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Energy-Efficient On–Off Power Control of Femto-Cell Base Stations for Cooperative Cellular Networks

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Abstract: Improving energy efficiency (EE) of mobile communication systems (MCSs) has been considered a key aim in recent years, and has been the subject of intense research interest. One of the simplest yet most powerful ways to increase the EE is to turn off redundant communication entities whose operation does not greatly affect the overall performance of the MCS. In this paper, we propose a novel on–off power control scheme for femto-cell base stations (FBSs) considering cooperative transmission in which multiple FBSs collaborate on the same data transmission. In the proposed scheme, the operation of the redundant FBSs is halted in an adaptive manner. For the proper determination of redundant FBSs with low computational complexity, we propose using the level of contribution (LOC), which specifies the importance of a given FBS in the cooperative transmission. Redundant FBSs are chosen based on their LOC value, and these FBSs are turned off in order to reduce the power consumption of MCSs while minimizing the degradation of the overall throughput of cooperative transmissions. The performance of the proposed scheme is verified through extensive simulations, which shows that near-optimal performance can be achieved without excessive computations.

Keywords: on–off power control; BS Switching-off; femto-cell BS; cooperative transmission; optimization problem

1. Introduction

1.1. Energy Efficiency Problem in MCS

Recently, the environmental pollution caused by CO_2 emission has become one of the biggest threats to humanity. Given that the generation of electricity is the dominating source of CO_2 emission, a lot of effort has been made in order to reduce the use of electricity in all areas including telecommunication systems [1]. Developing energy efficient mobile communication systems (MCSs), i.e., green cellular networks (GCNs), is important in this regard because the amount of electricity consumed by the information and communication infrastructure increases nearly 20% per year [1,2]. Moreover, improving energy efficiency (EE) of MCSs is also important because the amount of mobile traffic is expected to increase exponentially due to the widespread use of Internet of Things (IoT) technology [3].

As a consequence, various methods have been devised to improve the EE of MCSs [4–10]. The energy harvesting (EH) from radio frequency (RF) signals has recently been investigated, in which RF signals are converted into energy that can be used for data processing and transmission [11,12]. Energy efficient clustering of FBS using coordinated multi-point (CoMP) has been taken into account in [5]. The effective frequency resource allocation scheme with interference mitigation and energy efficient power allocation for two-tier Orthogonal Frequency-Division Multiple Access (OFDMA) femtocell networks was considered in [8,9], respectively. The authors of [7] investigated the energy efficient issues of cognitive radio networks (CRNs) where energy efficient spectrum sensing, resource allocation, and deployment of CRN were taken into account. Note that aforementioned works did not consider on–off power control of FBSs, which is described in the next section.

1.2. On–Off Power Control Schemes in MCS

The most straightforward way to improve the EE of MCSs is to simply turn off base stations (BSs) whose operation is unnecessary in view of overall network performance [1,13–20]. Through the shutdown of BSs, electricity consumption can be reduced significantly because more than half of total electricity consumption in MCSs is caused by BSs. Consequently, on–off power control schemes for BS have been extensively studied in previous literature, especially in the context of GCNs [1,3,13–22]. The on–off power control schemes for BSs can be divided into two categories: which are statistical scheme and adaptive scheme. In the statistical scheme, the network operators manually decide which BSs to shutdown [1]. For example, BSs which are located in rural areas can be turned off during the nighttime because the amount of traffic load is likely to be low, such that users can be served without experiencing the degradation of quality of services (QoS) by a fewer number of BSs [1]. Generally, the statistical scheme is applied to macro BS (MBS), whose coverage is wide.

On the other hand, in an adaptive scheme, BSs are flexibly turned off based on the real-time information, e.g., incurred traffic load on each BS [13–15,19]. For example, certain BSs can be turned off for the period when the traffic load incurred at those BSs is sufficiently low [13,14]. Unlike the statistical schemes, in the adaptive scheme, switched off BSs can also be turned on in real-time according to the environmental changes, e.g., sudden increase of traffic load. In general, the adaptive on–off power control scheme is applied to femto BSs (FBSs) whose transmission range is short [23–26]. Note that due to its possibility to improve the performance of MCS, the FBS has been studied extensively in recent days, especially in the view of resource allocation [24–26]. In this paper, we focus on the adaptive on–off power control scheme for FBSs.

Due to its importance, the adaptive on–off power control scheme has recently been the subject of extensive investigation [15–22]. In [21], the on-off state of BS which operates based on the renewable generation, e.g., wind power, was optimized where the main objective is to minimize the on-grid power consumption. The coverage probability and EE of MBS were analyzed using the stochastic geometry in [15], which reveals that the strategic sleeping where MBS is turned off is based on the amount of traffic load, gives better performance compared with the random sleeping of MBS. The authors of [16,17] considered the distance between the FBS and mobile station (MS) in the determination of which FBS to shut down, i.e., the operation of FBS which is far from MSs, is halted. Furthermore, in [18], the adaptive FBS switching-off scheme was considered for the indoor FBS in which the operation of redundant FBS is stopped by examining the achievable throughput. In addition, the switching-off of FBS was determined based on the results of subcarrier allocation such that FBS with a small number of allocated subcarriers, i.e., low traffic FBS, is turned off in [19]. Finally, the authors of [6] considered the on–off power control scheme for FBS in order to improve EE, where the FBS is turned on only when active MS is nearby.

In most conventional on–off power control schemes for FBSs, the traffic load incurred on each FBS is generally used to determine which FBSs are to be halted [15,18,19]. Although the use of the incurred traffic load is reasonable in most of cases, it can be inappropriate when the cooperative transmission is used, in which multiple FBSs cooperate in data transmission to improve the performance, e.g., CoMP [27–32]. More specifically, the contribution, i.e., the throughput improvement due to the participation of the FBS in the cooperative transmission, of each FBS on the cooperative transmission has to be taken into account in order to properly decide which FBS to switch off. Otherwise, the performance of cooperative transmission can be severely deteriorated. In [22], the switching-off of clustered FBSs which utilize the CoMP was considered. However, FBSs which collaborate in the same cooperative transmission cannot be selectively turned off, such that the performance of on–off power control is not fully optimized. The joint use of CoMP and switch off was considered in [20]. However, the CoMP is used to compensate the performance degradation caused by the shutdown of BSs, and the set of turned off BSs is determined without considering the CoMP.

1.3. Our Contributions

We herein propose a novel on–off power control scheme considering the cooperative transmission, i.e., CoMP. The main contributions are as follows:

1. Our proposed on–off power control scheme efficiently minimizes the power consumption of MCS. Unlike previous approaches, we take proper account of cooperative transmission, i.e., CoMP, of FBSs such that the data rate of MCS is not degraded excessively. To this end, we propose to use a new metric, which is level of contribution (LOC), such that the optimal set of turned off FBSs can be found with low computational complexity. Although the clustering of FBSs considering CoMP has been studied in previous literature [5], the switching-off scheme of FBSs considering CoMP has not been taken into account previously.
2. We evaluate the performance of our proposed scheme through simulations based on realistic system parameters. The results verify that the power consumption of MCS can be reduced without violating the constraint on data rate degradation. It is also shown that our proposed scheme achieves near-optimal performance while the number of computations can be greatly reduced compared with the optimal scheme.

The remainder of the paper is organized as follows. In Section 2, we show the limitation of the conventional on–off power control scheme that relies on the traffic load using toy example. We describe our system model, formulate the optimization problem to find the optimal set of shutdown FBSs, and explain the proposed scheme in Section 3. Our simulation results are shown in Section 4, and in Section 5, we provide our conclusions.

2. Limitation of Conventional On–Off Power Control Schemes

In this section, we illustrate the limitation of conventional on–off power control schemes in which the set of FBS to be turned off is determined based on incurred traffic load, when cooperative transmission is used, by using the toy example shown in Figure 1. In the considered toy example, we assume that two types of cooperative transmission are used: (1) three FBSs including FBS 1 cooperatively transmit data to MS 1 (i.e., Cluster 1); and (2) two FBSs, which are FBS 1 and 2, cooperatively transmit data to MS 2 (i.e., Cluster 2) [27]. Moreover, we assume that only one MS can be served at the same time, i.e., only one cluster can be activated simultaneously, in order to avoid excessive interference among cooperative transmissions, e.g., CSMA [28]. Furthermore, we assume that FBSs which are within the same cooperative cluster transmit the same data, i.e., CoMP, such that the amount of traffic load of the FBSs which participate in cooperative transmission is the same.

In conventional on–off power control scheme, it is more likely to turn off FBS 2 than switching off FBS 1 because FBS 2 participates in only one cooperative transmission, i.e., Cluster 2, while FBS 1 participates in both cooperative transmissions, i.e., Clusters 1 and 2. Accordingly, the traffic load of FBS 1 will always be larger than that of FBS 2 such that the operation of FBS 2 is more redundant in view of traffic load. However, if we take into account the throughput of cooperative transmission, it can be better to turn off FBS 1 because FBS 1 is far away from both MSs, i.e., MS 1 and MS 2, such that its effect on both cooperative transmission could be minor.

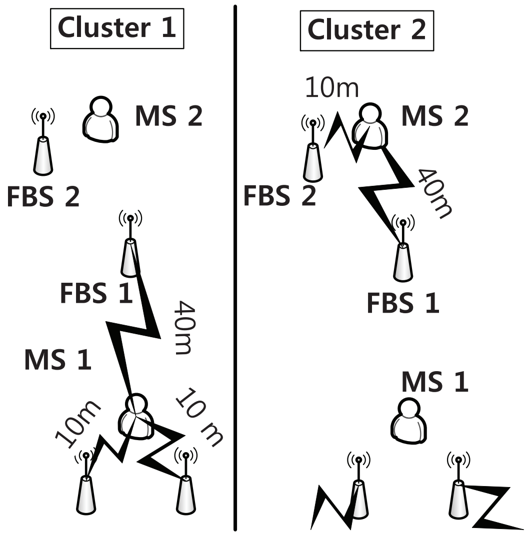

Figure 1. Toy example that depicts the limitation of conventional on–off power control scheme.

The advantage of shutdown of FBS 1 can be easily confirmed through the calculation of throughput. In the calculation, we consider the IMT-A M.2135 indoor hotspot path-loss model and assume that the transmit power of FBSs is 1 mW [33]. In this case, if FBS 2 is turned off, the throughput of cooperative transmission in Cluster 2 is reduced by 60% compared to that without the shutdown of FBS. Note that the throughput of Cluster 1 is unaffected by the shutdown of FBS 2. On the other hand, if FBS 1 is switched off, the degradation of throughput of both cooperative transmission is less than 0.1%. It should be noted that the reduction of energy consumption is the same for both cases because the operation of one FBS is halted. From this toy example, the limitation of conventional on–off power control scheme can be confirmed when cooperative transmission is taken into account.

3. System Model, Problem Formulation and Proposed Scheme

In this section, we present a system model, formulate the optimization problem, and describe the proposed on–off power control scheme for FBS which uses cooperative transmission.

3.1. System Model

In this paper, we consider the cooperative transmission in which multiple FBSs jointly transmit data to one MS simultaneously, i.e., downlink transmission. It is worth noting that the switching-off of FBS will not result in the additional end-to-end delay, because more than one FBS transmit data to MS. The set of all FBSs, active FBSs, and FBSs in shutdown state are denoted as $\mathbb{N}$, $\mathbb{A}$, and $\mathbb{I}$, respectively, and $|\cdot|$ denotes the number of elements in the set, e.g., $|\mathbb{N}|$ corresponds to the number of all FBSs. We assume that the number of MSs is K and K_i represents the set of FBSs which can participate in transmission to MS i. We assume that the transmit power of FBSs is denoted as P and this value is same for all FBSs, i.e., heterogeneous transmit power is not considered. Furthermore, both fast fading and slow fading are considered, which are denoted as $h_{i,j}(t)$ and $G_{i,j}$, respectively. Here, i is the index of MS, j is the index of FBS, and t represents the time. It is worth noting that the value of fast fading changes over time while that of slow fading remains the same in our system model. In addition, the noise at the MS is modeled to be independent and identically distributed (i.i.d.) circularly symmetric complex Gaussian (CSCG) with a zero mean and N_0 variance, i.e., $\mathcal{CN}(0, N_0)$, and the MS is interfered with by other communication systems, whose power is I_{inter}. Finally, we assume that the power consumption of active FBS is P_{active} and that of turned off FBS is $P_{inactive}$, where $P_{active} \gg P_{inactive}$. Our system model is depicted in Figure 2.

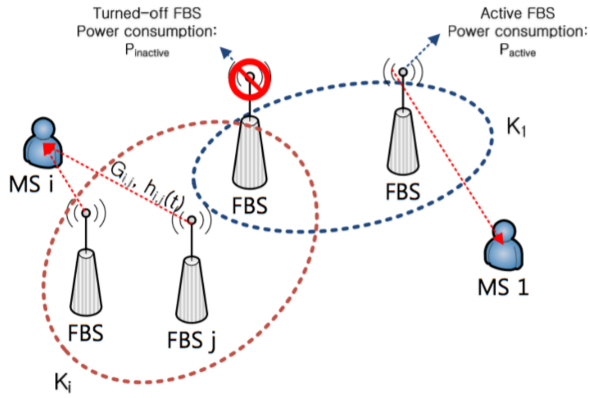

Figure 2. System model which depicts femto-cell base stations (FBSs) with cooperative transmission, MS: mobile station.

For the cooperative transmission, we assume that collaborating FBSs transmit the same signal at the same time [28,34]. Then, the throughput of MS i at time t can be formulated as follows:

$$R_{i,t}(\mathbb{A}) = W \log_2 \left(1 + \frac{\sum_{j \in \{\mathbb{A} \cap K_i\}} |h_{i,j}(t)|^2 G_{i,j} P}{N_0 W + I_{inter}} \right). \quad (1)$$

Here, j represents the index of active FBS which participates in the cooperative transmission for MS i.

We also derive the average traffic load of FBS j, which we denote as $L_j(\mathbb{A})$, as follows.

$$L_j(\mathbb{A}) = \mathbb{E}\left[\sum_{i=1}^{K} R_{i,t}(\mathbb{A}) \mathbb{1}_{j \in K_i} \mathbb{1}_{j \in \mathbb{A}} \right], \quad (2)$$

where $\mathbb{1}(x)$ is the indicator function whose value is 1 when x is true and 0, otherwise. Moreover, $\mathbb{E}(\cdot)$ is the expectation.

3.2. Problem Formulation

Based on our system model, we can formulate the optimization problem to find the optimal set of FBSs to be activated. In the formulated problem, the objective is to minimize the total power consumption of MCS. However, the data rate of cooperative transmission can be severely deteriorated because more FBSs are likely to be turned off to save more power. Accordingly, we also take into account an additional constraint that specifies the maximum allowable degradation of throughput. To be more specific, we assume that the expected throughput should be higher than R_{thr}.

Then, the optimization problem to find an optimal set of turned off FBSs can be formulated as follows:

$$\begin{aligned} \text{minimize} \quad & P_{active}|\mathbb{A}| + P_{inactive}|\mathbb{I}| \\ \text{s.t.} \quad & \mathbb{E}\left[\sum_{i=1}^{K} R_{i,t}(\mathbb{A}) \right] \geq R_{thr} \\ & R_{i_1,t} \cdot R_{i_2,t} = 0, \quad \text{for} \quad i_1 \neq i_2 \\ & \mathbb{A} \subset \mathbb{N} \\ & \mathbb{A} \cup \mathbb{I} = \mathbb{N} \\ & \mathbb{A} \cap \mathbb{I} = \emptyset. \end{aligned} \quad (3)$$

In problem (3), the second constraint, $R_{i_1,t} \cdot R_{i_2,t} = 0$, comes from the fact that only one MS can receive data at the same time.

Note that the problem (3) is non-convex integer programming such that the computational complexity needed to find the solution grows exponentially as $|\mathbb{N}|$ increases [35], as we have shown in the performance evaluation. Therefore, it is hard to find the optimal solution, in practice, especially when the number of FBSs is large, i.e., $|\mathbb{N}| \gg 0$.

It should be noted that when the conventional on–off power control scheme is considered, in which FBSs to shut down are selected based on the traffic load, the optimization problem to find an optimal set of active FBSs can be revised as follows:

$$\begin{aligned} \text{minimize} \quad & P_{active}|\mathbb{A}| + P_{inactive}\left(|\mathbb{N}| - |\mathbb{A}|\right) \\ \text{s.t.} \quad & \mathbb{E}\left[\sum_{i=1}^{K} R_{i,t}(\mathbb{A})\right] \geq R_{thr} \\ & R_{i_1,t} \cdot R_{i_2,t} = 0, \quad \text{for} \quad i_1 \neq i_2 \\ & L_a(\mathbb{N}) \geq L_b(\mathbb{N}), \forall a \in \mathbb{A}, b \in \mathbb{I} \\ & \mathbb{A} \subset \mathbb{N} \\ & \mathbb{A} \cup \mathbb{I} = \mathbb{N} \\ & \mathbb{A} \cap \mathbb{I} = \emptyset. \end{aligned} \tag{4}$$

In problem (4), the fourth constraint, $L_a(\mathbb{N}) \geq L_b(\mathbb{N}), \forall a \in \mathbb{A}, b \in \mathbb{I}$, is added in order to guarantee the FBSs with low traffic load, i.e., the FBSs which do not participate in many cooperative transmission, to be turned off.

3.3. Proposed Scheme

In order to resolve the problem of excessive computations in solving the optimization problem (3), we have proposed a heuristic scheme based on the concept of LOC that indicates the importance of specific FBS in cooperative transmission. In our proposed scheme, the LOC value of FBSs is used to decide which FBS to be turned off. More specifically, the LOC of FBS i at time t, which we denote as $\text{LOC}_i(t)$, is defined as follows:

$$\text{LOC}_i(t) = 1 - \frac{R_{i,t}(\mathbb{A} \backslash i)}{\mathbb{E}\left[R_{i,t}(\mathbb{N})\right]}. \tag{5}$$

Note that, in Equation (5), $R_{i,t}(\mathbb{A} \setminus i)$ and $\mathbb{E}\left[R_{i,t}(\mathbb{N})\right]$ correspond to the achievable throughput without FBS i and the expected data rate without the shutdown of all FBSs, i.e., all FBSs are activated, respectively.

If FBS i plays a crucial role in cooperative transmission, i.e., the data rate of cooperative transmission decreases severely without the use of the FBS i, $\text{LOC}_i(t)$ will be close to 1. Otherwise, if the role of FBS i is minor, $\text{LOC}_i(t)$ will be close to 0. In our proposed scheme, FBSs with low LOC value are switched off because the shutdown of those FBSs will not significantly deteriorate the performance of cooperative transmission.

Given that the LOC of FBSs is heavily affected by fluctuating channel environment, e.g., $h_{i,j}(t)$, $\text{LOC}_i(t)$ has to be accumulated in order to properly decide which FBS to switch off. Otherwise, FBS which temporarily undergoes bad channel condition will be switched off accidentally even though this FBS plays a significant role in the transmission. To this end, in our proposed scheme, FBS i is turned off if the following inequality is satisfied:

$$\prod_{t-M \leq k \leq t} \text{LOC}_i(k) < 1 - \epsilon, \tag{6}$$

where M is the window size and ϵ is the controlling parameter which determines the ratio of FBSs to be turned off. If ϵ is small, more FBSs will be turned off such that more energy can be saved, but, at the same time, the throughput of cooperative transmission can be deteriorated more severely, as can be seen from our simulation results in the following section. Moreover, in order to satisfy the tolerable performance degradation, the switched off FBS should be immediately turned on if $\mathbb{E}\left[\sum_{i=1}^{K} R_{i,t}(\mathbb{A})\right] < R_{thr}$.

Given that network environment changes over time, the switched off FBS should not be turned off permanently and be awakened at the proper time. To this end, we assume that turned off FBSs should periodically wake up and listen to the uplink pilot transmitted from neighboring MSs. If the average value of accumulated received signal strength indication (RSSI) of uplink pilot is larger than δ, the FBS gets up and participates in cooperative transmission because large RSSI implies that the MS is closely located such that the switched off FBS can play a significant role in data transmission to that MS. The criterion to turn on the FBS in shutdown state can be written as follows:

$$\frac{\sum_{t-M\leq k\leq t}|h_{i,j}(t)|^2 G_{i,j}P}{M} > \delta. \tag{7}$$

Algorithm 1 and Figure 3 depict the pseudo code and the illustrative procedure of our proposed scheme, respectively. First, the LOC of each FBS is accumulated as shown in Equation (6). If the accumulated LOC of specific FBS is smaller than $1-\epsilon$, the referenced FBS is turned off and shutdown notification message is sent to a central management unit (CMU). After the shutdown of FBS, the CMU monitors the degradation of service quality. If the level of degradation is larger than threshold, it sends an immediate turn-on message to the switched off FBS such that it can be awakened in order to recover the throughput, cf. FBS 1 in Figure 3. If the averaged value of accumulated RSSI of uplink pilot transmitted from the switched off FBS is larger than δ, i.e., Equation (7) is satisfied, the corresponding FBS is turned-on, cf. FBS 2 in Figure 3.

Algorithm 1 On–Off power control of femto-cell base station (FBS) based on the level of contribution (LOC)

1: Set $\mathbb{A} = \mathbb{N}$ and $\mathbb{I} = \emptyset$
2: **repeat**
3: Accumulate LOC$_i(t)$ for M time instants
4: **If** (6) is satisfied for active FBS j **then**
5: $\mathbb{A} = \mathbb{A} \setminus \{j\}$ and $\mathbb{I} = \mathbb{I} \cup \{j\}$
6: **If** $\mathbb{E}\left[\sum_{i=1}^{K} R_{i,t}(\mathbb{A})\right] < R_{thr}$ **then**
7: $\mathbb{A} = \mathbb{A} \cup \{j\}$ and $\mathbb{I} = \mathbb{I} \setminus \{j\}$
8: **If** (7) is satisfied for inactive FBS k **then**
9: $\mathbb{A} = \mathbb{A} \cup \{k\}$ and $\mathbb{I} = \mathbb{I} \setminus \{k\}$

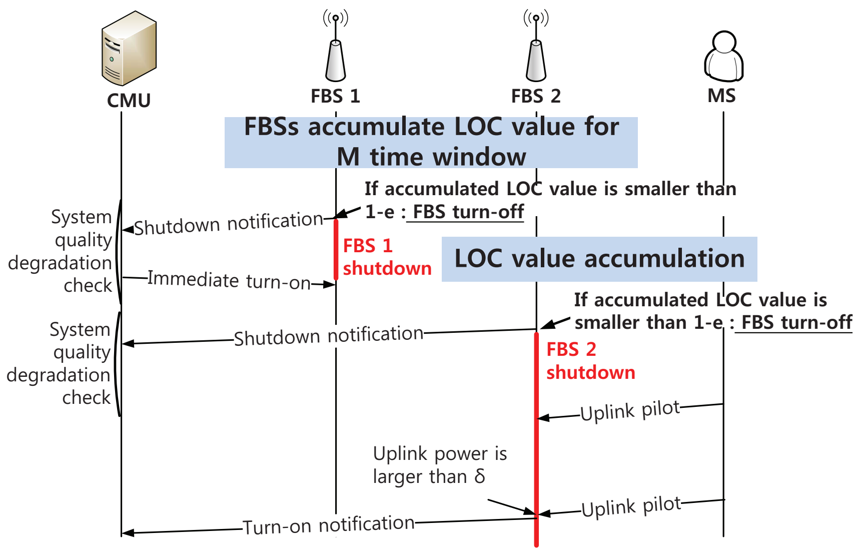

Figure 3. Procedure of proposed on–off power control scheme, LOC: level of contribution.

4. Performance Evaluation

In this section, the performance of our proposed on–off power control scheme is evaluated through a simplified system level simulator based on Matlab. In the performance evaluation, we assume that N FBSs are randomly deployed and they transmit data using CoMP to one MS which is located at the center, i.e., K = 1. Moreover, we assume that the maximum and the minimum distance between the FBS and MS are 50 m and 30 m, respectively. For path loss model, we used the IMT-R M.2135 urban macro model [33], i.e., $G_{i,j} = 34.5 + 38\log_{10}(d_{i,j})$, where $d_{i,j}$ is the distance between MS i and FBS j. Moreover, we assume that noise density is -174 dBm/Hz, bandwidth is 10 MHz, $I_{inter} = -70$ dBm, M = 5, and the transmit power of FBS is 23 dBm. In addition, we assume that the channel experiences the fast fading which is modeled as a CSCG with mean 0 and variance 1. The simulation parameters are summarized in Table 1.

Table 1. Simulation parameters, FBS: femto-cell base stations; MS: mobile station.

Parameters	Values
Transmit power of FBS	23 dBm
Noise variance	-174 dBm/Hz [29]
Channel bandwith	10 MHz
M	5
K	1
Maximum distance between FBS and MS	50 m
Minimum distance between FBS and MS	30 m
I_{inter}	-70 dBm
Path-loss model	$34.5 + 38\log_{10}(d)$ [33]

In Figures 4 and 5, we show the number of active FBSs, $|\mathbb{A}|$, and the spectral efficiency of our proposed scheme by varying N and ϵ, which corresponds to the threshold for switching-off. Note that the number of active FBSs is proportional to the power consumption of GCN, i.e., more power can be saved when the number of active FBSs is small. As can be seen from Figure 4, the number of active FBSs decreases as ϵ decreases because FBSs are easier to be turned off. However, given that more FBSs are turned off, which results in the deterioration of cooperative transmission, the spectral efficiency decreases as ϵ decreases, as can be checked from Figure 5. It is worth noting that the spectral efficiency is high when N is high, e.g., N = 50, because more FBSs participate in the cooperative transmission. Finally, we can observe that the variation of performance by varying ϵ is more abrupt when N is high. For example, the number of active FBSs when N = 50 decreases by 80% while that when N = 5 decreases by 45%. Moreover, the spectral efficiency when N = 50 decreases by 30% while that when N = 5 decreases by 20%. It is due to the fact that only a few number of FBSs dominate the performance of cooperative transmission even though a large number of FBSs participate in the transmission, such that many FBSs can be turned off without sacrificing the performance of cooperative transmission.

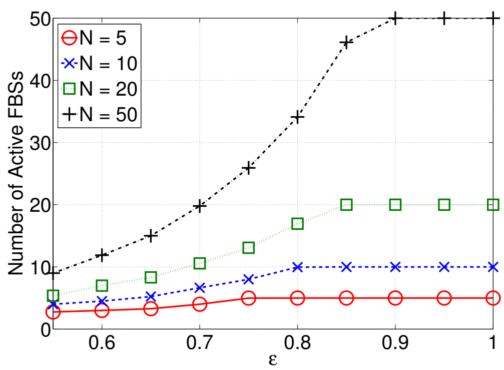

Figure 4. Number of active FBSs vs. ϵ by varying N.

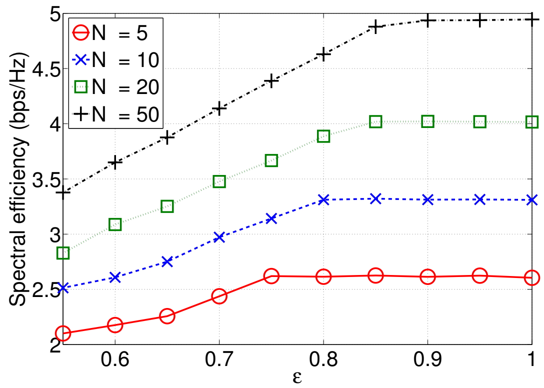

Figure 5. Spectral efficiency vs. ϵ by varying N.

The relative power consumption which is the ratio of power consumption with and without our proposed scheme, and spectral efficiency of our proposed scheme are depicted in Figures 6 and 7. In the simulation, we assume that $R_{thr} = \sigma\mathbb{E}\left[R_i(\mathbb{N})\right]$, such that σ represents the tolerable deterioration of spectral efficiency caused by FBS shutdown, i.e., more FBSs can be turned off when σ is low. For comparison, we have also evaluated the performance of FBS shutdown based on problem (3), which is denoted as ES. It should be noted that the performance of ES can be found by exhaustive search, which requires a huge number of computations as will be explained later. Moreover, the performance of our proposed scheme is denoted as Prop and R_{thr} is denoted as Thr. Finally, in our proposed scheme, the value of ϵ is adjusted in order not to deteriorate the spectral efficiency of cooperative transmission below R_{thr}.

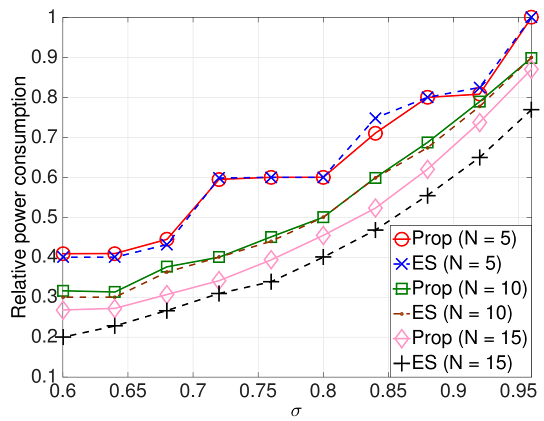

Figure 6. Relative power consumption of FBSs vs. σ by varying N.

As we can see from the simulation results, the relative power consumption and spectral efficiency decrease as σ decreases because more FBSs are likely to be turned off. Moreover, from Figure 7, we can find that the spectral efficiency of Prop and ES schemes is higher compared to that of Thr, which indicates that the constraint on R_{thr} is satisfied. It should be noted that the performance of our proposed scheme and that of ES are almost identical, which validates the optimality of our proposed scheme, especially when N is low. In practice, N is unlikely to be more than 10 such that our proposed scheme works well in practical cellular networks. In addition, we can observe that the relative power consumption is lower when N is high because only few FBSs have major influence on the performance of cooperative transmission.

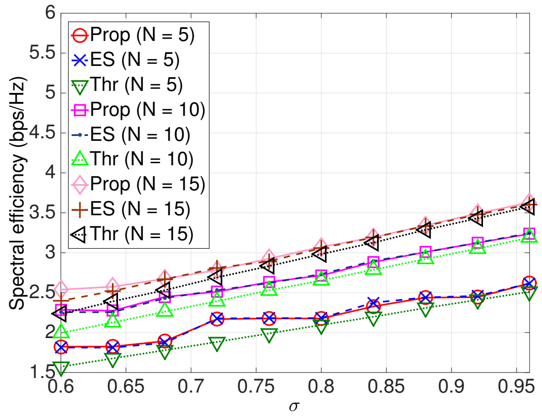

Figure 7. Spectral efficiency vs. σ by varying N.

Finally, we compare the computation times of our proposed scheme and that of the ES scheme in Figure 8. We can observe that the computation time of ES scheme increases exponentially as N increases because all the combinations of FBSs have to be examined to determine the optimal set $\mathbb{A}$. However, the computation time of our proposed scheme does not increase abruptly as N increases, which validates the merit of our proposed scheme.

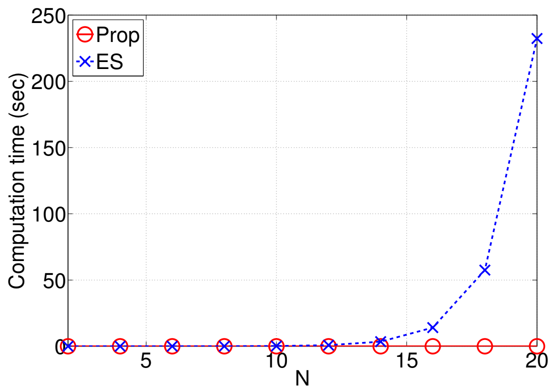

Figure 8. Computation time vs. N.

5. Conclusions

In this paper, the on–off power control of FBSs in order to reduce power consumption of MCSs was proposed when cooperative transmission is taken into account. Through the toy example, we showed that the conventional scheme where FBSs are turned off based on their traffic load is not appropriate when cooperative transmission is used. Then, the optimization problem to determine the FBSs to be turned off was formulated. In order to resolve the problem of huge computational complexity of the formulated problem, we proposed a new metric, i.e., LOC, which indicates the importance of specific FBS in cooperative transmission, and devised a heuristic scheme in which an FBS whose accumulated LOC is less than the threshold is turned off to reduce power consumption without excessively deteriorating the performance of cooperative transmission. Through simulations, we showed that the power consumption of MCSs can be greatly lowered without significant deterioration of the throughput of the system and with a lower number of computations. An interesting extension of this work might be the consideration of a more generalized cooperative transmission, in which FBSs in the same cooperative set can transmit different data with heterogeneous transmit power. Another interesting extension will be the verification of performance in a more generalized environment using sophisticated links and system level simulators such as NS-3.

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Author Contributions: Woongsup Lee and Bang Chul Jung conceived and designed the scheme; Woongsup Lee and performed the simulations and analyzed the data; Woongsup Lee and Bang Chul Jung wrote the paper.

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Abbreviations

The following abbreviations are used in this manuscript:

MCS	Mobile communication system
IoT	Internet of Things
EH	Energy harvesting
EE	Energy efficiency
RF	Radio frequency
BS	Base station
GCN	Green cellular network
QoS	Quality of services
MBS	Macro base station
FBS	Femto base station
CoMP	Coordinated multi-point
LOC	Level of contribution
MS	Mobile station
CMU	Central management unit
RSSI	Received signal strength indication
CSCG	circularly symmetric complex Gaussian
CRN	cognitive radio network

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