempt}} = 0$
end for
while $\prod_{j=1; I_j^{\text{ON}}=1}^{N_{\text{BS}}} I_j^{\text{attempt}} = 0$ **do**
  Find: $j^* = \arg \min_{I_j^{\text{ON}}=1, I_j^{\text{attempt}}=0} U_j$
  for all k_{j^*} served by BS j^* **do**
    Implement (1) and (2) after excluding j^* from the BS search in (1); i.e the search is done over BSs $l \neq j^*$
  end for
  for all $j \neq j^*$ such that $I_j^{\text{ON}} = 1$ **do**
    Compute $U_j^{(\text{new})}$ obtained after moving the users k_{j^*} as described above
    Set $U_{j^*}^{(\text{new})} = 0$
  end for
  if $\sum_{j=1}^{N_{\text{BS}}} U_j^{(\text{new})} > \sum_{j=1}^{N_{\text{BS}}} U_j$ **then**
    for all j such that $I_j^{\text{ON}} = 1$ **do**
      Set: $U_j = U_j^{(\text{new})}$ and $I_j^{\text{attempt}} = 0$
      Set: $I_{j^*}^{\text{ON}} = 0$
    end for
  else
    No changes are made (Keep the old utility values)
    Set: $I_{j^*}^{\text{attempt}} = 1$
  end if
end while

in the case of centralized control in the coalition, or in the case of a single operator that would hardwire the intelligence of Algorithm 1 in all its BSs.

B. BS Competition Approach

In this section, we consider that BSs are competing selfishly to maximize their individual utilities. However, we consider that they negotiate the allocation of resources and users by communicating with each other. This corresponds in game theory to a bargaining game, where each player attempts to maximize its payoff (or utility) by bargaining with other players to share the resources in a way they cannot jointly improve on. The solution in game theory to this bargaining game consists of maximizing the Nash product, and it is known as the Nash bargaining solution (NBS) [14]. Hence, this translates into:

$$\max_{\alpha_{k_l,i,l}^{(\text{DL})}, \alpha_{k_l,i,l}^{(\text{UL})}, P_l^{(\text{DL})}, P_{k_l}^{(\text{UL})}} \left(\prod_{l=1}^{N_{\text{BS}}} U_l \right) \tag{10}$$

subject to the constraints (5)-(9). Since the logarithm is a continuous strictly increasing function, (10) is equivalent to:

$$\max \prod_{l=1}^{N_{\text{BS}}} U_l \Longleftrightarrow \max \ln \left(\prod_{l=1}^{N_{\text{BS}}} U_l \right) = \max \sum_{l=1}^{N_{\text{BS}}} \ln(U_l) \tag{11}$$

Interestingly, the algorithmic implementation of (11) can be handled by Algorithm 1, by using, in that algorithm, $U_l^{(\text{NBS})} = \ln(U_l)$ as the BS utility instead of U_l. Thus, to model a bargaining game in a practical network, bargaining "negotiations" do not need to take place between BSs, and the implementation of Algorithm 1 with $U_l^{(\text{NBS})} = \ln(U_l)$ is sufficient to lead to the NBS, i.e. to the equilibrium solution of the bargaining problem. Hence, with this approach, the BS knows it is achieving its best possible utility, given the utilities of the other BSs and the conditions of the network. Thus, the NBS solution can be hardwired in the BSs, even if multiple operators are involved (in this case, pricing and billing issues due to potentially moving subscribers of one operator to the BS of another by Algorithm 1 should be taken into account, e.g. by being included in a suitable utility).

IV. Utility Calculations

This section presents utility metrics used with the game theoretic methods of Section III. The utilities presented focus either on traffic load and QoS (Section IV-A), or on the QoS versus the consumed power in the network (Section IV-B).

A. Utility Based on Load and QoS Performance

In this section, we define a utility that depends on the traffic load and QoS performance of each BS. It is selected as follows:

$$U_l = N_{\text{served},l} \cdot \exp\left(P_{\text{out,th}} - \frac{N_{\text{out},l}}{N_{\text{served},l} + N_{\text{out},l}} \right) \tag{12}$$

The utility in (12) increases with the number of served users and decreases with the number of users in outage. When the outage rate exceeds the tolerated threshold $P_{\text{out,th}}$, the exponential term in (12) becomes negative and the utility decreases quickly towards zero. If no users are served by a certain BS, then $U_l = 0$ and the BS will be switched off by Algorithm 1.

In the NBS case, we have: $U_l^{(\text{NBS})} = \ln(U_l)$. However, to avoid having $\ln(0)$ in computer implementations, the utility needs to be redefined for boundary conditions. Thus, when a BS is "on", we set the utility to:

$$U_l^{(\text{NBS})} = \begin{cases} \ln(N_{\text{served},l}) + \left(P_{\text{out,th}} - \frac{N_{\text{out},l}}{N_{\text{served},l}+N_{\text{out},l}} \right); N_{\text{served},l} > 0 \\ -1 + \left(P_{\text{out,th}} - \min(N_{\text{out},l}, 1) \right); N_{\text{served},l} = 0 \end{cases} \tag{13}$$

When a BS is switched-off, we set $U_l = 0$ and $U_l^{(\text{NBS})} = 0$. In the NBS case with $N_{\text{served},l} = 0$, the utility in (13) will have a negative value. This will favor the switching-off of the corresponding BS by Algorithm 1, since this will lead to an increase in its utility (which will become zero).

B. Utility Based on Load and Power Consumption

In Section IV-A, the utility defined in (12) does not explicitly depend on the consumed power at the BS. In this section, we define a utility that reflects the number of served users versus the power consumption in the network. The selected utility is given by:

$$U_l = \frac{N_{\text{served},l}}{P_{\text{C},l}} \quad (14)$$

where $P_{\text{C},l}$ is the total power consumed by BS l (not to be confused with the transmit power at the antenna, which is included as a fraction of this power term). In general, utilities aiming at maximizing the sum rate while being concerned with energy efficiency can be defined in terms of bps/Hz/Watt. However, in this paper, the interest is in maximizing the number of served users satisfying the constraints in (3), while minimizing the power consumption in the network.

In the NBS case, we have: $U_l^{(\text{NBS})} = \ln(U_l)$. Thus, when a BS is "on", we obtain:

$$U_l^{(\text{NBS})} = \begin{cases} \ln(N_{\text{served},l}) - \ln(P_{\text{C},l}); N_{\text{served},l} > 0 \\ -1 - \ln(P_{\text{C},l}); N_{\text{served},l} = 0 \end{cases} \quad (15)$$

When a BS is switched-off, we have $U_l = 0$ and $U_l^{(\text{NBS})} = 0$.

V. Results and Discussion

In the simulations, a uniform user distribution is considered over a coverage area of size 5×5 km^2. BSs are placed on a rectangular grid uniformly in the area. The cell radii are set to $R_M = 0.5$ km and $R_S = 0.1$ km for macrocells and small cells, respectively. The transmit power is set to $P_{l,\max}^{(\text{DL})} = 10$ W for macrocell BSs, $P_{l,\max}^{(\text{DL})} = 1$ W for small cell BSs, and $P_{k_l,\max}^{(\text{UL})} = 0.125$ W for mobile devices. The power consumption is set to $P_{\text{C},l} = 500$ W for macrocell BSs and $P_{\text{C},l} = 100$ W for small cell BSs. The outage threshold is set to $P_{\text{out,th}} = 0.05$. We consider an LTE bandwidth of 10 MHz for each of the UL and DL directions, subdivided into 50 RBs. LTE parameters are obtained from [12], [15], and channel parameters are obtained from [16]. Different services are analyzed depending on their UL and DL target data rates. They are presented in Table I. Service 1 could correspond to a symmetric voice service, Services 2 and 4 are asymmetric services with different rates (e.g. comparable to fixed ADSL services), and Scenario 3 can represent a symmetric service with rates sufficient for video conferencing. It should be noted that significantly higher data rates can be reached compared to these services when the whole LTE bandwidth of 20 MHz (100 RBs) is allocated to a single user in the absence of interference. But these services are more realistic in the case of one RB allocated per user in a loaded network with high interference levels.

The simulation results are shown in Figs. 1 and 2. It can be seen that the coalitional approach outperforms the NBS approach since it leads to a lower number of active BSs, which leads to a lower power consumption in the network, as shown in Fig. 1, for both utilities (12) and (14). Fig 2 shows that both game theoretic techniques (coalition and NBS), when used with either of the utilities of Section IV, satisfy the QoS requirements by leading to an outage rate below $P_{\text{out,th}}$. However, it should be noted that the utility in (14) leads to a slightly worse outage performance, since it is not explicitly dependent on $N_{\text{out},l}$, conversely to the utility in (12), which is highly dependent on the increase of the number of users in outage.

TABLE I
Studied Scenarios

Scenario	$R_{\text{Target},k_l}^{(\text{UL})}$ (kbps)	$R_{\text{Target},k_l}^{(\text{DL})}$ (kbps)
Service 1	64	64
Service 2	56	256
Service 3	384	384
Service 4	384	1000

On the other hand, the utility in (14) is more sensitive to the power consumption. This is clearly seen in Fig. 1, where, although the number of active small cell BSs is comparable between the two utilities, the number of active macrocell BSs is obviously less with the utility in (14). This is particularly true with the coalitional game theoretic approach, where power consuming macrocell BSs are replaced by lower power small cell BSs, to an extent that the number of active macrocell BSs is zero most of the time. This is due to the "altruistic" behavior of BSs in the coalitional model, where the players act in the interest of the coalition as a whole. In the NBS case, where each player "bargains" to increase its own utility, the overall performance becomes worse than the coalition scenario. This translates into a higher number of active macro and small cell BSs, and a higher power consumption, although large gains are achieved compared to the "traditional" scenario where no BSs are switched-off: in such a scenario, the network power consumption in the simulated model is around 75 kW, even when the number of users is reduced.

VI. Conclusions and Future Work

A game theoretical framework was proposed for ensuring green energy efficient communications in heterogeneous LTE cellular networks. Two game theoretic concepts were studied within this framework: a coalition-based approach and a competition approach based on the Nash bargaining solution. Within each approach, the tradeoffs between QoS and energy consumption were investigated, depending on the utility selected. In fact, the game theoretic techniques were implemented with utilities focusing either on traffic load and QoS, or on the QoS versus the consumed power in the network. Results show that centralized coalition-based decision making leads to better performance, and that the utility can be selected to tune the results depending on the metrics of interest to the mobile operator.

Future work consists of investigating additional utility functions focusing on various combinations of metrics. In addition, BS power consumption models can be taken into account, where the impact of transition times for switching BSs on and off is considered. Furthermore, solar powered small cell BSs can be included in the network and their impact on reducing energy consumption can be studied. The game theoretic utilities in this case can be tuned to favor the use of BSs powered by renewable energy and reduce the usage of mains powered BSs.

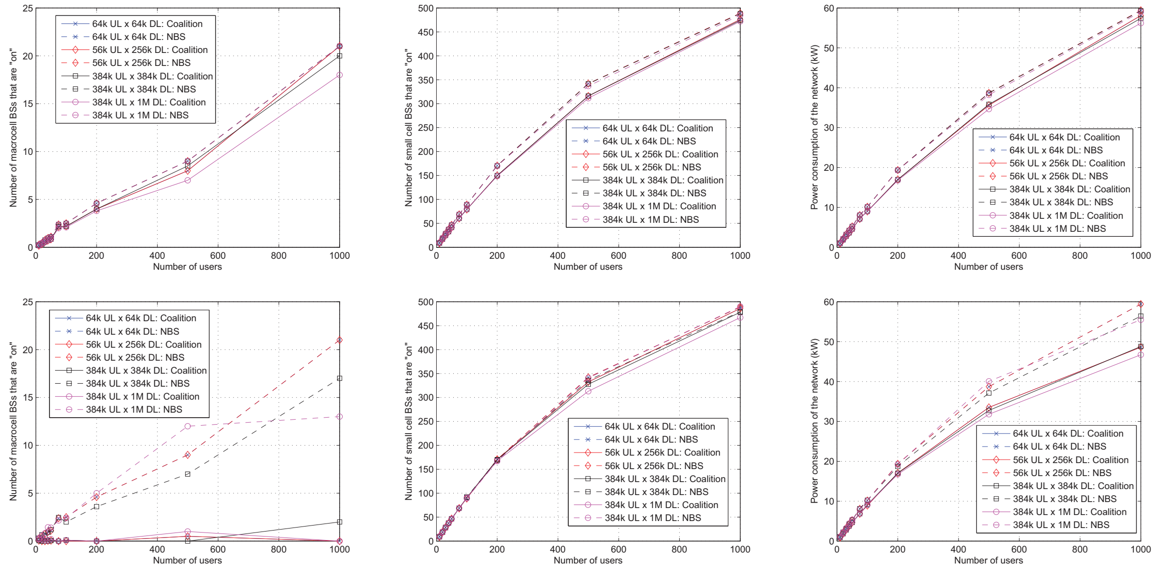

Fig. 1. Number of BSs switched on and network power consumption. Upper row: Utility (12). Lower row: Utility (14). Left: Macrocell BSs. Center: Small cell BSs. Right: Network power consumption.

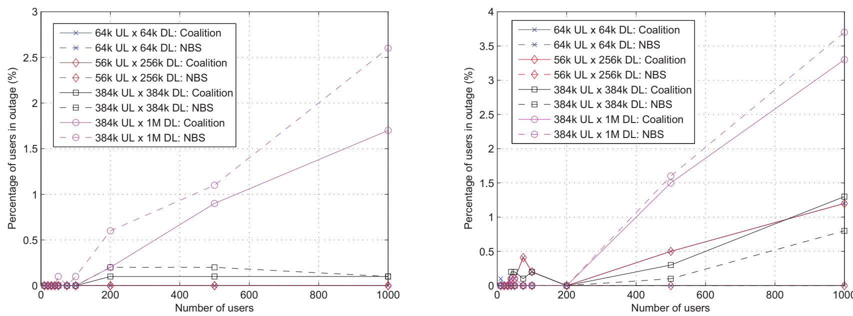

Fig. 2. Percentage of users in outage. Left: Utility (12). Right: Utility (14).

REFERENCES

[1] Z. Hasan, H. Boostanimehr, and V.K. Bhargava, "Green Cellular Networks: A Survey, Some Research Issues and Challenges," *IEEE Communications Surveys and Tutorials*, vol. 13, no. 4, pp. 524–540, Fourth Quarter 2011.

[2] A. Bousia, A. Antonopoulos, L. Alonso, and C. Verikoukis, "Green Distance-Aware Base Station Sleeping Algorithm in LTE-Advanced," *IEEE ICC 2012*, June 2012.

[3] T. Han and N. Ansari, "On Greening Cellular Networks via Multicell Cooperation," *IEEE Wireless Communications*, vol. 20, no. 1, pp. 82–89, February 2013.

[4] Z. Niu, Y. Wu, J. Gong, and Z. Yang, "Cell Zooming for Cost-Efficient Green Cellular Networks," *IEEE Communications Magazine*, vol. 48, no. 11, pp. 74–79, November 2010.

[5] L. Xiang, F. Pantisano, R. Verdone, X. Ge, and M. Chen, "Adaptive Traffic Load-Balancing for Green Cellular Networks," *IEEE PIMRC 2011*, September 2011.

[6] Y. Lan and A. Harada, "Interference Analysis and Performance Evaluation on the Coexistence of Macro and Micro/Pico Cells in LTE Networks," *IEEE VTC Spring 2012*, pp. 1–5, May 2012.

[7] X. Zhao and X. Yang, "Downlink Ergodic Capacity Analysis for Wireless Networks with Cooperative Distributed Antenna Systems," *IEEE ICC 2012*, pp. 5911–5915, June 2012.

[8] M. Salem, A. Adinoyi, M. Rahman, H. Yanikomeroglu, D. Falconer, Y.-D. Kim, E. Kim, and Y.-C. Cheong, "An Overview of Radio Resource Management in Relay-Enhanced OFDMA-Based Networks," *IEEE Communications Surveys and Tutorials*, vol. 12, no. 3, pp. 422–438, Third Quarter 2010.

[9] J. Hoydis and M. Debbah, "Green, cost-effective, flexible, small cell networks," *IEEE ComSoc MMTC E-Letter Special Issue on "Multimedia Over Femto Cells"*, vol. 5, September 2010.

[10] J. G. Andrews, "Seven Ways that HetNets Are a Cellular Paradigm Shift," *IEEE Communications Magazine*, vol. 51, no. 3, pp. 136–144, March 2013.

[11] H. G. Myung and D. J. Goodman, *Single Carrier FDMA: A New Air Interface for Long Term Evolution*. Wiley, 2008.

[12] 3rd Generation Partnership Project (3GPP), "3GPP TS 36.213 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical layer procedures, version 11.0.0, Release 11," 2012.

[13] E. Yaacoub, "Performance Study of the Implementation of Green Communications in LTE Networks," *International Conference on Telecommunications (ICT 2012)*, April 2012.

[14] F. Carmichael, *A Guide to Game Theory*. Prentice Hall, 2005.

[15] 3rd Generation Partnership Project (3GPP), "3GPP TS 36.211 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, version 11.0.0, Release 11," 2012.

[16] 3rd Generation Partnership Project (3GPP), "3GPP TR 25.814 3GPP TSG RAN Physical Layer Aspects For Evolved UTRA, v7.1.0," 2006.