Energy Efficient BS Cooperation in DPS CoMP Based Cellular Networks with Hybrid Power Supply

[1]Abu Jahid, [2]Ahnaf S. Ahmad and [3]Md. Farhad Hossain
[1]Department of Electrical, Electronic and Communication Engineering, Military Institute of Science and Technology, Dhaka-1216, Bangladesh,[2,3]Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh
Email: [1]setujahid@gmail.com, [2]ahnaf2194@gmail.com, [3]mfarhadhossain@eee.buet.ac.bd

***Abstract*—Energy efficient cellular networking has recently drawn increasing attention for reducing network operation cost without sacrificing the quality of service (QoS). This paper proposes a framework for energy cooperation among base stations (BSs) in coordinated multi-point (CoMP) transmission based cellular networks, where the BSs are powered by hybrid power supplies including both the conventional grid and renewable energy sources. The considered network deploys BSs having independent energy storages, which are assumed interconnected by resistive power lines for energy sharing. The network also integrates dynamic point selection (DPS) CoMP technique for selecting the best serving BSs for an user equipment. The objective of the proposed cooperation is to maximize the usage of renewable solar energy leading to reduced on-grid power consumption. The proposed energy cooperation among BSs exploits the tempo-spatial diversities of both the renewable energy generation and the traffic demand. Monte Carlo based simulations are carried out for analyzing the energy efficiency (EE) performance of the proposed network. Simulation results validate the proposed inter-BS cooperation demonstrating substantial energy savings.**

***Index Terms*—Energy efficiency, BS cooperation, CoMP, Hybrid power supply.**

I. Introduction

Recently, with the increasing environmental concerns and energy saving considerations, researchers don't only focus on increasing spectral efficiency (SE) but also pay deep attention to energy saving methods. Information and Communication Technology (ICT) industry has been identified to be a major future contributor to overall greenhouse gas emissions which is currently responsible for around 2-2.5% of the global energy consumption and this is expected to increase every year with the exponential growth of the mobile traffic [1]. As the mass deployment of 4G systems worldwide occurs, mobile communications would consume significant more energy if no effective actions are taken.

Therefore, the rising energy consumption and carbon footprint of operating cellular networks have led to an emerging trend of addressing energy efficiency (EE) among the researchers, network operators and regulatory bodies such as 3GPP and ITU [2]. BSs in the cellular access networks are the most dominant energy consuming equipments responsible for around 60%-80% of the total consumption and exhibit a high degree of tempo-spatial diversity [3]. Several strategies have been proposed [4]–[6] in order to reduce the power consumption in the RAN infrastructure. Therefore, improving the energy efficiency of RANs compared to core networks (CN) has become the center of focus for the researchers of green cellular networks. However, hybrid energy supply combining renewable energy sources with conventional sources has been found to be a promising alternative. We envision the future BSs to be powered by hybrid supplies in order to minimize the operation cost while maintaining the quality of service (QoS).

In this regard, few distinctive researches have been carried out discussing energy-efficient wireless communications in a cellular network with hybrid energy supplies [7]–[9]. Authors in [7] have proposed a model for energy sharing between two cellular BSs with hybrid conventional and renewable energy sources. The proposed hybrid algorithm has some constraint when the energy profiles are non-deterministic. In [8], authors proposed an energy aware cell size adaption algorithm that balances the energy consumption among BSs enabling more users to be served with green energy. Authors also pointed out the optimization of green energy utilization during the peak traffic hours and saving a significant amount of on-grid energy consumption. A new approach for designing large-scale renewable powered wireless networks that models the energy field using stochastic geometry has been discussed in [9].

However, in recent times, coordinated multi-point (CoMP) transmission technique is considered as a promising candidate for both downlink and uplink of future 4G cellular networks like LTE-Advanced (LTE-A) cellular systems [10]. CoMP is a technique adopted by 3rd generation partnership project (3GPP) for LTE-A that has shown great promise to increase network coverage, cell-edge throughput and overall system spectral efficiency (SE) [11]. Specifically, downlink CoMP techniques take advantage of multiple transmission points, termed as base stations (BSs) which coordinate with one another to provide best possible services to a particular user equipment (UE). Joint transmission (JT), dynamic point selection (DPS) and coordinated scheduling/coordinated beamforming (CS/CB) are the three major downlink CoMP techniques outlined by 3GPP. The considered cellular network model employs DPS CoMP for serving it users. In DPS scheme, based on some selected criteria, only one of the BSs is selected for transmission in spite of UE data being available to multiple coordinating BSs. Authors in [12] demonstrated a joint model of cell switch off and CoMP on the existing cellular networks and achieved 24% energy efficiency increase in comparison to the traditional cell switch off schemes. Moreover, authors in [13] have proposed a novel CoMP technique for the downlink of two-tier heterogeneous LTE-A cellular networks combining both JT and DPS CoMP schemes. Their proposed technique has demonstrated superior EE performance compared to only JT, only DPS and non-CoMP transmission schemes.

It is note-worthy that very few works have discussed CoMP combined with hybrid energy supply. Authors of [14] focused

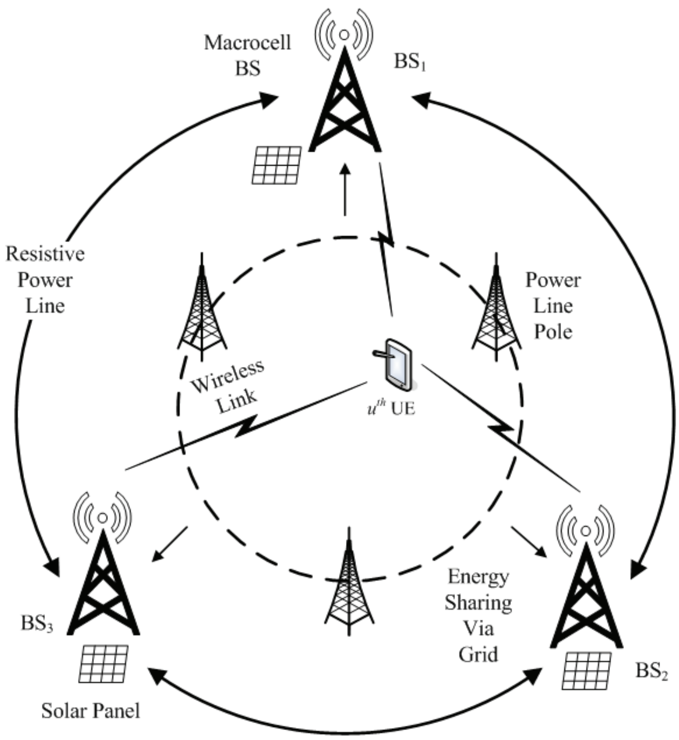

Fig. 1. Proposed Network Model.

on energy harvesting and CoMP enabled wireless communication by investigating a joint energy and communication cooperative approach. In the proposed paradigm, energy cooperation can be implemented by the cellular network operator via signing a contract with the grid operator, so that BSs can exchange energy via the existing grid infrastructure.

In this paper, we propose energy cooperation between BSs of CoMP transmission based LTE-A cellular network with hybrid supplies. DPS CoMP technique is integrated in order achieves higher energy efficiency. A sharing of energy between BSs allows compensating the deficit in other BSs. A deficit may happen due to either high traffic demand or lower green energy generation resulting shortage in storage. In the presence of storage decay and resistive power loss in the connected line, we analyze the reduction of conventional on grid energy consumption and downlink energy efficiency (EE) of the proposed system. Extensive simulations are carried out to evaluate the performance of the proposed system in terms of energy efficiency and total savings in on-grid energy. Performance of the given model with hybrid supplies is evaluated through Monte-Carlo simulations, which is then compared with that of non-CoMP system. Realistic wireless channel and propagation models in accordance to 3GPP specifications are used throughout this work.

The rest of the paper is organized as follows: In section II, a discussion of the system model is provided along with network layout and green energy model. In addition, energy consumption model for macrocell BS and formulation of performance metrics are also briefly explained. Section III shows the simulation results with discussion and finally, section IV concludes the paper with key findings.

II. System Model

A. Proposed Network Model

We consider a cellular network whose BSs are powered by hybrid supplies including conventional energy and solar energy. Our interest will be on the case of the BSs with on-site energy harvester, energy storage devices, grid energy sources and all of them are inter-connected with one another through resistive power lines. In such cellular networks, BSs are powered by green (i.e., solar) energy if they have sufficient amount of green energy stored in their respective batteries; otherwise the BSs seek green power from nearest BS. However, the BSs switch to on-grid energy in the absence of surplus energy stored in the nearest BS. For simplicity, in this paper we only consider the cooperation between two BSs, but this can be readily generalized to multiple BSs in a cluster. Such a network is depicted in Fig. 1. Under the proposed network model, energy sharing for an UE is taken place between the two BSs offering higher SINR among the available BSs, say BS_1 and BS_2. On the other hand, as DPS CoMP is implemented in the system, BS offering the highest SINR (assume BS_1) is selected for serving UE. At a finite horizon time slot, if stored green energy in BS_1 is larger than its energy demand, the BS is powered by green energy storage itself; otherwise BS_1 will share green energy from BS_2. It is worth mentioning that if BS_2 does not have not sufficient energy to fully meet the deficit of BS_1, then BS_1 is powered by both on-grid energy and surplus energy stored in BS_2 or in the worse case scenario only by the on-grid energy. We contemplate that the cellular network experiences variable traffic throughout the day and our aim is to maximize the utilization of green energy resulting in minimum on-grid energy utilization.

B. Mathematical Model of the Proposed System

For the proposed system, the green energy storage of the n^{th} BS at time t is governed by

$$s_n(t) = \mu s_n(t-1) + i_n(t) - d_n(t) \tag{1}$$

where s_n is the green energy storage, i_n is the incoming energy from solar panel, d_n is the energy demand of the particular BS and $0 \leq \mu \leq 1$ is the storage factor i.e. percentage of storage energy retained after unit period of time. For example, $\mu = 0.9$ indicates that 10% energy will be lost in the storage during the time interval. We also assume that the initial storage of the BSs follows an uniform distribution as $s_1(1) = s_2(1) = s_3(1) = ... = s_n(1) = U(0, s_{max})$ where s_{max} is the maximum capacity of the storage cells.

Now, we take two BSs, BS_1 and BS_2 and consider their energy consumption and sharing in different scenarios as follows:

Case I: If $[s_1(t), s_2(t)]^T \geq [d_1(t), d_2(t)]^T$ then each BS will be served by its respective storage so there is no need of energy sharing between the BSs. However, no on-grid energy will be consumed whatsoever.

Case II: If $s_1(t) < d_1(t)$ and $s_2(t) - d_2(t) \geq d_1(t) - s_1(t)$ then BS_2 would supply its surplus storage energy to BS_1. Therefore, total green energy sharing in this case, $g_{21}(t)$ can be expressed as

$$g_{21}(t) = \alpha[d_1(t) - s_1(t)] \tag{2}$$

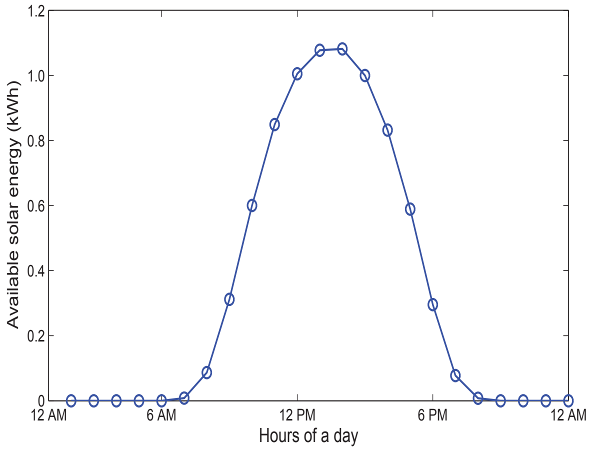

Fig. 2. Average hourly solar energy generation.

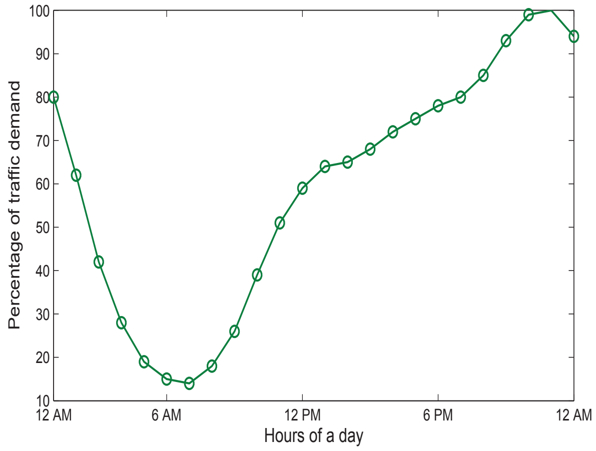

Fig. 3. Daily traffic profile of a residential area.

where $0 \leq \alpha \leq 1$ is the utilization factor of the line connecting the two BSs. That is, while sharing, $\alpha \times 100\%$ of the energy is dissipated as line loss.

Case III: If $s_1(t) < d_1(t)$ but $s_2(t) - d_2(t) < d_1(t) - s_1(t)$ then both green energy sharing and on-grid consumption will be required to meet the deficit of BS_1. So, the green energy sharing in this case, $g_{21}(t)$ would be same as in Eq. 2. However, the conventional on-grid consumption of BS_1, $c_1(t)$ in this case is

$$c_1(t) = d_1(t) - s_1(t) - g_{21}(t) \tag{3}$$

Case IV: However, if $[s_1(t), s_2(t)]^T < [d_1(t), d_2(t)]^T$ then no energy sharing would take place between the BSs and the total deficit of BS_1 would be mitigated by the on-grid supply. Therefore, conventional on-grid consumption by BS_1, $c_1(t)$ is now

$$c_1(t) = d_1(t) - s_1(t) \tag{4}$$

C. Green Energy Model

Exploiting available energy from green energy sources along with existing power grid infrastructure is expected to be the long-term environmental solution for the large-scale mobile cellular networks. In this research, photovoltaic solar panel is considered as the green energy harvester. The solar energy generation profile is stochastic and depends on factors like temperature, solar light intensity, panel materials and the geographic location of solar panel. However, the daily solar energy generation exhibits temporal variation for a particular area and shows spatial dynamics with geological location. Due to the temporal behavior of green energy generation, the available solar energy may not guarantee the sufficient energy supplies to the BSs. Furthermore, in the moment of peak energy generation during noon the surplus energy may be stored for future use. We assume that the solar panels of all BSs are located in the same geographical region and experience the same energy generation rate. In this paper, hourly solar energy generation for a particular region is estimated by adopting System Advisor Model [15].

Fig. 2 shows hourly solar energy profile of full year in 2015 in Dhaka City. In this estimation, we set 2 kWdc capacity and the DC to AC conversion rate factor 0.85. The curve indicates that the green energy generation starts from around 6:00 AM, reaches peak value around at noon and ends at about 6:00 PM. We assume a finite non-zero initial storage and the storage batteries are rated at 200 AH and 12 V.

D. BS Power Consumption Model

It is important to investigate the traffic demand to be served by the BSs in order to analyze the energy consumption of the network. Because, the BS energy consumption depends on the mobile traffic and the mobile traffic volume exhibits both temporal and spatial diversity [3]. We assume mobile users are randomly distributed and number of users on individual BSs is different. Practically, not all subscribers are always active and traffic volume at individual BSs are highly dynamic over time. Moreover, we assume BSs transmit data to all users with the same data rate. Based on internal surveys on operator traffic data within the EARTH project and the Sandvine report [16], the daily traffic demand in the network is characterized by the normalized traffic profile illustrated in Fig. 3.

From aforementioned traffic dynamics, the BSs energy consumption is directly related to the traffic volumes [17]. The energy consumption of BSs can be sub-divided by two parts: the static energy consumption and the dynamic energy consumption. It was found in [18] that the power input of a BS can be approximated a linear function of RF output power P_{OUT} and load sharing parameter χ. Hence the total power consumption considering number of sectors M_{sec} is defined as

$$P_{supply} = \begin{cases} M_{sec}(P_1 + \triangle_p P_{MAX}(\chi - 1)), & \text{if } 0 < \chi \leq 1 \\ M_{sec} P_{sleep}, & \text{if } \chi = 0 \end{cases} \tag{5}$$

where $P_1 = P_0 + \triangle_p P_{MAX}$ and p_0 is the consumption at idle state. The load dependency is accounted for by the power gradient, $\triangle_p$. The scaling parameter $\chi = 1$ indicates that a fully loaded system, i.e. BS transmitting at full power with all of their resource blocks occupied and and $\chi = 0$ indicates idle state. Furthermore, without any traffic load BS may enter a sleep mode with lowered consumption, P_{sleep}. The parameters are summarized in Table. I.

E. Link Model

In this paper, we consider a channel model with log-normally distributed shadow fading. For a particular separation

TABLE I
BS POWER CONSUMPTION MODEL PARAMETERS [18]

BS Type	M_{sec}	$P_{MAX}[W]$	$P_0[W]$	$\triangle P$	$P_{sleep}[W]$
Macro	1	20.0	130.0	4.7	75

between transmitter and receiver in a large scale network, the path loss can be formulated as a function of distance by using a path loss exponent n and can be expressed as

$$PL(d) = PL(d_0) + 10nlog(\frac{d}{d_0}) + X_\sigma, \text{ dB} \quad (6)$$

$PL(d_0)$ is usually computed assuming free space propagation model with reference distance d_0 km. X_σ is a zero-mean Gaussian random variable with standard deviation σ which is also in dB.

Thus, the received power for j^{th} UE at a distance of $d^{i,j}$ from i^{th} BS is given by

$$P_r^{i,j}(dBm) = P_t^{i,j}(dBm) - PL(dB) \quad (7)$$

where $P_t^{i,j}$ is the transmitted power at by the i^{th} BS in dBm.

Then the received SINR $\gamma_{i,u}$ at u^{th} UE from i^{th} BS can be given by

$$\gamma_{i,u} = \frac{P^r_{i,u}}{\mathcal{I}_{u,inter} + \mathcal{I}_{u,intra} + \mathcal{P}_N} \quad (8)$$

where $\mathcal{I}_{u,inter}$ is the inter-cell interference, $\mathcal{I}_{u,intra}$ is the intra-cell interference, $\mathcal{P}_N$ is the additive white Gaussian noise (AWGN) power given by $\mathcal{P}_N = -174 + 10log_{10}(\Delta f)$ in dBm with Δf is the bandwidth in Hz. However, LTE-A system employs orthogonal frequency division multiple access (OFDMA), which results in zero intra-cell interference.

F. Performance Metrics

The total achievable network throughput can be calculated by Shanon's capacity formula as given below

$$R_{total} = \sum_{u=1}^{U}\sum_{i=1}^{N_B} \Delta f log_2(1+\gamma_{i,u}), \text{ bps} \quad (9)$$

where N_B is the number of transmitting BS for serving u^{th} UE and U is the total number of UEs in the network. For the proposed DPS CoMP based system, N_B=1.

In this paper, we evaluate the EE performance of the network with the proposed CoMP technique in terms of bits per joule, which is defined as the ratio of aggregate throughput R_{total} of the network to the total power consumed by the network P_{total}. Thus the EE metric denoted as η_{EE} can be written as

$$\eta_{EE} = \frac{R_{total}}{P_{total}}, \text{ bit/joule} \quad (10)$$

On the other hand, we evaluate the savings of on-grid energy when the proposed model is implemented. The average on-grid energy savings in a serving BS at a time t, $AES(t)$ of such a system is determined as

$$AES(t) = \frac{1}{N}\sum_{i=1}^{N}\frac{G_{i,s}(t) - G_{i,0}(t)}{G_{i,0}(t)} \times 100\% \quad (11)$$

where $G_{i,0}(t)$ is the on-grid energy consumption of i^{th} BS at time t when there is no energy sharing among the BSs, $G_{i,s}(t)$ is the on-grid energy consumption of i^{th} BS at time t when BSs share energy among themselves as per the proposed model and N denotes the total number of BSs in the system.

In this paper, we evaluate our proposed model in terms of EE and observe the average energy savings of the serving cell using the proposed model.

TABLE II
SIMULATION PARAMETERS

Parameters	Value
System bandwidth	5 MHz (25 RBs), 300 subcarriers
Carrier frequency, f_c	2 GHz
Duplex Mode	FDD
Cell radius	1000 m
BS Transmission Power	43 dBm
Noise power density	-174 dBm/Hz
Number of sectors, M_{sec}	1
Number of antennas	1
Path loss exponent, n	3.574
Shadow fading SD, σ	8 dB
Access technique, DL	OFDMA
Initial Storage, $s_n(1)$	$U(0, s_{max})$
Maximum Storage Capacity, s_{max}	2.4 kWh
Storage Factor, μ	0.92 i.e. 8% loss
Line Utilization Factor, α	0.96 i.e. 4% loss
Traffic model	Randomly distributed

III. RESULTS AND ANALYSIS

A. Simulation Setup

In this section, we analyze the performance of the proposed model presented in section II. We consider a hexagonal grid of macro sites and UEs are distributed randomly over the geographical area following a uniform distribution. Monte-Carlo simulation method is used in order to investigate the system performance and a single UE is served by reference cell in each Monte-Carlo iteration. The key model parameters of the simulated system are set according to the LTE standard [10], which are summarized in Table II.

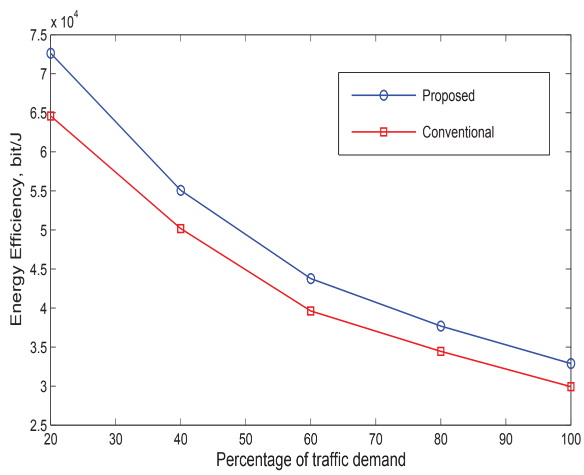

Fig. 4. Energy efficiency of the proposed network compared to non - CoMP scheme.

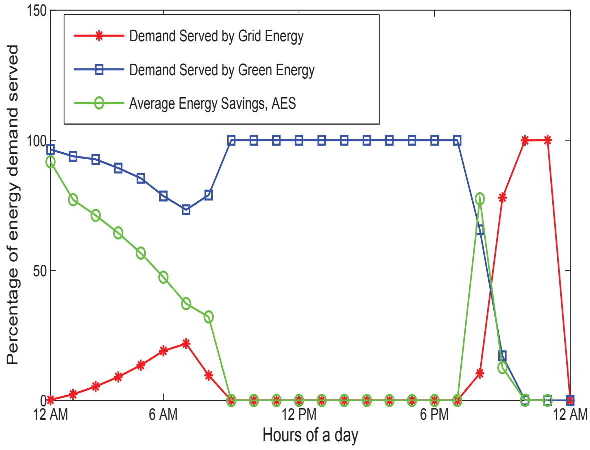

Fig. 5. Percentage Sharing of energy demand between on-grid and green energy and average energy savings of on-grid energy through green energy utilization.

B. Result Analysis

Fig. 4 presents the variation of EE metric with the traffic load variation χ. The total BS power consumption varies with χ from no load ($\chi = 0$) to full traffic load ($\chi = 1$) as more resource blocks get occupied with increasing traffic load. The figure depicts the energy efficiency comparison between conventional scheme and the proposed model integrating DPS CoMP technique. Here, conventional scheme indicates system utilizing hybrid energy but without any energy sharing or CoMP mechanism. In general, the supply power consumption of a BS is a function of transmission power as well as the traffic demand at the moment. Therefore, with the increase of χ, the network power consumption also increases leading to lower EE which is evident from the figure. In conventional macrocell based approach, UE receives data from the nearest BS around it. In contrast, in the proposed method, among two or more BSs, UE is connected to the BS which provides the best SINR. Here, it is mention-worthy that the nearest BS is never fully guaranteed to provide the best possible SINR due to the random nature of shadow fading. As total throughput is a function of SINR, improved SINR guarantees improved throughput. As a result, total throughput increases manifold which results in direct improvement of EE. Therefore, as seen from the figure, our proposed scheme shows better EE performance compared to the non-CoMP scheme.

Fig. 5 demonstrates the green energy utilization, on-grid energy consumption and average savings of a cellular network implementing the proposed model. For simplicity, we consider two BSs for this scenario. Here, we examine a particular BS and to fully realize the green energy sharing phenomenon, we take in to account another BS in conjunction with it. The BS in consideration always tends to run fully in green energy given there is adequate energy in the storage. However, if the present green energy storage is less than the required BS power consumption, the BS would request the second BS in consideration to share energy. Provided the second BS has surplus energy meeting its own demand, it would then share energy from its storage with the requesting BS. As a consequence of green energy sharing, the overall on-grid energy consumption will be reduced. It is note-worthy that BS_2 share energy only after fulfilling the demand of its associated users. Otherwise there will be no energy cooperation among BSs that described in sec II-B. So it can be concluded that BS_2 will not sacrifice its own performance. Furthermore, if the second BS can not provide sufficient energy, the first BS would seek on-grid energy in order to serve its associated users. However, as mentioned before in (11), average savings of BS_1 in the system is defined as the average difference of on-grid energy consumption of the BSs without and with sharing and this can be readily identified as the average of the energy shared among the BSs. So, for the rest of the discussion, the terms average savings and sharing are interchangeable. However, as discussed before in section II, our model is designed such that any value of savings/sharing greater than zero indicates the maximum possible use of green energy at that given instant.

As seen from fig. 5, on-grid energy consumption typically peaks between 8:00 PM to 12:00 PM and is quite low between 9:00 AM to 7:00 PM and remains zero at noon, when there is adequate solar energy generation to meet the BS demand. Since solar energy can only be generated during day time, at night, green energy is not sufficient to guarantee QoS to the users and hence commercial energy is needed to be drawn from conventional grid. Between 12:00 PM to 9:00 AM, the BS is mainly run by the green energy storage left-over from the previous day with the help of a little sharing from the second BS. As time goes, storage gradually decreases and on-grid energy is needed to fulfill the deficit. However, closing to the period of mid-noon, there is adequate solar energy available so there isn't any need of any kind of sharing. Until almost 6:30 PM, green energy can alone take care of the BS power consumption. Due to this temporal dynamics, the available solar energy cannot always guarantee sufficient energy supply to the BSs. The figure also indicates the green energy utilization is maximum during 9:00 AM to 7:00 PM. This happens because solar energy generation reaches peak at noon and keeps the green energy storage healthy enough to provide for the period. On the other hand, average energy savings is peak at the initial stage and sharply decreases as time goes. Between 9:00 AM to 7:00 AM, the BS is run by the storage itself and hence AES remains to zero. After diminishing sunlight the BS would share green energy in order serve its associated users and thus minimizes the utilization of grid energy. It is clearly evident from the figure that there is a significant amount of energy savings yielding around 90% during 8:00 PM due to green energy sharing from another BS. Therefore, it can be safely inferred that while the utilization of green energy inherently reduces on-grid energy consumption, green energy sharing among BSs minimizes it.

IV. Conclusions

This paper has proposed a novel energy cooperation technique among BSs of cellular network for saving energy. The proposed network has integrated DPS CoMP technique, while the BSs have been powered by both on-grid energy and renewable solar energy. Under the proposed model, based on the instantaneous traffic demand and the availability of solar energy storage, solar energy has been shared between two BSs for serving UEs and thus have reduced the on-grid energy consumption. System performance has been evaluated through extensive simulations over 24 hours of a day. We have shown the average savings of conventional on-grid energy over the period of a day and successfully overcome the tempo-spatial disadvantage of solar energy generation using the notion of energy sharing among BSs. Our future work will focus on the development of generalized algorithms for sharing green energy among any number of BSs. We will also consider multi-tier heterogeneous networks and other CoMP systems.

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