

---

This is an electronic reprint of the original article.  
This reprint may differ from the original in pagination and typographic detail.

Hossain, M.M.; Cavdar, Cicek; Jäntti, Riku

## Dynamic capacity sharing based energy saving market for MNOs

*Published in:*

GLOBECOM 2017 - 2017 IEEE Global Communications Conference

*DOI:*

[10.1109/GLOCOM.2017.8254460](https://doi.org/10.1109/GLOCOM.2017.8254460)

Published: 01/12/2017

*Document Version*

Peer reviewed version

*Please cite the original version:*

Hossain, M. M., Cavdar, C., & Jäntti, R. (2017). Dynamic capacity sharing based energy saving market for MNOs. In *GLOBECOM 2017 - 2017 IEEE Global Communications Conference* (IEEE Global Communications Conference). IEEE. <https://doi.org/10.1109/GLOCOM.2017.8254460>

---

This material is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

# Dynamic capacity sharing based energy saving market for MNOs

M M Aftab Hossain and Cicek Cavdar  
Wireless@KTH,  
KTH Royal Institute of Technology, Sweden  
Email: {mmaho, cavdar} @kth.se

Riku Jäntti  
School of Electrical Engineering  
Aalto University, Finland  
Email:riku.jantti@aalto.fi

**Abstract**—As the larger share of total energy consumed by mobile network operators (MNOs) is wasted in order to ensure coverage, three to five MNOs covering the same geographical area results in enormous energy waste. In order to cater for the data tsunami with almost zero marginal revenue, required densification of cells are not sustainable from both Capex and Opex perspective. Even with densification of networks, it is hard to satisfy the performance requirement of the cell edge users due to interference. However, the performance can be upgraded as well as energy can be saved by the offloading of the cell edge users to other MNOs if regulator and MNOs resort to appropriate mechanism. In our previous work, we proposed a double auction based energy saving market mechanism where MNOs participate in bidding to share coverage and capacity in order to save energy, especially during low to medium load. Unlike previous work, in this paper we use this mechanism that involve cell level bidding, i.e., cells bid for each user which not only allows total offloading of the cells at the low load but also offloading of cell edge users among the MNOs during high load. As a result, the energy saving potential becomes very high also at high load conditions along with improvement in performance of cell edge users.

**Index Terms**—Energy market, Double auction, Multi-MNO Resource sharing, offloading, Mechanism design

## I. INTRODUCTION

The current trend of mobile data increase has been forecasted to continue at a compound annual growth rate of 53%, resulting a 8-fold growth from 2015 to 2020 [1]. Densification of cells are needed for this increasing traffic demand and upcoming 5G applications. However, it is understood that the revenue from meeting this excess capacity demand will not increase significantly or may not increase at all. This revenue gap poses a huge challenge to the MNOs to come up with sustainable business model. Note that traffic varies significantly throughout the day and network densification is mainly required to support during the busy hours. As a result, a huge percentage of BSs suffer energy waste with insignificant contribution to revenue as the energy consumption of BS does not scale proportionally with the load. In fact, a recent study shows that around 90% of total energy is consumed by the BSs to ensure only coverage [3] and the rest is consumed for transmitting actual user data. Unfortunately, in many countries, especially the developing ones, energy is a very precious resource and shortage of electricity impact important sectors, e.g., irrigation. Therefore, the MNOs are required to take resort to alternative ideas than network densification to reduce energy consumption. Fortunately, there are ways to cater for higher

capacity demand and also improve performance without further densification, e.g., by multi-MNO resource sharing. However, the MNOs consider their information sensitive and are not willing to share among them. In this paper, we propose a market mechanism that allows the MNOs to offload traffic among each other so that the energy consumption can be reduced significantly throughout the day and performance is improved during high load even without revealing their information among each other.

In recent years, extensive research has been carried out to improve energy efficiency in wireless network. Numerous studies suggest dynamic cell range so that a portion of the network can be switched off when network load becomes low [4], [5]. However, it is very difficult to maintain proper coverage while switching off arbitrary number of base stations (BSs). Mobile data offloading to Wi-Fi and small cells is another option [6]–[8]. However, they mainly boost capacity and energy is mainly wasted for coverage. The multi-MNO network sharing proposals range from sharing few sub-carriers to sharing everything, e.g., infrastructure, spectrum, capacity. In [9]–[11], cooperation among multi-MNOs has been suggested in order to accomplish greener operation. In [9], cooperation during off-peak hours has been studied by offloading one MNO’s users to the other. In [10], different techniques including inter-MNO cooperation has been discussed. A cooperative switching off scheme for both eNodeBs and small cells under multi-MNO heterogenous network has been proposed in [11]. However, it is difficult to implement in reality a collaborative scheme that requires sharing of information. In [12], an infrastructure-sharing algorithm has been proposed that encourages MNOs to share their resources and switch off redundant BSs during low traffic periods.

Double Auction (DA) has been proposed extensively as the mechanism to solve different problems in wireless network for both intra-MNO and inter-MNO setting, e.g., power and spectrum allocation, spectrum sharing [6], [13], [14]. In DA market mechanism, sellers compete with each other in order to attract buyers and the buyers compete among themselves and can offer bids for some or all the sellers. Normally, an independent auctioneer collects the bids and asks from the buyers and sellers respectively, determines the winning sellers and buyers, allocate the items from the sellers to the buyers and prices from the buyers to the sellers [15]. The main

motivation of using DA mechanism is the fact that the MNOs can participate in this dynamic market in order to make profit without revealing their private information which they consider sensitive. In [16], [17], we proposed DA based energy saving market among the MNOs. In [16], we show how the MNOs can offload cells during low load and benefit from offloading traffic at high load when the network loads are dissimilar. In [17], we provided a market mechanism that allows MNO(s) to offload totally and release their spectrum so that the active MNO(s) can serve the total traffic with the aggregated spectrum. However, we did not consider cell level analysis in previous work and the energy saving potential was significant at low to medium load only.

In this paper, we investigate the energy saving potential by allowing the MNOs to trade resources by establishing a DA based energy saving market. Under this mechanism, the MNOs participate in a bidding process where cells bids for each user in order to either offload cells totally (especially during the off peak hours) or offload cell edge users during busy hour in order to reduce total energy consumption along with enhancement of performance. We show that this mechanism still allows saving major share of energy at low load as it allows most of the cells to switch off. The saving percentage keep reducing with increase of load up to a certain point due to the requirement of more cells to be switched on. Once all the cells of all MNOs are required to be active to cater for the offered load, the saving percentage (compared to individual MNO operation) keep increasing with further increase in load as users are offloaded to the nearest BS of other MNOs. This huge energy saving at the high load condition along with improvement in throughput performance is very important to note as it gives a cost effective solution for the MNOs to combat huge peaks in the daily load profile and save Capex.

The rest of the paper is organised as follows: In Section II we provide the system models and assumptions and in Section III we formulate the energy minimization problem. In Section IV we provide the energy consumption model and evaluate energy consumption. In Section V we present the energy saving market. In Section VI, we illustrate the numerical analysis. We discuss about the technical challenges in Section VII and our paper closes in Section VIII.

## II. SYSTEM MODEL AND ASSUMPTIONS

We consider the down-link of I MNOs whose serving areas are overlapping in the same geographical area and each MNO consists of a set  $\mathcal{J} = \{1, \dots, j, \dots, J\}$  of cells. We consider hexagonal lattice for cells of each MNO. The BSs of different MNOs are not co-located. A BS serves only one cell, hence BS and cell is used interchangeably hereafter. Each BS is assumed to have its own power amplifier (PA). Note that we incorporate realistic PA efficiency model for traditional power amplifiers [18], [19]. Also, we consider that each BS is similarly loaded and hence the central cell represents the network of an MNO. However, while calculating interference for the central cell, interference from all the neighbouring cells of its own MNO has been taken into account. Let us consider a grid of a finite

set of locations  $\mathcal{K} = \{1, \dots, k, \dots, K\}$  in the cell  $j \in \mathcal{J}$  where a potential user is placed. Note that we consider homogenous distribution of the users in the cells in order to get a first insight about the average behaviour of the system, however, this mechanism is not limited to such distribution.

## III. PROBLEM FORMULATION

Our goal is to devise a mechanism that allows MNOs serving the same geographical area to minimize the total energy consumption and boost performance of cell edge users under heavy traffic load. With this purpose, the MNOs trade their users in this market mechanism. At low to medium load, MNOs can totally offload as many cells possible and at high load the cell edge users can be offloaded to a nearby BS of another MNO. We do not allow any cell to serve a user outside its service area which is predefined.

### A. Problem statement

#### Given:

- i) Energy that can be saved in each cell of any MNO by offloading a specific user.
- ii) Energy that is needed to serve if a cell of any MNO accepts a specific user from another MNO

#### Find:

Which users to be offloaded to which MNO.

#### Objective:

Minimization of total energy consumption in the geographical area where the MNOs service areas overlap.

### B. Notation and problem formulation

In order to formulate the energy minimization problem mathematically the following notations are used for variables and parameters.

#### Input parameters

$\mathcal{O}_{\mathcal{I}}$	set of MNOs; where $\mathcal{I} = 1, \dots, i, \dots, I$
$\mathcal{C}_{\mathcal{I}\mathcal{J}}$	set of cells; where $\mathcal{I} = 1, \dots, i, \dots, I$ ; $\mathcal{J} = 1, \dots, j, \dots, J$
$\mathcal{L}_{\mathcal{I}\mathcal{J}\mathcal{K}}$	set of user locations; where $\mathcal{I} = 1, \dots, i, \dots, I$ ; $\mathcal{J} = 1, \dots, j, \dots, J$ ; $\mathcal{K} = 1, \dots, k, \dots, K$
$E_{ijk}$	energy consumed to serve the user at location $k$ of cell $j$ of MNO $i$
$E_{mn,ijk}$	energy required if the user at location $k$ of cell $j$ of MNO $i$ is served by cell $n$ of MNO $m$
$\lambda_{ijk}$	packet rate for the user at location $k$ of cell $j$ of MNO $i$
$d_{mn,k}$	distance of user at location $k$ from the center of cell $n$ of MNO $m$
$r_{mn}$	radius of cell $n$ of MNO $m$
$C_{mn,k}$	binary variable is 1 if $d_{mn,k} \leq r_{mn}$ , i.e., if user at location $k$ is covered by cell $n$ of MNO $m$

#### Variables

$p_{ijk}$	binary variable is 1 if the user at location $k$ of cell $j$ of MNO $i$ is offloaded
$q_{mn,ijk}$	binary variable is 1 if $n$ -th cell of MNO $m$ accepts the user $k$ of cell $j$ of MNO $i$

The problem statement can be written as

$$\underset{\mathcal{P}, \mathcal{Q}}{\text{maximize}} \sum_i \sum_j \sum_k E_{ijk} p_{ijk} - \sum_i \sum_j \sum_k E_{mn,ijk} q_{mn,ijk} \quad (1i)$$

$$\text{s. t. } p_{ijk} = \sum_m \sum_n q_{mn,ijk}, \quad \forall i, j, k \quad (1ii)$$

$$\sum_k \lambda_{mnk} \leq \lambda_{max}, \quad \forall m, n \quad (1iii)$$

$$q_{mn,ijk} \leq C_{mn,k}, \quad \forall m, n, k \quad (1iv)$$

where  $\lambda_{mnk}$  is the packet arrival rate for the users at location  $k$  of cell  $n$  of MNO  $m$  after offloading of users. The first term of the objective function gives the total energy consumption of all the users that are offloaded to other MNOs and the second term gives the excess energy required to serve the offloaded users by the accepting MNOs. (1ii) ensures that if the user at the location  $k$  of cell  $j$  of MNO  $i$  is offloaded, it is offloaded to a single MNO, (1iii) ensures that the load of the accepting cell does not cross the threshold and (1iv) ensures that no cell picks a user outside its cell range.  $\mathcal{P}$  and  $\mathcal{Q}$  are matrix that keep the track of the users that are offloaded among the MNOs.

#### IV. ENERGY CONSUMPTION MODEL AND COMPUTATION

In this work, we model traffic at flow level and consider that flows are generated in the BS with rate  $\lambda_k$  packets per second and packet size  $S_k$  for the user at location  $k$  of cell  $j$  of any MNO. The transmission rate for the user at location  $k$ ,  $r_k$  is a function of the BS transmit power  $p$  and the interference received,  $I_k(\mathbf{p}_{-j})$ , received from other cells of the same MNO. The service time for a packet at location  $k$  is  $x_k = S_k r_k^{-1}$ . Let  $P_{PA}$  denote the total power consumed by the PA of the BS for the fixed downlink transmit power  $p$ . Note that we do not consider any downlink power control which is inline with current technology, LTE. The consumed power other than the PA consumption during the transmission and during the idle state is denoted by  $P_c$  and  $P_{idle}$  respectively.

The energy consumed to transmit a single packet at location  $u$  is

$$\begin{aligned} E_k(p_k, \mathbf{p}_{-j}) &= (P_{PA}(p_k) + P_c)x_k(p_k, I_k(\mathbf{p}_{-j})) \\ &= S_k \frac{P_{PA}(p_k) + P_c}{r_k(p_k, I_k(\mathbf{p}_{-j}))}. \end{aligned} \quad (2)$$

The total energy consumption for serving offered load,  $L = \sum_k S_k \lambda_k$  including the energy consumed during idle time can be written as

$$\begin{aligned} E_{tot}(L) &= \sum_{k \in \mathcal{L}_j} \lambda_k E_k(S_k) + \left(1 - \sum_{k \in \mathcal{L}_j} \lambda_k x_k\right) P_{idle} \\ &= \sum_{k \in \mathcal{L}_j} \lambda_k S_k \frac{P_{PA} + P_c - P_{idle}}{r_k} + P_{idle} \end{aligned} \quad (3)$$

where  $\sum_{k \in \mathcal{L}_j} \frac{\lambda_k S_k}{r_k} < 1$  is the queue stability constraint. Note that the fraction of time the server is busy, i.e.,  $\sum_{k \in \mathcal{L}_j} \frac{\lambda_k S_k}{r_k}$ , is the activity of a BS and is coupled among BSs due to

the dependence of achieved rate on received interference from neighboring cells.

In order to find the energy consumption at different locations for a given traffic load, we resort to iterative method to determine the activity of the BSs. Once the activity is determined, we use equation (2) along with  $\lambda_k$  in order to find the energy consumption for the users. Note that we model the BS as a single server processor sharing (PS) queue, i.e.,  $M/G/1$ -PS queue that serves the users in one-by-one fashion. This assumption allows a simple expression for the flow level throughput for proportional fair scheduling, i.e., the flow level throughput at location  $k$ ,  $\rho_k$ , becomes [20], [21]

$$\rho_k = \left(1 - \sum_{k \in \mathcal{L}_j} \frac{\lambda_k S_k}{r_k}\right) r_k. \quad (4)$$

#### V. MNO ENERGY MARKET

One of the main goals of this work is to devise a market mechanism that allows the trading among the MNOs so that i) a subset of all the cells end up carrying total load of a geographical area when the load is low and ii) the cell edge users are served by the other MNOs which have a BS closer to those users to save energy and enhance user performance. This energy market models the trading of the users among the cellular MNOs in order to minimize the network energy consumption. One particular key feature of our energy market is that each MNO submits both bids (i.e., offers to offload users) and asks (i.e., offers to accept users) simultaneously to a DA clearinghouse with the view to maximize their profit. The MNOs participate in the auction repeatedly where they submit asks and bids. In each round, MNOs revise their bids and asks based on their current user locations. The parameter values for each MNO, e.g., the users it wants to trade and the corresponding anticipated trade prices are private to each MNO and are not shared with other MNOs. The clearinghouse collects the bids and asks from each MNO and matches them following its criterion to minimize total energy consumption, determines the winning buyer and seller MNOs, trade price and quantity.

In order to generate the bid to offload a user, an MNO determines how much energy it can save by offloading that user. Similarly, in order to generate the ask to accept a user, it calculates the energy cost it suffers while accommodating that additional user. The clearinghouse use Preston McAfee's DA (PMD) protocol to determine the trade price,  $p_{trade}$ [22] and allocation process. The reason behind using PMD protocol is that it has the properties of being i) dominant-strategy incentive compatible, i.e., truthful bidding is the best strategy for the bidders, ii) budget balanced: auctioneer ends up with non-negative payments and iii) individual rational: bidders do not get worse by participating. However, PMD cannot always ensure maximum social welfare, i.e., efficiency. Note that no DA mechanism can ensure all these properties. The sacrifice in efficiency is required to make the bidding process incentive compatible, i.e., making the truthful bidding the preferred option to maximize the participants utility. In PMD protocol,

bids (**b**) and asks (**a**) are arranged in descending and ascending order respectively. Then lowest bid,  $b_j$  is identified such that  $b_j \geq a_j$  and  $b_{j+1} < a_{j+1}$ . The trade price that clears the market is determined as

$$p_{trade} = \frac{1}{2}(b_{j+1} + a_{j+1}) \quad (5)$$

If  $b_j \geq p_{trade} \geq a_j$ , the traded quantity is  $j$  and if  $b_j \leq p_{trade}$  or  $p_{trade} \leq a_j$ , the traded quantity is  $j - 1$ . The winning buyer for the last unit pays  $b_j$  and the winning seller for the last unit receives  $a_j$ .

#### A. Bid and ask generation

Each MNO  $i$  submits both bid and ask for the user at each location  $k$  of any cell  $j$ . The bid equals to the amount of energy it is going to save if it offloads the user. Similarly, the ask for a user at the same equals to the excess energy it requires to serve that user at that location. The bid and ask offered for a user at location  $k$  of cell  $j$  by MNO  $i$  are assumed to be equal. This assumption is based on the fact that MNOs rarely operate with very high load and hence the excess energy part due to increase in interference from joining a new user is ignored. In fact, after the offloading of the cell edge users, interference is expected to get reduced. So, the bid and ask submitted by MNO  $i$  for a user at location  $k$  of any cell  $j$  is given by

$$b_{ijk} = a_{ijk} = E_{ijk}$$

where  $E_{ijk}$  is the energy consumption by the MNO  $i$  in order to serve the user at location  $k$  of cell  $j$ . Note that the ask for the user at location  $k$  of cell  $j$  of MNO  $i$  offered by the cell  $n$  of MNO  $m$ ,  $a_{mn,ijk} = E_{mn,ijk}$ . Let us represent the set of all bids for the users of all locations of all MNOs by  $b_{\mathcal{I}\mathcal{J}\mathcal{K}}$  and similarly the asks by  $a_{\mathcal{I}\mathcal{J}\mathcal{K}}$ .

#### B. Utility of the MNOs

Once the clearinghouse find the social optimal allocation that minimizes the total energy consumption, the maximum of the rest of the asks (i.e., the unsuccessful asks) and the minimum of the rest of the bids (i.e., the unsuccessful bids) are used as the input in (5) to determine the trade price,  $p_{trade}$ . When the  $p_{trade}$  is determined, the utility of the offloading  $i$ -th MNO for the user at  $k$ -th location of  $j$ -th cell is determined as

$$U_{ijk} = b_{ijk} - p_{trade}$$

and the utility of the  $m$ -th MNO to accept a user at location  $k$  of cell  $j$  of MNO  $i$  is given by

$$U_{mn,ijk} = p_{trade} - a_{mn,ijk} \quad (6)$$

where the  $n$ -th cell of  $m$ -th MNO accepts the user at location  $k$  of cell  $j$  of MNO  $i$ .

#### C. Clearinghouse mechanism

The target of the auctioneer is to maximize the social welfare (SW) in (1i), i.e., minimize the total energy consumption in the service area. In any geographical area, there are normally 3 to 5 overlapping MNOs. Also, the traffic varies significantly

throughout the day. During off-peak hours, it is possible that a lot cells can be totally offloaded. If a cell offloads totally, there is a huge energy saving due to the fact that each BS consumes enormous static energy in order to stay active. As a result, the social optimal solution requires as many BSs possible to be totally offloaded. In order to solve the clearinghouse problem, first we consider the possibility of total offloading. However, random shutting down of BSs from different MNOs might yield maximum energy saving but that is not feasible from the QoS point of view. As it is very difficult to ensure proper coverage by such switching off, we make two assumptions, i) we keep all the cells of one of the MNOs always on and ii) we start from the lowest loaded cell to be offloaded first. However, we check which MNO being on yields maximum saving. The reason behind starting with the lowest loaded cell to be offloaded is to ensure least handover in the serving zone and highest energy saving due to the dominating static energy consumption.

In order to maximize energy saving keeping this facts in mind, first, we consider the cases where cells can be totally offloaded. In order to do that

i) we consider all the cells of any MNO  $i$  to be on. We find the least loaded cell among the other MNOs and for each user of that cell we find the MNO whose ask is minimum. Note that in case of total offloading of a cell, we divide the static part of energy consumption of the BS among the users in proportional to their dynamic energy consumption (i.e. transmit energy) and update the bid for each user accordingly. Each user is offloaded to the cell with minimum ask only provided the asking cells own loads do not exceed its capacity constraint. If a cell offloads all of its users, the cell is registered as switched off and is not considered eligible to accept users from other cells in that round. We repeat the similar process for all the cells except the cells of the MNO  $i$ . Once all the cells are identified which can be totally offloaded, we store the offloaded cells and total utility achieved by the operators through DA mechanism. In the next step, we consider the offloading of users among the active cells of different MNOs. In each case, a user is offloaded if there is an valid ask from another MNO (i.e. ask is less than the bid of the serving MNO and the capacity threshold of the accepting MNO is not violated). For each offloading (total of partial for a cell), in order to find the trade price we consider the highest of the unsuccessful asks and lowest of the unsuccessful bid. From the trade price, the corresponding total utility is calculated and stored.

ii) Similar procedure is repeated by keeping each of the MNO  $i \in I$  active.

iii) Finally, among these  $I$  cases, the one yielding maximum utility, i.e., maximum energy saving is chosen.

#### D. Incentive to be truthfull

In order to show that the mechanism is incentive compatible (i.e., every MNO can achieve its best outcome just by offering truthful bid and ask), we need to show that no MNO benefit from increasing its ask or lowering its bid. In this market mechanism, the trade price for a user to be offloaded is

---

**Algorithm 1** Clearinghouse Algorithm

---

**Input:**  $O_I, C_{IJ}, L_{IJK}, b_{IJK}, a_{IJK}$ **Output:**  $SW, \mathcal{P}, \mathcal{Q}, \mathcal{U}$ 

```
1: set of MNOs,  $S_I$ ;  
2: set of cells  $S_C \leftarrow \{S_{IJ}\}$   
3: set of locations  $S_L \leftarrow \{S_{IJK}\}$   
4: sets of bids  $S_B \leftarrow \{b_{IJK}\}$   
5: sets of asks  $S_A \leftarrow \{a_{IJK}\}$   
6:  $SW \leftarrow 0, p_{trade} \leftarrow 0$   
7: for all  $S_I$  do  
8:  $S_{C,temp} \leftarrow S_C \setminus S_{iJ}$  {All cells of MNO  $i$  remains active}  
9: sort  $S_{C,temp}$  in ascending order with respect to load  
10: for all  $S_{C,temp}$  do  
11: update bids of the users to distribute static energy  
12: offload all users (considering capacity constraints), mark offloaded cell inactive  
13: update  $SW, \mathcal{P}, \mathcal{Q}, \mathcal{U}$  using DA mechanism {  $\mathcal{U}$ , set of utilities of the cells }  
14: end for  
15: set of active cells  $S_{CA}$   
16: for all  $S_{CA}$  do  
17: DA mechanism to offload users  
18: update  $SW, \mathcal{P}, \mathcal{Q}, \mathcal{U}$   
19: print  $SW, \mathcal{P}, \mathcal{Q}, \mathcal{U}$   
20: end for  
21: end for
```

---

determined by the maximum of the unsuccessful asks and the minimum of the unsuccessful bids for that user. Therefore, submitting an untruthful inflated ask or untruthful reduced bid do not result in any immediate gain. However, note that the ask and bid submitted by any MNO for a particular location based user is the same. As a result,

i) increasing the ask to accept a user at a particular location increases the bid for its own user at that location as well. Consequently, an untruthful inflated ask (i.e., inflated bid) by a cell not only reduces the chance of acceptance of the user but also increases the chance of offloading its own user at that location as the inflated bid yields higher welfare through offloading compared to accepting a user from another MNO. For these reasons, the cell might end up offloading the user instead of accepting a user at that location and reduce its utility.  
ii) Similar reasoning also holds for reducing the bid. For these reasons, the truthful bidding maximize the utility which makes the mechanism incentive compatible.

## VI. NUMERICAL ANALYSIS

We consider the network of each MNO consisting of 19 regular hexagonal cells where wrap around technique has been employed to avoid border effects. We also assume that the BSs of different MNOs are not co-located and in order to get some first insight we assume all the cells are offered same load. Hence, the energy consumption in the central cell represents the average energy consumption of the network. A grid of 64

TABLE I  
SIMULATION PARAMETERS

Reference parameters	
Parameter	Value
Number of cells	19
Grid size inside each cell	64 points
Cell radius	1 km
PA maximum output power, $p_{max,PA}$	53 dBm
Maximum average BS transmit power, $p$	46 dBm
Maximum PA efficiency at $p_{max,PA}$	80%
Path loss exponent	3.6
Shadow fading standard deviation	5.5 dB
Bandwidth	20 MHz
Noise level	-106 dBm
Target outage	10%

points emulating the possible locations of users is generated inside each cell. As the energy required for processing packets at the BS is negligible, we consider the power consumed during idle mode and the static energy consumption during transmission as equal, i.e.,  $P_c = P_{idle}$ . For TPA we use  $P_{idle} = 58.6W$  as derived in [23] based on the values given in [24]. The parameter settings for a network are summarised in the Table I [19]. We consider 3 MNO for this numerical analysis and we produce results considering two maximum capacity constraints of the cells at 80% and 90% .

### A. Energy saving potential

In Figure 1, we present the energy saving potential if three MNOs participate in the energy saving market. We compare the energy consumption after the mechanism with the total energy consumption of the MNO's individual operation. One can see that the energy saving potential is very high at very low load as all the cells of two MNOs can be totally switched off. However, when load keeps increasing, the energy saving potential reduces as more and more number of cells are required to be activated to provide the required capacity. After a certain point, when all the cells are required to be active, further increase of load increases the saving potential as dynamic energy consumption becomes significant and the energy consumption is reduced due to the cell edge users being offloaded to other MNOs. One can see that with 80% cell load threshold, the MNOs can handle 100% load from individual operation. This is due to the fact that through this mechanism each cell ends up serving smaller area, hence path-loss to the users and interference gets reduced.

### B. Quality of service

In Figure 2, we show the QoS (average throughput per user) for both the individual operation and combined operation with offloading . One can see that, there is a loss in average

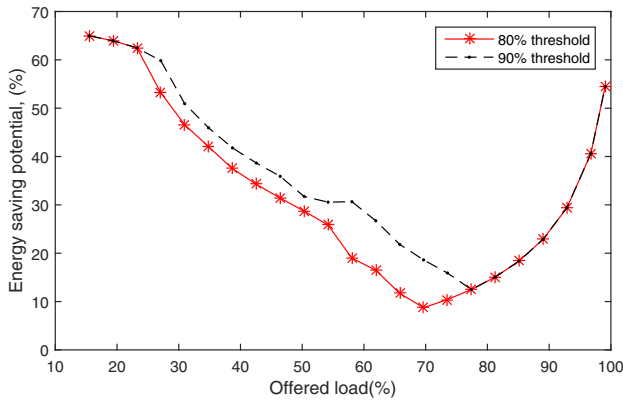


Fig. 1. Energy saving potential when three MNOs participate compared to their individual operations

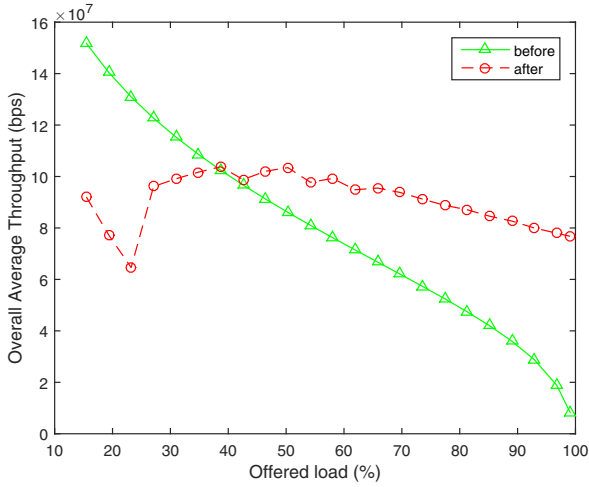


Fig. 2. Comparison of throughput before and after the double auction mechanism.

throughput during low load, as only one MNO is carrying the load of three MNOs. However, during low load, the MNOs serve few number of users, as a result the users will not perceive this degradation of average throughput. On the other hand, when the load requires the switching on of the cells other than the always one MNO, the average throughput starts increasing again. This is due to the fact that the users are served by the closest BS of any operator which reduces the path loss as well as interference.

### C. Utility of individual operators

In Figure 3, we present the individual cost saving of each MNO. We express both the utility of the offloading and accepting operators in terms of energy cost. One can see that the MNOs can save huge percentage of energy cost by adopting this market mechanism. The individual trend follows the combined energy saving as shown in Figure 1. One can also see that there is some difference in energy saving potential among the MNOs even though we consider the MNOs are similarly and uniformly loaded. This anomaly comes from the fact that the trade price for each transaction has been

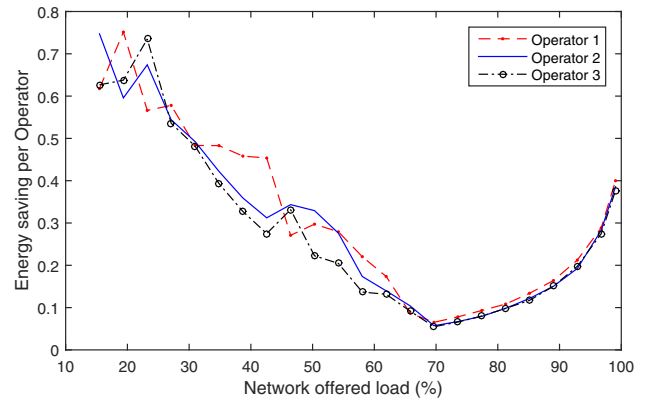


Fig. 3. Individual utility of each MNO in terms of their energy saving after the mechanism

determined by the average of the highest of the unsuccessful asks and lowest of the unsuccessful bids in order to ensure the truthful bidding.

## VII. CHALLENGES

Even though the customers of one MNO can already roam seamlessly in the other MNO's network [25], several other technical challenges need to be addressed to reap the benefit of this multi-MNO energy saving scheme. Hiding the identity of the users might be another issue to look at. Routing traffic through the auctioneers server might be one solution to mask the identity, so that the participating MNOs can only know about the aggregate traffic but not any information of the individual MNOs traffic. In reality the MNO's are rarely similar in size and different MNOs have different number of BS. However, this diversity does not pose any threat to the feasibility of this mechanism. Time granularity to conduct a new round of auction is another issue that need to be investigated further.

## VIII. CONCLUSION

The data tsunami with almost zero marginal revenue is pressing the MNOs to reduce their Capex and Opex. By adopting appropriate mechanism and policy, e.g., national roaming, multi-MNO capacity sharing, it is possible to reduce network cost for operators, save energy for the society and reduce environmental impact of CO2 emission. In this paper, we have shown that DA is a suitable mechanism for multi-MNO capacity sharing which make sure that the MNOs privacy of information is not violated. Our proposed energy saving market is a very efficient one as it allows saving huge percentage of energy not only during the low load condition but also when the load is very high. Also, it is accompanied by huge improvement in quality of service. Note that in this study we do not consider energy saving features in a network during the off-peak hours which might impact the reported saving percentage during those hours. Also, we do not consider the change in energy consumption due to the change of interference when a user is exchanged during generation of bid and ask. However, the networks usually does not operate with such high load

where this change would be significant. Also, the interference always reduces significantly when the users are offloaded to the nearest BS.

#### ACKNOWLEDGMENT

This work was supported by Academy of Finland funded FUN5G, and EU Celtic Plus project, Service Oriented Optimization of Green Mobile Networks (SooGREEN).

#### REFERENCES

- [1] "Cisco Visual Network Index," Mobile Forecast Highlights, 2015 - 2020. Available online: [http://www.cisco.com/assets/sol/sp/vni/forecast\\_highlights\\_mobile/](http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/)
- [2] Blume O. *et al.*, "Energy savings in mobile networks based on adaptation to traffic statistics," *Bell Labs Technical Journal*, vol. 15, no. 2, pp. 77-94, 2010.
- [3] Pal Frenger, Marten Ericson, "Assessment of Alternatives for Reducing Energy Consumption in Multi-RAT Scenarios," in *Proc. VTC* Spring 2014.
- [4] Marsan, M.A *et al.*, "Multiple daily base station switch-offs in cellular networks," in *ICCE* pp.245,250, 1-3 Aug. 2012.
- [5] Yong S. S. *et al.*, "Energy Efficient Heterogeneous Cellular Networks," *IEEE Jour. Selected Areas*, vol.31, no.5, pp.840-850, May 2013.
- [6] Iosifidis, G. *et al.*, "An iterative double auction for mobile data offloading," in *Proc. WiOpt*, 2013 pp.154-61, 2013.
- [7] Dimatteo, S. *et al.*, "Cellular Traffic Offloading through WiFi Networks," in *Proc. IEEE MASS*, pp.192,201, 17-22 Oct. 2011.
- [8] Lin G. *et al.*, "Economics of mobile data offloading," in *proc. IEEE INFOCOM WKSHPs*, 2013 pp.351,356, 14-19 Apr. 2013.
- [9] Marsan M.A., and Meo M., "Energy efficient wireless Internet access with cooperative cellular networks," *Elsevier Journal Computer Networks* 55 (2), pp.386-398, 2011.
- [10] Oh E. *et al.*, "Toward dynamic energy-efficient operation of cellular network infrastructure," presented at *IEEE Commun. Mag.*, pp.56-61, 2011,.
- [11] Oikonomakou M., "Cooperative base station switching off in multi-operator shared heterogeneous network," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2015, pp. 1-6.
- [12] Bousia A., "Game-Theoretic Infrastructure Sharing in Multioperator Cellular Networks," in *IEEE Trans. on Vehicular Tech.*, vol. 65, no. 5, pp. 3326-3341, May 2016
- [13] Wenchao X.; Jiangzhou W., "Double auction based spectrum sharing for wireless operators," in *Proc. PIMRC*, 2010, pp.2650,2654, 26-30 Sep. 2010
- [14] Iosifidis, G.; Koutsopoulos, I., "Double auction mechanisms for resource allocation in autonomous networks," *IEEE J. Selected Areas in Commun.*, vol.28, no.1, pp.95-102, Jan. 2010
- [15] Iosifidis G. and Koutsopoulos I., "Auction driven market mechanisms for dynamic spectrum management," in *Mechanisms and Games for Dynamic Spectrum Allocation* Cambridge University Press, 2013
- [16] Hossain M. M. A., Jäntti R. and Cavdar C., "Energy saving market for mobile operators," *IEEE ICC Workshop (ICCW)*, London, 2015, pp. 2856-2861
- [17] Hossain M. M. A., Jäntti R. and Cavdar C., "Traffic offloading based energy saving market for cellular operators," *IEEE ICC workshop (ICCW) 2017*, Paris.
- [18] Hossain M. M. A. and Jäntti R., "Impact of efficient power amplifiers in wireless access," *Online Conference on Green Communications* pp.36-40, Sep. 2011.
- [19] Hossain M. M. A. *et al.*, "Minimum energy power and rate control for fair scheduling in the cellular downlink under flow level delay constraint," in *IEEE Trans. Wir. Commun.* vol .12, issue 7, 2013
- [20] T. Bonald *et al.*, "A queuing analysis of max-min fairness, proportional fairness and balanced fairness," *Queue. Syst.*, vol. 53, pp. 65-84, 2006.
- [21] T. Bonald, "Throughput Performance in Networks with Linear Capacity Constraints," in the *Proc. of Annu. Conf. on Inform. Sci. and Syst.*, pp. 644-649, 2006.
- [22] R. Preston McAfee, "A dominant strategy double auction," in *Jour. of Economic Theory* Volume 56, Issue 2, pp. 434-450, Apr. 1992.
- [23] M. M. A. Hossain *et al.*, "Energy Efficient Deployment of HetNets: Impact of Power Amplifier and Delay," in *Proc. IEEE WCNC*, 2013.
- [24] Auer G. *et al.*, D2.3: Energy efficiency analysis of the reference systems, areas of improvements and target breakdown. INFSO-ICT-247733 EARTH, ver. 2.0, 2012. [Online]. Available: <http://www.ict-earth.eu/>
- [25] Network-sharing, Nokia networks, [Online] Available: [www.networks.nokia.com/portfolio/solutions/network-sharing](http://www.networks.nokia.com/portfolio/solutions/network-sharing)