Research Article

Energy Efficient and High Capacity Tradeoff in Distributed Antenna System for a Green Cellular Network

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Two main concerns for designing a wireless system are more network capacity and less energy consumption. Recently, distributed antenna system (DAS) has received considerable attention due to its potential to provide higher spectral efficiency (SE) and uniform coverage for cellular networks. In this regard, this paper compares the performance of DAS with centralized antenna system (CAS) in LTE-A system in terms of energy efficiency (EE), where practical restrictions such as out-of-cell interference, path loss, and small scale fading are taken into account. Furthermore, the EE and system power consumption are investigated under three different cell-load scenarios (high, moderate, and low load) where different numbers of antennas are activated and remaining of antennas are under sleep mode. Finally, based on the tradeoff between power-saving and EE, two optimal DAS antenna deployments are proposed for low and moderate cell-load scenarios. The results reveal that DAS considerably outperforms CAS in terms of EE and by optimal deploying antennas of DAS significant power-saving and EE are achievable. The proposed methodology achieved savings of up to 27.63% in terms of energy savings in a macrocell with guarantee of a high capacity of data.

1. Introduction

The sudden increase in subscribers and demand for high-speed data has prompted cellular operators to increase the number of base stations (BSs) to fulfil the needs of mobile subscribers. This increase has subsequently increased the overall energy consumption, operational costs, and carbon footprint of cellular networks. Accordingly, improving the energy efficiency (EE) of wireless networks has become a compelling challenge for researchers, vendors, and mobile operators, not only to reduce the operational costs but also to reduce the global carbon emissions. The focus is on creating green cellular networks at BSs because in real mobile networks most of power consumed by BSs, which is approximately 57% of the total energy consumption [1]. While [2] reported that the total energy consumed by the internet communication technology (ICT) takes more than three percent of the worldwide electric energy consumption, this portion is going to increase in the future. A number of interesting works have been carried out to address the issue, by implementation of "greener" cellular networks that are less expensive to operate. Overall, these improvements

can be achieved through two approaches. The first approach is to reduce the power consumption of BSs using power-efficient hardware. The second approach is to adopt the intelligent management of network elements based on traffic load variations [3], which is the focus of this work.

Spectral efficiency (SE) and EE are two key figures of merit to consider the performance of wireless communication networks. It is investigated in [4] that the SE of cellular networks must be increased from 0.5–2.5 b/Hz (in 2010) to 5–20 b/Hz (in 2015). Therefore some technologies are required to enhance the SE and capacity for cellular networks. In this regard, LTE and LTE-A systems are designed to operate in midhigh SE region [5]. In conventional cellular system, all antennas are colocated at the central BS, which is known as centralized antenna systems (CASs). In such systems, by increasing the distance between user equipment (UE) and BS, transmitted downlink signal exponentially attenuated and most portion of signal power wasted which results in poor network coverage.

On the other hand, by increasing the transmit power sever interference is experienced by users especially at the cell-edges. Consequently, system performance degrades in

such system, while distributed antenna system (DAS) is one of the upcoming technologies, which improves coverage and capacity for both hot and dead spots without the need for extensive base station deployments. Therefore, recently applying DAS technology in LTE and LTE-A has drawn much attention.

In DAS some of the antennas are located at the central BS and other antennas are distributed throughout the cell which is known as radio remote units (RRUs). The RRUs have minimal intelligence of their own and controlled by the central BS and contain a low-complex processor, up/downconverters, and low noise amplifiers [6] and are connected to the central BS via high-bandwidth low-latency dedicated connections such as fiber optics [7]. In contrast to CAS, DAS reduces the access distance (between UE and BS) therefore reducing the interference by minimizing the transmit power (while channel quality is kept the same). DAS provides uniform coverage [8], enhances capacity [9] and area SE [10], mitigates path loss and shadowing effects, and reduces outage on the downlink [11]. Results in [9] show that DAS reduces other-cell interference in a multicell scenario and significantly improves throughput especially for users near cell-edges, while out-of-cell interference is the main restriction factor to achieve system capacity. The results in [12] show a lower power consumption of DAS on the uplink versus CAS. The current perspective of DAS and its application to the downlink of cellular systems can be found in [8].

Moreover, multiple-input multiple-output (MIMO) is a well-known and promising technology which can improve the SE and throughput for wireless communication systems [13]. In this regard, the application of MIMO to DAS is a topic of ongoing research where recent works in [10, 14–16] investigated the performance of (multiuser) MIMO in DAS and stated that MIMO is an effective and promising strategy for DAS, which provides higher data rate for system, while authors of [17] compared the EE of MIMO and single input single output (SISO) in CAS over different transmission distances. The comparison shows that, in CAS, MIMO is not always more EE than SISO especially at a short distance. Therefore, the fundamental issues of this paper are as follows: how to exploit MIMO technique to optimize energy consumption in the network and how to exploit DAS in LTE-A system in such way that operates in EE power-saving tradeoff regime. In this regard, some techniques are well-known to enhance power-saving in the cellular network such as switching off cells, reducing number of BS's antenna, and reducing cell bandwidth. In the cellular network, power amplifier (PA) consumes most of power in BSs. Therefore, to reduce the power consumption of network (while the number of BSs is very large), one effective solution is reducing the number of antennas (switching off the PAs) based on the traffic load conditions, which is the focus of our work, since each PA roughly consumes the largest portion of energy in a BS (approximately 65% of the total energy consumption).

In this regard, less attention has been paid to investigate the EE and power-saving for DAS. Authors of [18] investigated the EE and SE of CASs in multicell and multiantenna scenarios. Performance of DAS and CAS was compared in [4] that exploits that DAS can provide significant enhancement

in transmit power efficiency. By considering EE and SE of DAS, the optimal location and number of RRUs were investigated in [19]. An optimal power allocation method was proposed in [20] to maximize EE for DAS. EE and SE of DAS were investigated in [5, 6, 21, 22] which reveal remarkable performance of DAS versus CAS; nevertheless impact of out-of-cell interference was ignored.

To investigate the performance of DAS, it is important to consider the out-of-cell interference where RRUs are distributed throughout the cell and impacts the signal to interference plus noise ratio (SINR) level. Moreover, there is a lack in investigation the performance of DAS under some realistic channel parameters such as path loss, fading, and shadowing. In this regard, this paper concentrates to investigate the performance of DAS under practical constraints such as out-of-cell interference, path loss, and small- and large-scale fading, where a LTE-A standard compliant simulator is utilized. Moreover all results are provided under considerations of practical system parameters such as user scheduling, received antenna combiner, and precoding transmission. To obtain the optimal network architecture for DAS (in terms of EE), performance of DAS with different antenna configurations is investigated and compared with CAS. Moreover, EE of DAS is investigated under different antenna architectures, cell-loads, and channel bandwidths. Furthermore, the system power consumption is investigated in the three different cell-load scenarios: high, moderate, and low load, where different system architectures with different antenna deployments are examined. Finally, by making tradeoff between EE and power-saving in two sleep modes, low and moderate load scenarios, optimal antenna deployments are proposed for DAS.

The rest of the paper is organized as follows. In Section 2, the system model is described. Section 3 discusses the methodology. The results and discussion are presented in Section 4 and Section 5 concludes the paper.

2. System Model

2.1. Downlink Model. Figure 1 depicts the architecture of considered DAS with I cells which each cell $i = \{1, \ldots, I\}$ contains one central BS with $M_{c,i}$ transmit antennas and R_i RRUs which each of them equipped with $M_{r,i}$ antennas, where $r \in \{1, \ldots, R_i\}$. The total number of served users in cell i is K_i and each user $k \in \{1, \ldots, K_i\}$ is equipped with $N_{k,i}$ received antennas. The input-output relationship on kth user in cell i is given by

$$
\begin{aligned}
\mathbf{y}_{k,i} = \mathbf{H}_{k,i}\mathbf{x}_{k,i} &+ \mathbf{H}_{k,i} \sum_{u=1,u \neq k}^{K_i} \mathbf{x}_{u,i} \\
&+ \sum_{j=1,j \neq i}^{I} \mathbf{H}_{k,i}^{(j)} \mathbf{X}_j + \mathbf{n}_{k,i},
\end{aligned}
\tag{1}
$$

where $\mathbf{y}_{k,i}$ is the perturbed received signal vector to user k in cell i and $\mathbf{H}_{k,i}^{(j)}$ is the channel matrix between user k in cell i and all transmit antennas of cell j, M_j as

$$
M_j = M_{c,j} + \sum_{r=1}^{R_i} M_{r,j},
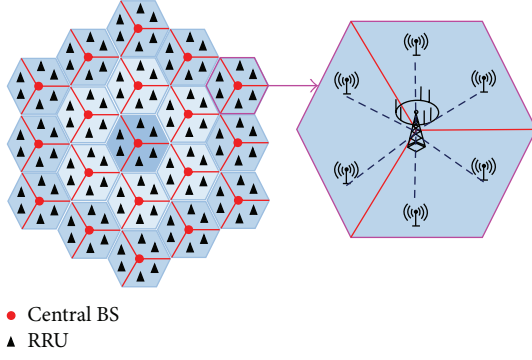\tag{2}
$$

● Central BS
▲ RRU

FIGURE 1: Example of considered DAS, consisting of 19 cells with 2-2/1 configuration. Each cell contains one sectorized central BS which each sector equipped with 2 central-antennas and 2 RRUs that each of which equipped with one antenna and connected to the central BS via fiber optic.

$\mathbf{n}_{k,i} \sim N(0, \sigma_n^2 \cdot I)$ is additive white Gaussian noise (AWGN). $\mathbf{x}_{k,i}$ is the scheduled and precoded symbol vector, and $K \subseteq \{1, \ldots, K_i\}$ is the set of selected users that are served in parallel over a given time-frequency resource in cell i. Here proportional fair scheduler is employed, whereby users are selected based on a greedy algorithm, where BS uses the available SINR value and searches through the unscheduled users to select users which can maximize sum-rate (for original definition see Algorithm 2 in [23]). Prior to transmit user symbol vector, $\mathbf{s}_{k,i}$ over the downlink channel, it should be precoded with precoder vector, $\mathbf{f}_{k,i}$ to map the transmit symbol vector onto the M_i transmit antennas and allocates the available transmit power (P_{tx}) among users, $p_{k,i}$ (for details refer to section 2.2 in [16]). Therefore,

$$\mathbf{x}_{k,i} = \mathbf{f}_{k,i} \mathbf{s}_{k,i},$$
$$\mathbf{F}_i = \widehat{\mathbf{H}}_{k,i}^H \left(\widehat{\mathbf{H}}_{k,i} \widehat{\mathbf{H}}_{k,i}^H \right)^{-1} \operatorname{diag} \left(p_{k,i} \right)^{1/2}, \quad (3)$$

where $\mathbf{F}_i = \sum_{k \in K} \mathbf{f}_{k,i}$ is the precoding matrix.

To extract the multiplexing gain, MU-MIMO technique is utilized, where multiusers are served in parallel over a given time-frequency resource. Although transmission strategy such as multiple streams per users is possible, it has been shown in [24] that schemes such as zero-forcing (ZF) [25] which transmits single stream per user exploit more multiuser diversity gain.

By distributing RRUs throughout the cell, different path losses are experienced. Therefore, the channel matrix should be decomposed as follows [16]:

$$\mathbf{H}_{k,i}^{(j)} = \overline{\mathbf{H}}_{k,i}^{(j)} \mathbf{C}_{k,i}^{(j)1/2}, \quad (4)$$

where $\overline{\mathbf{H}}_k$ is small-scale fading channel matrix, where for Rayleigh fading channel its elements are independent identically distributed $\mathcal{N}(0, 1)$. $\mathbf{C}_{k,i}^{(j)}$ is the channel gain matrix, which characterizes large-scale shadow fading and path loss with respect to the different RRUs, where

$$\mathbf{C}_{k,i}^{(j)} = \operatorname{diag} \left(\left[\gamma_{k,i}^{(1,j)}, \gamma_{k,i}^{(2,j)}, \ldots, \gamma_{k,i}^{(M_j,j)} \right] \right), \quad (5)$$

where $\gamma_{k,i}^{(n,j)}$ is the large-scale channel gain between transmit antenna n in cell j and received antenna of user k in cell i

$$\gamma_{k,i}^{(n,j)} = 10^{-L_{k,i}^{(n,j)}/10}, \quad (6)$$

where $L_{k,i}^{(n,j)}$ is the macroscale path loss between antenna n in cell j and user k in cell i

$$L_{k,i}^{(n,j)} = \max \left(70, 128.1 + 37.6 \log_{10} \left(\frac{d_{k,i}^{(n,j)}}{1000 \, \text{m}} \right) \right), \quad (7)$$

where $d_{k,i}^{(n,j)}$ is the distance between user k in cell i and transmit antenna n in cell j.

2.2. Power Model. Power consumption can be decomposed into two parts: fixed and dynamic. The fixed part is the baseline BS power consumption (e.g., signal processing, site cooling, power supply, and battery backup), which depends on both the hardware and software configurations of the BS and it is independent of the traffic load, whereas the dynamic part accounts for the power consumed in RF transmission and depends on the traffic load. The total power consumption is calculated as [26]

$$P_{tot}^{macro\text{-}BS} = N_{TRX} \left[\frac{P_{tx}/\eta_{PA} \left(1 - \sigma_{feed} \right) + P_{RF} + P_{BB}}{\left(1 - \sigma_{DC} \right) \left(1 - \sigma_{MS} \right) \left(1 - \sigma_{cool} \right)} \right], \quad (8)$$

where σ_{feed}, σ_{DC}, σ_{MS}, and σ_{cool} denote losses incurred by the feeder, DC-DC power supply, main supply, and cooling, respectively. P_{tx}, P_{RF}, and P_{BB} are the output power per transmit antenna, radio frequency, and baseband power, respectively. η_{PA} denotes the PA power efficiency, and N_{TRX} is the number of transceiver, which can be computed as follows:

$$N_{TRX} = N_{Carriers} \times N_{Sectors} \times N_{Antennas}, \quad (9)$$

where $N_{Carriers}$, $N_{Sectors}$, and $N_{Antennas}$ denote the number of carriers, sectors, and antennas, respectively.

The total daily consumed power in our studied system can be computed as

$$P_{Cons}^{day} = \left[hr_{high} + hr_{mod} + hr_{low} \right] \times (a), \quad (10)$$

where hr_x refers to the number of hours per day in which an antenna is activated in three different cell-load scenarios (high, moderate, and low load) where it will be discussed in more detail in Section 3. $a = N_{ant}^{active} \times P$, where N_{ant}^{active} refers to the number of activated antennas and P is the total consumed power as (8).

2.3. Throughput Model. To achieve the throughput, the achievable mutual information introduced in [27] is used

$$L = \max_{F \in \mathscr{F}} \sum_{k=1}^{N_{tot}} Z B_{sub} \log_2 \det \left(\mathbf{I}_N + \frac{1}{\sigma_n^2} H_k \mathbf{F} \mathbf{F}^H \mathbf{F}_k^H \right), \quad (11)$$

where N_{tot} is the total number of usable subcarriers, $\mathscr{F}$ is the set of precoding matrices, I_N is an identity matrix of size of

N, and σ_n^2 is the energy of the noise and interference at the receiver. B_{sub} is the bandwidth of a subcarrier, given as

$$B_{\text{sub}} = \frac{N_s}{T_{\text{sub}} - T_{\text{cp}}}, \qquad (12)$$

where $N_s = 14$ is the number of OFDM symbols in one subframe, $T_{\text{sub}} = 1$ msec is the duration of one subframe, and T_{cp} is the time required for the transmission of all cyclic prefixes within one subframe. Z is a factor of the system losses due to the transmission of the reference symbols and the cyclic prefix

$$Z = \frac{T_{\text{sub}} - T_{\text{cp}}}{T_{\text{sub}}} \cdot \frac{N_{\text{sc}} \cdot N_s/2 - N_{\text{ref}}}{N_{\text{sc}} \cdot N_s/2}, \qquad (13)$$

where $N_{\text{sc}} = 12$ is the number of subcarriers in one resource block and N_{ref} is the number of reference symbols per resource block.

2.4. Energy Efficiency (EE). The number of bits transmitted per Joule of energy, called energy effciency (EE), is used as a performance measure, which is defined as [28]

$$\text{EE} = \frac{L}{P_{\text{tx}}}. \qquad (14)$$

3. Methodology

In this study, results are provided based on computer simulation and mathematical analysis. To simulate the results, the Vienna LTE-A link-level simulator [27] is used which is compliant to the LTE-A specifications. According to the remarkable impact of out-of-cell interference on the DAS, multicell scenario is considered. System level simulation of multicell MU-MIMO scenario requires detailed knowledge of physical layer for downlink transmission and feedback procedure, which results in massive computational complexity. Therefore, Vienna simulator uses the hybrid link/system level simulations to consider the physical details for one cell (central cell) and rest of cells are considered as out-of-cell interference (interference model can be found in [10]). Since Monte Carlo simulations are performed, the cell throughput is evaluated in terms of 95% of empirical cumulative density function of (11) and EE is computed according to (14).

The simulation parameters under considerations are listed in Table 1. Figure 1 illustrated the considered cellular network, where central cell is surrounded with two interfering BSs tiers, and all cells are configured as DASs. Each cell is covered by one central BS and R_i uniformly distributed RRUs which located equiangularly on a ring with radius of (2/3)x cell radius. According to (2) the total number of transmit antennas is shared among the central BS and RRUs. The central BS is equipped by sectorized antennas ($3 \times 120°$) and RRUs are equipped by omnidirectional antennas. Users are randomly distributed in the central cell and the number of transmit antennas and RRUs are determined based on the cell-load densities.

For downlink transmission, only one antenna with best channel quality is selected which results in lower interference

TABLE 1: Simulation parameters [27].

Parameters	Value
Carrier frequency	2.6 GHz
Subcarrier bandwidth	15 kHz
Noise power spectral density	−174 dBm/Hz
Maximum power	46 dBm
Shadowing standard deviation	4 dB
Channel model	Temporally correlated block fading frequency flat Rayleigh fading
CSI feedback	Perfect
Received antenna combiner	MMSE
User scheduler	Greedy scheduler Algorithm 2 in [23]
Transmission strategy	ZF beamforming
Number of BSs	19
Cell radius	500 m
Number of UE's antennas	1
UE speed	3 Km/h
Number of UEs in high load scenario	36
Number of UEs in moderate load scenario	18
Number of UEs in low load scenario	6
Number of simulation positions	20

and higher downlink performance [9]. Furthermore, each UE is connected just to a RRU that provides the highest EE [5].

The configurations of DAS are denoted as $M_{c,i} - R_i/M_{r,i}$, for example, 2-6/1 means 2 antennas are allocated at the central BS and there are 6 RRUs that each of which is equipped with 1 antenna. The total transmission power, P_{tx}, is shared among the central BS and RRUs as

$$\sum_{i=0}^{j} p_i = P_{\text{tx}}, \qquad (15)$$

where index $i = 0$ is for central BS and $i = \{1, \ldots, j\}$ is for RRUs. Therefore, based on the number of RRUs, the power is shared among transmitter antennas, for example, in the 2-6/1 scenario $p_0 = 0.4 \times P_{\text{tx}}$ and $p_i = 0.1 \times P_{\text{tx}}$ where $i = \{1, \ldots, 6\}$.

Generally, the infrastructures of cellular networks are designed to support daytime traffic. Traffic loads during the day differ from those at night. Hence, one cannot ignore the amount of energy that is wasted due to the lack of efficient use of resources, particularly for low loads. Herein, according to the results of [29], three different cell-load scenarios are assumed: (i) normal case at a high traffic load ($0.8 < \lambda$), where the period of time for this case ranging from 9:00 to 21:00; (ii) moderate traffic load ($0.3 \leq \lambda \leq 0.8$), where the period of time ranging from 7:00 to 9:00 and from 21:00 to 0:00; (iii) low traffic load ($0 < \lambda < 0.3$) and the period of time from 0:00 to 7:00. Figure 2 summarizes the three aforementioned cases.

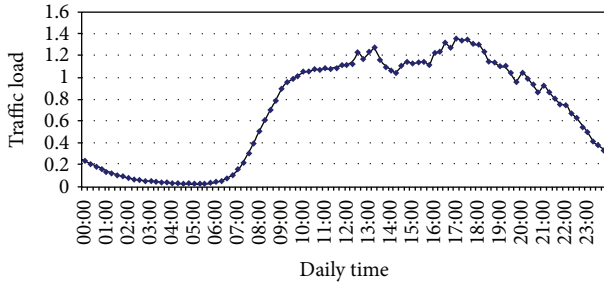In order to reduce the daily system power consumption, we propose two sleep modes: one for low load case and

FIGURE 2: Average traffic distribution over a day for urban environment [29].

FIGURE 3: EE of CAS and DAS with different number of antennas/RRUs. High load scenario and $B_w = 1.4$ MHz.

another for moderate load scenario. Therefore, it is assumed that the numbers of activated antennas are changed three times a day. To find the optimal number of activated antennas (DAS configuration), for two sleep modes, the objective is to jointly maximize the EE and power-saving for DAS. To do so, the antenna switch-off decision is determined based on two considerations. The first consideration meets the need of subscribers where it provides a high data rate according to the traffic load. The second consideration is that the largest possible number of antennas should be switched off to obtain the greatest decrease in energy consumption. The following two steps describe the considerations in detail.

Step 1 (optimal number of antennas for EE maximization (minimum EE degradation under sleep modes)). In order to maximize the EE in (14), on the one hand, the system throughput, L, has to be maximized. On the other hand, the transmit power, P_{tx}, in the denominator has to be minimized.

Based on (11), L scales with the number of activated antennas in (2), therefore, larger number of transmit antennas will result in higher system throughput. Moreover, (5), (6), and (7) show that the lower access distance (distance between UE and transmit antenna) provides lower path loss and interference-level. Therefore, by distributing all transmit antennas throughout the cell (RRUs), the probability of access distance will be increased, since UEs are randomly distributed, which consequently would result in higher system throughput.

The minimum of P_{tx} is achievable by reducing the transmission power. Therefore, according to (15) and its power sharing criteria (per central and distributed-antenna power constraints), by increasing the number of RRUs, the P_{tx} per antennas will be reduced. Therefore, fully distributed antennas will result in the minimum P_{tx}. However, it should be noted that, since the total number of deployed antennas is variable, while the coverage area of the network is fixed, the maximum transmit power for all scenarios is constant (i.e., 46 dBm), in order to keep the coverage area acceptable/constant. Therefore, analytical analysis show that, by increasing the number of antennas and fully distributing them throughout the cell, the maximum of EE can be achieved.
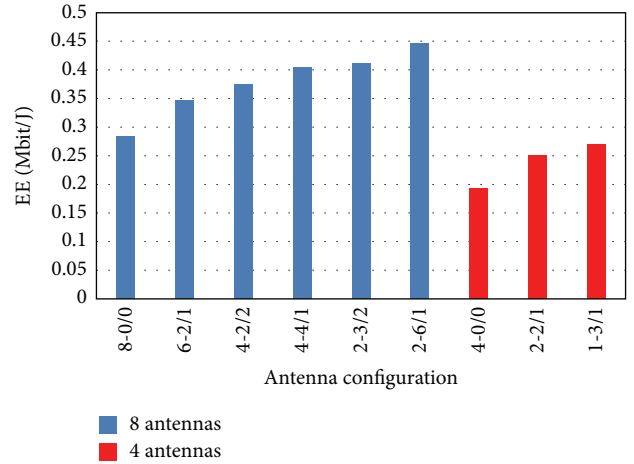
Step 2 (optimal number of antennas for power-saving maximization (minimizing the total daily consumed power)). According to (8), the minimum power consumption, $P_{tot}^{macro-BS}$, can be achieved by reducing the number of activated antennas (minimizing the dynamic part of consumed power). For this purpose, we calculate the total consumed power according to (8) and set an EE degradation constraint based on the cell-load.

Note that the maximization of EE and power-saving depends on the number of activated antennas. The minimum of $P_{tot}^{macro-BS}$ can be achieved by reducing N_{ant}^{active}, and the maximum of EE can be achieved by increasing N_{ant}^{active}. By these means, N_{ant}^{active} is the interconnected variable in the aforementioned two steps, and the optimal number of N_{ant}^{active} is the solution to our problem. Therefore, number of activated antennas has to be reduced in order to jointly maximize the EE and power-saving in different traffic loads (by making tradeoff between EE degradation and power-saving). Finally, the amount of saved power by the proposed method can be calculated by solving (10).

4. Result and Discussion

4.1. Comparison of Energy Efficiency of DAS and CAS. Figure 3 compares the performance of different DAS configurations with CAS (8-0/0 and 4-0/0) in terms of EE. The results are shown for the high load scenario and to speed up the simulations, the smallest channel bandwidth of $B_w = 1.4$ MHz is considered. The simulation results show that in CAS by doubling the number of transmit antennas the EE increased by 48%. While in DAS the improvement of EE highly depends to the number of RRUs, where the larger number of RRUs provides the higher EE. Because, in contrast to CAS, where all antennas are colocated at the central BS, by increasing the number of antennas and RRUs, more transmit antennas are distributed throughout the cell which results in more uniform cell coverage. Moreover, in this case, the access distance between UE and BS is reduced; therefore, lower
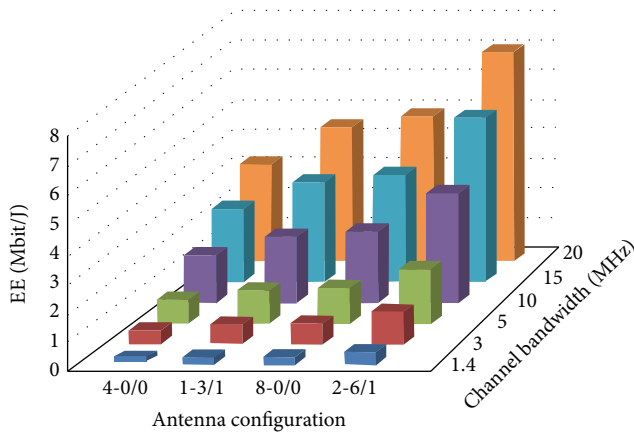
Figure 4: Comparison of EE of DAS and CAS in terms of different antenna configurations and channel bandwidth. High load scenario.
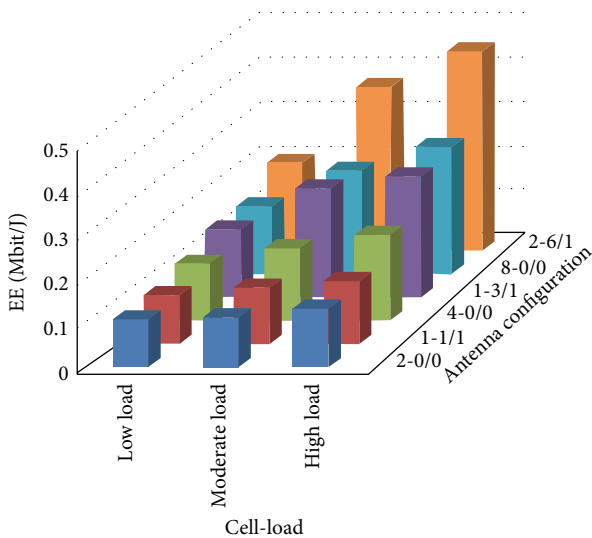

Figure 5: Comparison of cell throughput in three different cell-load scenarios and antenna configurations. B_w = 1.4 MHz.

Table 2: EE degradation and power-saving in different antenna switching-off modes.

Antenna muting mode	EE degradation (%)	
	Low load	Moderate load
2-6/1 $\Rightarrow$ 1-3/1	22.8	33.4
1-3/1 $\Rightarrow$ 1-1/1	28.4	48.2
2-6/1 $\Rightarrow$ 1-1/1	44.7	65.5

demonstrates the dependency of DAS to the cell-load and number of RRUs. DAS plays significant role to improve EE in congested networks especially where the number of antennas is high. Because, more RRUs are distributed among the cell, which results in more uniform cell coverage, less path loss, and lower interference, while, in the presence of low number of users, there is no significant gap between EE of DAS and CAS. Moreover, it can be seen that in this case by increasing the number of antennas no significant EE gain can be achieved.

In this regard, 2-6/1 configuration is selected for high load scenario since it provides the best performance for DAS and significantly surpasses the CAS (8-0/0) in terms of EE by 56.6%. Moreover, a comparison between two DAS configurations with 8 and 4 transmit antennas reveals that in high load scenario by switching off 4 transmit antennas (2-6/1 to 1-3/1) the system throughput degrades by 60%. Therefore, the 2-6/1 configuration is selected as the best DAS configuration for high load scenario.

Toward selecting the best DAS configurations (sleep modes) for low and moderate load scenarios, Table 2 presents the amount of EE degradation in different sleep modes. The results reveal that, in contrast to the congested networks, in the presence of lower number of users, the dependency of EE to the number of activated antennas is lower. It should be mentioned that the system throughput (data rate) scales with parameters such as number of transmit antennas, available bandwidth, number of activated users, and degree of SINR. Therefore, in the presence of a small number of users, few number of antennas could also provide the required service. On the other hand, it is clear that the power consumption degrades proportionally with reducing the number of antennas. So far, a cross comparison of results reveals that a good DAS configuration for moderate load scenario is 1-3/1 where 4 antennas are switched off and EE degrades by 33.4%. On the other hand, 1-1/1 configuration could provide an optimal performance for low load scenario where 6 antennas are switched off and only 28.4% of EE is degraded (versus moderate load). However, in order to find the optimal number of antennas (DAS configuration) for two sleep modes, the following subsection considers the amount of power consumption for the aforementioned cases in detail and by making tradeoff between EE degradation and energy saving concludes the results.

4.2. Energy Saving. The goal of this paper is to obtain the optimal number of activated antennas in the sleep modes in order to maximize the EE and power-saving in DAS. In this

power is required for downlink transmission where results in lower path loss and interference. Among the different antenna deployments, 2-6/1 and 1-3/1 (where all transmit antennas are fully distributed) provide best EE for DAS and considerably outperform CAS by 57% and 40%, respectively.

Results of Figure 4 are provided in the high load scenario where EE of DAS and CAS is evaluated under different antenna configurations and channel bandwidths. For DAS the 2-6/1 and 1-3/1 were chosen as they provided the best performance. The results show that by increasing the channel bandwidth, the EE increases as well and leads to the higher EE gap between DAS and CAS. Interestingly, it can be seen that DAS with 4 transmit antennas (1-3/1) performs close to CAS with 8 transmit antennas (8-0/0), while the network considerably consumes less energy (this is because 4 PAs are switched-off).

Figure 5 compares EE in different cell-load scenarios where different antenna configurations are applied. The result

TABLE 3: Power consumption of different DAS configurations.

| Parameter	Unit	High load 2-6/1		Moderate load 1-3/1		Low load 1-1/1	
		CAS (2)	DAS (6)	CAS (1)	DAS (3)	CAS (1)	DAS (1)
Max transmit rms power	[Watt]	20	4	20	7	20	7
Max transmit rms power	[dBm]	43	36	43	38.5	43	38.5
Power-added efficiency	[%]	38.8	28.5	38.8	28.5	38.8	28.5
P_{PA}	[Watt]	51.6	14.1	51.6	24.61	51.6	24.61
P_{RF}	[Watt]	10.9	5.4	10.9	5.4	10.9	5.4
P_{BB}	[Watt]	14.8	13.6	14.8	13.6	14.8	13.6
DC-loss	[%]	6	6.4	6	6.4	6	6.4
MS-loss	[%]	7	7.2	7	7.2	7	7.2
Cooling-loss	[%]	9	0	9	0	9	0
Total 1 antenna	[Watt]	97.04	38.11	97.04	50.21	97.04	50.21
Number of antennas	#	2	6	1	3	1	1
Total N antenna	[Watt]	194.1	228.64	97.04	150.62	97.04	50.21
Total power cons./sector	[Watt]	422.72		247.66		147.25	
Number of sectors	#	3		3		3	
Total power cons./cell	[Watt]	1268.17		743		441.75	
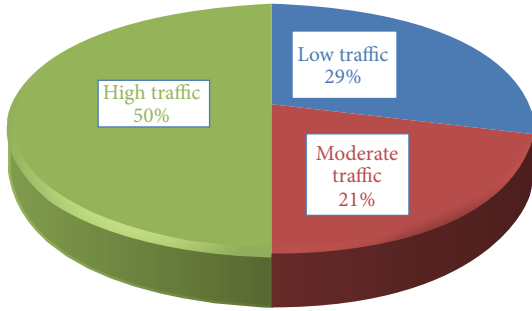
FIGURE 6: Percentage for each category of daily traffic.

regard, Figure 6 describes the percentage for each category of daily traffic. In addition, according to (8), Table 3 summarizes and compares the power consumption of different DAS configurations proposed in the present study. The last row of Table 3 gives the consumed power per hour for each selected DAS configuration in three different cell-load scenarios. The results show a power-saving of 41% and 66% for the two proposed sleep modes, moderate and low load scenarios, respectively (versus high load scenario).

Finally, we discuss aspects of the total daily energy saving that can be achieved by our proposed scheme. To do so, according to (10), the following briefly computes the daily power consumption for two cases.

(1) During normal operation (without switch-off scheme), where 2 antennas are located at the central BS and 6 antennas are distributed (RRUs) over 24 hours. Therefore,

$$P_{Cons}^{day} = \left(N_{ant}^{active} \times P \right) \times \text{day-time}$$
$$= 126817 \times 24 = 30.44 \text{ K Watt/day}. \tag{16}$$

(2) During the proposed DAS switch-off scheme, during moderate load scenario, half of the total antennas are activated (one in central BS and 3 RRUs) for five hours, whereas during low load scenario, number of antennas reduce to one in the center and one RRU, as described in Table 3. Therefore,

$$P_{Cons}^{day} = 12 \, (126817) + 5 \, (743) + 7 \, (441.75)$$
$$= 22.03 \text{ K Watt/day}. \tag{17}$$

The results show that, by applying the proposed scheme to the cellular system, the amount of energy consumption can be reduced by 8.41 K Watt per day, which means that 27.63% of the network power can be saved.

5. Conclusion

In this paper, the performance of different DAS configurations has investigated in terms of energy efficiency and compared with the CAS where all antennas are colocated at the central base station. It has shown that by distributing all transmitter antennas throughout the cell significant energy efficiency can be achieved versus CAS. Moreover, results have revealed high dependency of DAS to the cell load and number of RRUs, where DAS can provide significant EE gain in congested networks. Finally, based on the tradeoff between EE and power-saving, two DAS configurations (sleep modes) have been proposed for moderate and low load scenarios. The proposed methodology achieved 27.63% power-saving while guaranteeing a high capacity of data.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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