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Energy Efficient Dynamic Cooperating Set Planning for CoMP in LTE/LTE-A Systems

*Jen-Jee Chen[1], Jia-Ming Liang[2], Po-Min Hsu[3], and Yi-Chan Huang[1]
[1]Dept. of Electrical Engineering, National University of Tainan, Tainan, Taiwan
[2]Dept. of Computer Science and Information Engineering, Chang Gung University, Taoyuan, Taiwan
[3]Dept. of Electrical Engineering, National Cheng Kung University, Tainan Taiwan
*jjchen@mail.nutn.edu.tw

Abstract—Coordinated Multi-Point (CoMP) **is considered as one of the most important techniques in 3GPP LTE/LTE-A. In CoMP, several base stations can be grouped together to form the *cooperating set*, where the cooperating set is used to improve the system throughput as well as the throughput of cell edge users. Most of the studies discussed how to relieve the overload condition or maximize the system throughput by exploiting CoMP. In these studies, static cooperating set is adopted, i.e., the size of the cooperating set is fixed. Different from previous studies, this paper provides a complete discussion by considering both off-peak hours and overload conditions. In off-peak hours, we try to save the transmit power of base stations and utilize the idle radio resource to achieve energy-efficient green communications while guarantee users' service quality. On the contrary, when big activities occur with gathered crowds or during the peak hours, we propose to dynamically form the cooperating set according to the actual traffic demand condition and adapt the transmit power of base stations, so that the system can effectively offload the traffic demand to the member cells with free radio resource in the cooperating set. Our proposed approach is a decentralized-based method, which avoids excess computing being executed in a base station. Simulation results show that our proposed method achieves the best system throughput, radio resource utilization, and energy efficiency in all schemes.**

Keywords—Long Term Evolution-Advanced (LTE-A); energy efficiency; CoMP; cooperating set; Dynamic Cell Selection (DCS); resource management; Soft Frequency Reuse (SFR)

I. INTRODUCTION

Over the last decade, cellular networks have evolved from ubiquitous coverage for voice services to "anytime-anywhere" available for high bandwidth data services. Given the worldwide growth in the number of mobile subscribers, and the increasing contribution of information technology to the overall energy consumption of the world, there is a need to reduce the energy requirements of radio access without significantly compromising the quality of service (QoS) experienced by the users [1].

To support large number of devices to access wireless networks at the same time, Long-Term Evolution (LTE)/LTE-Advanced (LTE-A) networks [2] is developed to provide users high data rate up to tens or hundreds of Mb/s. Furthermore, a variety of new technologies, such as Coordinated Multi-Point (CoMP) [3][4][5], relay networks, and femtocells with collocation of 4G networks, are presented to enhance the system throughput and satisfy user's QoS (Quality of Service). This paper thus focuses on CoMP and energy efficiency in the 4G LTE-A network. CoMP is considered as one of the most important techniques in 3GPP LTE/LTE-A. CoMP is classified into two categories. The first is *Coordinated Scheduling and/or Beamforming (CS/CB)* [6][7][8]. The second is *Joint Processing (JP)*. In terms of the transmission mode, JP can be further assorted into two types: *Joint Transmission (JT)* [6][9] and *dynamic cell selection (DCS)* [10][11][12]. The former delivers the data of a mobile equipment by scheduling a couple of base stations (BSs) to transmit at the same time, which can improve the receiving signal quality of users. The latter allows the cooperating set to dynamically select users, but the BS doesn't have to be the user's serving cell. In the paper, we focus on DCS, which as mentioned above can dynamically assign the transmitting BSs for users. The cooperating set can thus share free resource of member cells with the overloaded cells. Exploiting this feature, we propose the concept of the *dynamic cooperating set*. When cells have to serve gathered crowds in the big activities, such as gala parades, the demands of wireless communication in such areas are always over the capacity of serving base stations. At this moment, the system can dynamically organize the BSs around the overloaded base stations to compose cooperating set to meet the people's necessities and enhance the system efficiency and throughput. On the contrary, in off-peak hours, since the base station is in a low load condition, we can choose to reduce the base station's output power for power saving. This can not only decrease the energy consumption of base stations, but also improve the utilization of radio resources. Note that the output power reduction must be acted on the premise that users Quality of Service (QoS) is guaranteed.

There are several researches discussing the dynamic cell selection and cooperating set. In [13], the LDA-SFR (Load Distribution Aware-Soft Frequency Reuse) scheme partitions the cells into groups and each group comprises seven base stations. For each group, the center of each base station uses the same frequency and transmits with less power, while the cell edges of the seven cells use different frequencies and transmit with larger power than the center. Though LDA-SFR can avoid Inter channel Interference (ICI), the frequency reuse of the cell edge is only 1/7. In an LTE heterogeneous network, reference [14] proposes to achieve load balancing by dynamic cell adapting pico-eNBs cell sizes according to the network load and traffic distribution. In [15], an adaptive soft frequency reuse algorithm is proposed, which dynamically allocate subcarriers and transmit power to each cell to maximize the soft frequency reuse system capacity. Reference [16] assumes each BS has 3 sectors and only considers static cooperating set. Each cooperating set are comprised by the dynamically selected sectors according to historical information. In [17], a cooperative frequency reuse scheme is proposed, which divides the cell-edge area of each cell into two types of zones, and defines a frequency reuse rule to support CoMP transmission for users in these zones. The frequency reuse scheme with CoMP improves the frequency efficiency.

In this paper, we exploit power allocation and CoMP to achieve energy efficient and load balancing communication networks. In off-peak hours, the radio resource utilization and energy efficiency are usually low if BSs output power as usual. So, our method will enter power saving mode to reduce the transmit power of BSs while still maintain users' QoS. When big activities occur with gathered crowds, the amounts of wireless communication demands in such areas are always over the capacity of serving BSs. In this case, the static cooperating set can bring only limited help and fail to adapt to the actual conditions. Different from the aforementioned static cooperating set schemes, we propose the dynamic cooperating set with adapted transmit power to solve the overload problem.

The remainder of this article is as follows. Sec. II describes our system model and formulates the problem. In Sec. III, we present our proposed energy efficient dynamic cooperating set planning algorithm. Simulation results are shown in Sec. IV. Finally, we conclude the paper in Sec. V.

II. System Model And Problem Definition

A. System Model

LTE-A uses Orthogonal Frequency Division Multiple Access (OFDMA) technology in downlink. In OFDMA systems, User Equipment (UEs) simultaneous data transmission activities will interfere with each other if they adopt the same frequency. To avoid this, we adopt traditional SFR model [18][19][20][21] to mitigate interference and ICI and enhance frequency efficiency. SFR model is as shown in Fig. 1, we can see that 3 cells consist of a frequency reuse unit. Each cell contains center and edge areas. Frequency band is partitioned into 3 subbands, F_1, F_2 and F_3, where each cell edge in a frequency reuse unit allocates different frequency subband, F_1, F_2 or F_3, as shown in Fig. 1, while the center of each cell uses the frequency subbands other than that of its cell edge, i.e., in Fig. 1, the edge area of cell 1 allocates subband F_3 while the center area allocates F_1 and F_2. To effectively reduce the ICI, subbands of centers are allocated low power while the subband of edges is allocated high power. So the system can mitigate interference problem by SFR model. Other spectrum allocation schemes can also be combined with our proposed method (not limited to SFR), but this is not within the scope of this article.

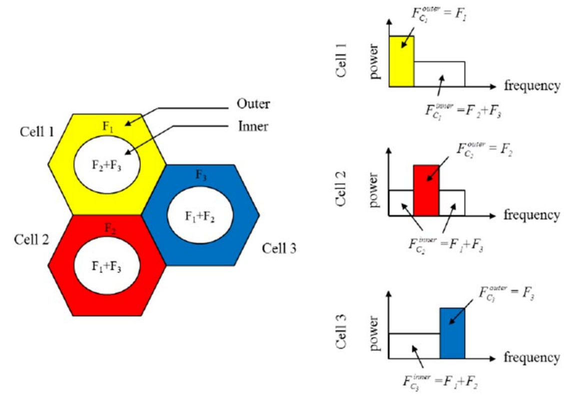

Fig. 1. SFR model.

The cell edge area is covered by multiple cells. When the resource of a cell is not enough, transferring some UEs in the cell edge to other adjacent cells by DCS can achieve the goal of offload. Previous work usually use a fixed cooperating set [13][16]. Although these schemes work and are simple, they are inflexible and cannot fit the cooperating set to the actual traffic situation, which is actually changed time to time. This motivates us to propose the concept of dynamic cooperating set combined with DCS. According to the actual traffic situation, a dynamic cooperating set based scheme can dynamically invite proper adjacent cells to organize cooperating set, such that more users can be served and the system resource can be efficiently utilized.

To evaluate the channel quality, we use the Signal to Interference plus Noise Ratio (SINR) model. Based on the received SINR, the system selects a suitable MCS for a UE. TABLE I shows the MCS and its required received SINR. If the SINR value of a UE is high (resp., low), it can use high (resp., low) level MCS.

TABLE I. TABLE STYLES

Modulation	Code rate	SINR(dB)
16QAM	1/2	7.9
	2/3	11.3
	3/4	12.2
	4/5	12.8
64QAM	2/3	15.3
	3/4	17.5
	4/5	18.6

B. Problem Definition

Our problem is defined as follows: We assume that in the LTE network, there are *M* cells and *N* UEs. For each UE_i,

i=1..N, it has an average data rate δ_i bits/s. In off-peak hours, large amount of radio resource is idle. We consider how to reduce the output power of base stations on the premise that the service quality of users can still be met. Thus, the energy consumption of base stations can be reduced and the utilization of radio resource can be improved. On the other hand, when in peak hours or a big activity occurs with gathered crowds, we show how to dynamically organize the cooperating set initiated from the overloaded area by inviting the surrounding BSs according to the actual traffic distribution and the status of the neighbor BSs. Via these neighbor base stations with free resource, we can balance the load (or offload) in the cooperating set by DCS and power adaptation, thus more users can be served. Then the system throughput can be significantly increased and the system resource can be effectively utilized.

III. OUR PROPOSED ALGORITHM

Our proposed algorithm considers both off-peak and peak hours. In off-peak hours, we execute the *power-saving resource allocation sub-algorithm* to schedule resource and power in an energy-saving way. When a big activity occurs with gathered crowds, we exploit dynamic cooperating set, DCS, and power adaptation to offload the crowded area. The offload method is composed of two sub-algorithms, *dynamic cooperating set planning sub-algorithm* and *transmit power allocation sub-algorithm*, which are described in Section III.B and III.C, respectively.

A. Power-Saving Resource Allocation (PSRA) Sub-algorithm

The procedure of the power-saving resource allocation in off-peak hours is as follows. We assume that initially each BS itself is an independent and single cell cooperating set. The first step is to estimate each user j's required TTIs according to its demand r_j. Assume that we can evaluate each user's channel condition and interference by existing techniques. BS i's inner transmission power and outer transmission power are TP_i^{inn} and TP_i^{out}, respectively, in unit of watt/TTI. Each base station i allocates radio resource to serve user j according to its demand r_j and located area, i.e., If j is in the inner region, j needs resource of $TTI^{inn}_{(i,j)}$; if j is in the outer region, j needs resource of $TTI^{out}_{(i,j)}$. To derive $TTI^{inn}_{(i,j)}$ or $TTI^{out}_{(i,j)}$, calculate the SINR of j, then we can conduct the available modulation and coding scheme $MCS^{inn}_{(i,j)}$ or $MCS^{out}_{(i,j)}$ by SINR (refer to TABLE I), the $TTI^{inn}_{(i,j)}$ and $TTI^{out}_{(i,j)}$ are calculated as follows:

$$TTI_{(i,j)}^{inn} = \left\lceil \frac{r_j}{Eff\left(MCS_{(i,j)}^{inn}\right)} \right\rceil, \quad (1)$$

$$TTI_{(i,j)}^{out} = \left\lceil \frac{r_j}{Eff\left(MCS_{(i,j)}^{out}\right)} \right\rceil, \quad (2)$$

where $Eff(x)$ with MCS x represents the amount of data bits that a TTI can carry. The overall requirements of BS j for inner and outer regions can be calculated by following formulas:

$$TTI_i^{inn} = \sum_{j=1}^{N_i} TTI_{(i,j)}^{inn}, \quad (3)$$

$$TTI_i^{out} = \sum_{j=1}^{N_i} TTI_{(i,j)}^{out}, \quad (4)$$

where N_i is the number of users served by the base station i. We set lower and upper thresholds for the inner and outer regions. The lower and upper thresholds of inner region are Thr^{inn}_{lw} and Thr^{inn}_{up}, respectively, while those of outer region are Thr^{out}_{lw} and Thr^{out}_{up}, respectively. According to the relationship of TTI_i^{out} and TTI_i^{inn} to the thresholds, we adapt the transmit power of BS i to achieve power saving and increase resource utilization. Specifically, if $TTI_i^{inn} < Thr^{inn}_{lw}$ or $TTI_i^{out} < Thr^{out}_{lw}$, the base station will reduce TP_i^{inn} or TP_i^{out} to decrease energy consumption and increase the wireless resource utilization until $TP_i^{inn} \geq Thr^{inn}_{lw}$ or $TP_i^{out} \geq Thr^{out}_{lw}$, respectively.

B. Dynamic Cooperating Set Planning Sub-algorithm

In this section, we present how to dynamically organize the co-operating set (or cluster) to offload the traffic. Initially each BS operates independently, i.e., every BS itself is a cooperating set of size of 1. Considering that somewhere (or some BS) in the system may have a big activity or event with gathered crowds, so traffic demand increases. This induces much people cannot communicate on the network. To solve this problem, we propose to dynamically organize the cooperating set by inviting the BSs around the overloaded area based on the actual traffic distribution and the status of the neighbor BSs. Then the cooperating set effectively disperses the overloading traffic demand to the BSs with free resource via DCS, thus enhancing the spectrum efficiency and satisfying more users. Our method is composed of two parts : In the first part, we consider the direct adjacent BSs to the overload BS (C_h), i.e., one-hop neighbors of C_h, denoted by ψ^1_{Ch} ={ N^1_i, i=1..6}, N^1_i is the *ith* direct adjacent cell of C_h. To alleviate the load of C_h, the users, which are originally serviced by C_h and are also covered by any neighbor BS in ψ^1_{Ch}, are dynamically scheduled to use the free resource of cells in ψ^1_{Ch} via DCS, i.e., transferring part of the edge users from C_h to neighbor BSs, N^1_i, i = 1..6. If overload still exists after all $N^1_i \in \psi^1_{Ch}$, i=1..6, joining the cooperating set, our method will continue the second part. In the second part, the BSs which are adjacent to the cooperating set are considered; note that they are not directly adjacent BSs of C_h but two-hop neighbors of C_h. Then, we continue selecting suitable BSs to join the cooperating set. These BSs can *relay* their resource to N^1_i, i=1..6, by serving N^1_i*'s* edge users, thus increasing the free resource of N^1_i which can be used to offload more users in C_h. Fig. 2 shows an example of dynamic cooperating set planning. As shown in Fig. 2(a), an overload condition, which occurs in cell 1 in this example, triggers the whole procedure. Then, cell 1 starts to ask the one-hop neighbors to join the cooperating set, as shown in Fig. 2(b)-Fig. 2(d), to help offload. If the one-hop neighbors are not enough to solve the overload condition, then the cooperating set will continue to invite the two-hop neighbors, like Fig. 2(e) and 2(f), to join the cooperating set. Through this way, we can achieve load balancing, improve the spectrum efficiency, and get higher throughput.

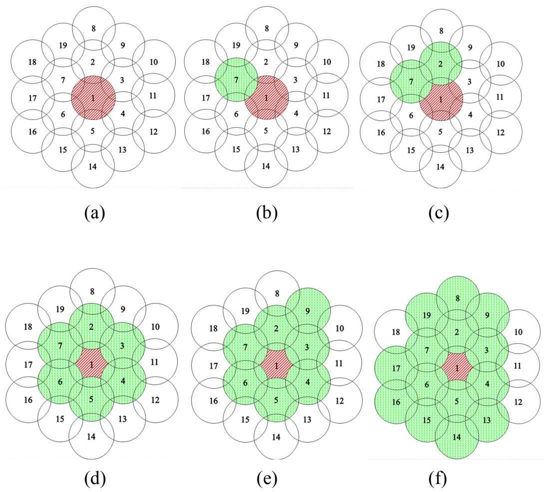

Fig. 2. An example of dynamic cooperating set planning.

C. Transmit Power Allocation (TPA) Sub-algorithm

In Sec. III.B, we present to dynamically form cooperating set to improve the overload condition. The cooperating set can help to offload the overloaded traffic demand and serve more users. The offload capability is related to the size of α and the SINRs of cell edge users. When the SINRs of edge users are bad, the surrounding base stations can offload very limited users. Moreover, when α is small, even the surrounding base stations are with large amount of free resource can hardly off load the traffic demand of overloaded cell. In this case, improve the SINR and α by adjusting the inner and outer transmission power, i.e., TP_i^{inn} and TP_i^{out}, to achieve better load balancing. Note that base stations have to meet the maximum transmit power constraint; furthermore, when the system is overloaded, power saving is not the main concern anymore. So once overloaded, we consider how to relieve the overload problem by dynamically forming Cooperating Set, and adjust TP_i^{inn} and TP_i^{out}.

Fig. 3 shows the effect of different TP_i^{inn} and TP_i^{out} on system throughput. As we can see from the figure, TP_i^{inn} does not influence the inner region throughput too much, but reducing TP_i^{out} decreases the throughput of outer region. This is because once the system overload, inner region can always pick enough users with good SINR to satisfy their demand no matter TP_i^{inn} is high or low. On the other hand, the value of TP_i^{out} significantly affect the values of SINR and α of cell edge users.

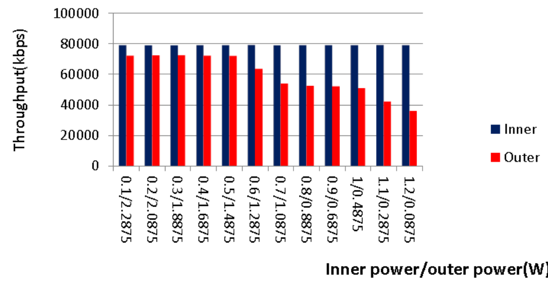

Fig. 3. Power allocation VS. inner/outer area throughput.

Therefore, if the system is still overload after performing dynamic cooperating set planning algorithm, we will then adjust the transmission power. Here we redefine C_h as C_1 and the other base stations in G are numbered sequentially from the inside to the outside cell as C_i, $i = 2..|G|$. The concept of transmit power adjustment approach is to allocate more transmit power to outer regions such that the SINRs and the size of α can increase, but the performance of the inner region, cannot be affected. The following is the transmit power allocation sub-algorithm:

S=G

while $S \neq \emptyset$

  for $TP_i^{inn}=\{TP_{MAX}/|S^{inn}_i|, TP_{MAX}/|S^{inn}_i|-\Delta p, \ldots, 0\}$

    find $\Theta_i^{inn\_new}$

    if $\Theta_i^{inn\_new} < \Theta_i^{inn\_old}$

      $TP_i^{inn}=TP_i^{inn}+\Delta p$

      break

    else

      $\Theta_i^{inn\_old}= \Theta_i^{inn\_new}$

    end if

  end for

  $TP_i^{out} = (TP_{MAX}-|S^{inn}_i|*TP_i^{inn})/ |S^{out}_i|$

  for $TP_i^{out}=\{TP_i^{out}, TP_i^{out}-\Delta p, \ldots, 0\}$

    find $\Theta_i^{out\_new}$

    if $\Theta_i^{out\_new} < \Theta_i^{out\_old}$

      $TP_i^{out}=TP_i^{out}+\Delta p$

      break

    else

      $\Theta_i^{out\_old}= \Theta_i^{out\_new}$

    end if

  end for

  S=S-C_i

end while

Above demonstrates how the transmit power is assigned to optimize SINR and α so that the base stations can increase throughput, well utilize the radio resource and help to offload more users. In the algorithm Θ_i is the throughput of C_i note that after the execution of the algorithm, the level of interference will be changed. So, each base station will need to make fine-tuning. The value of Δp will affect the degree of trimming.

IV. Simulation Results

In this section, we evaluate the performance of the proposed method in LTE/LTE-A networks. In the network, there are 19 base stations. The bandwidth of the system is 10MHz. The distance between two neighboring cells is 866 meters. The transmit power of a BS and a UE is 46dBm and 23dBm, respectively. The antenna height of a BS is 32 meters. The inner area of each cell occupies 2/3 of the total area in default. The average data rate of each user is 500kbps. We first randomly distribute a number of UEs in the system and then generate overloaded UEs uniformly in the central cell only. Our method is compared to the following three schemes: (1) *Single(no CoMP)*: Each base station operates independently. None of them compose a cooperating set. (2) *Static Cooperating Set Planning (SCSP)*: Every three base stations from a cooperating set. This is done in the initialization stage and after that, all cooperating sets are fixed. (3) *Dynamic Cooperating Set Planning with fixed power configuration (DCSP(0.625))*: DCSP(0.625) uses the same dynamic cooperating set planning scheme as our proposed algorithm, DCSP, but applies fixed transmit power settings. The transmit power settings are referred to the reference [18], which suggests the transmit power of outer area of a cell to be twice that of inner area. We will evaluate all the four schemes by using the following performance metrics: (1) throughput, (2) bandwidth utilization, (3) dropped users, and (4) the size of cooperating set.

We first distribute 450 users randomly in the whole network, and then generate extra users, η, in the center cell to simulate the overload condition. Such scenario can be seen in a marketplace or a department store when a special sale is held and users will gather in the hotspot. In the following, we will investigate the effect of such kind of scenario on different performance metrics.

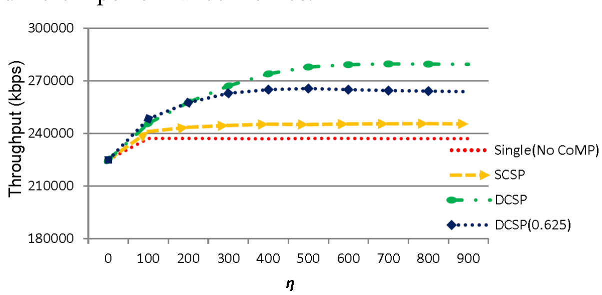

Fig. 4. The effect of η on throughput.

Fig. 4 shows the effect of η on the throughput for the four methods. We can see from the figure that as η increases, the throughput of all four methods increase. In all schemes, our proposed DCSP is the best and DCSP(0.625) is the second. This experiment shows that dynamic cooperating set planning approach is indeed effective in help offloading the excessive data transmission requirements, thus improving the throughput of the system. In addition, the power distribution also enhances the overall throughput significantly.

Fig. 5 shows the effect of η on the number of dropped users. We can see from the figure that the number of dropped users increases as η increases for all the four schemes. Our proposed methods, DCSP and DCSP(0.625), perform the best and the second, respectively, in all four schemes. Single(No CoMP) performs the worst because once the system overloaded, no neighbor cells help offload. Even DCSP drops more and more users as η increases.

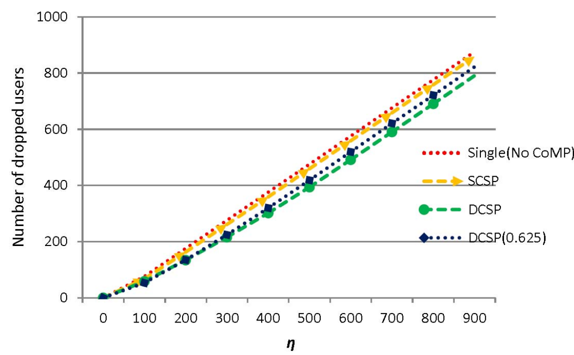

Fig. 5. The effect of η on the number of dropped users.

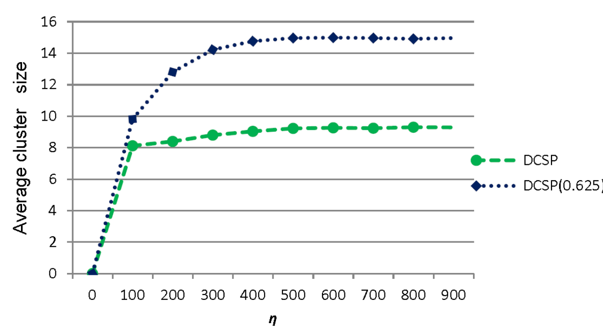

Fig. 6. The effect of η on the average cluster size.

Fig. 6 shows the effect of η on the average cluster size. We can see that as η increases, the average cluster size (or the average size of the cooperating set) increases, too. This demonstrates that DCSP and DCSP(0.625) will dynamically increase the size of the cooperating set according to the actual traffic condition to help offload. The cluster size of DCSP is smaller than DCSP(0.625) because DCSP will do power adaptation to make a better use of power and bandwidth compared to DCSP(0.625).

Fig. 7 shows the effect of η on the total amount of used TTI (bandwidth utilization). As η increases, we can see that the total amount of used TTI increases for all four schemes. Our DCSP scheme performs the best in all methods.

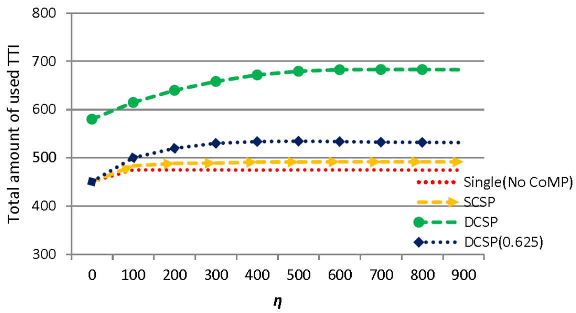

Fig. 7. The effect of η on the total amount of used TTI.

V. Simulation Results

In this paper, we proposed a decentralized energy-efficient dynamic cooperating set planning scheme in LTE/LTE-A networks for downlink CoMP. In off-peak hours, our approach reduces unnecessary energy and power consumption for energy saving and radio resource utilization improvement. While in peak hours or when a big activity occurring with gathered crowds within a specific area, our scheme aims at offloading excess traffic demand (or load-balancing) by dynamically forming the cooperating set according to the actual traffic demand distribution, adapting transmit power of cells, and dynamic service area selection. This effectively improves the system resource utilization and the energy efficiency such that the system throughput thus significantly increases. Simulation results show that, compared to other methods, our proposed method has higher system throughput, lower number of dropped user, and greater radio resource utilization. The results demonstrate that the presented method can effectively help offloading (load balancing) and improve energy efficiency of the system.

Acknowledgment

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