

Energy-Saving Coordinated Napping (CoNap) for Wireless Networks

Koichi Adachi, Jingon Joung, Sumei Sun, and Peng Hui Tan

Institute for Infocomm Research, A*STAR

1 Fusionopolis Way, #21-01 Connexis (South Tower), Singapore 138632

Email: {kadachi, jgjoung, sunsm, phtan}@i2r.a-star.edu.sg

Abstract—We propose a time-slot-based transmission strategy, referred to as *coordinated napping (CoNap)* for energy saving in cellular networks. In CoNap, multiple base stations (BSs) form a cluster and each BS operates in a transmit mode (TM) and a nap mode (NM) independently through an implicitly coordinated manner. The implicit coordination is implemented by the binary matrices to assign TM and NM to each BS in the cluster. CoNap can effectively reduce the network energy consumption and reduce the inter-cell interference, especially during the non-peak traffic load hours. Our numerical results based on a realistic energy consumption model in a cellular network show that as high as 50% saving can be achieved without compromising the quality of service to users.

I. INTRODUCTION

Recently, power efficiency or energy efficiency (EE) has become one of the important performance metrics of the cellular communication systems due to the high demand for energy saving. Therefore, the objective has been shifted from how to achieve the high spectrum efficiency (SE) to how to reduce the required power/energy while satisfying the quality-of-service (QoS) requirement, i.e., a high EE is desired [1], [2] or how to achieve a good tradeoff between SE and EE [3].

The traffic load of the cellular systems has dynamic nature in both time and space (location) [4]. Under a *high traffic load* condition, all resources, such as time slots, frequency bands, and multiple antennas, are utilized with a high probability to satisfy the high traffic demands. Accordingly, all base stations (BSs) are activated. On the other hand, under a *low traffic load* condition, only a part of the resources is necessary to satisfy the QoS requirement. Hence, power consumption can be reduced by deactivating BSs for a long period of time (e.g., up to several hours) during the low traffic load condition. To cover the service areas of the deactivated BSs, a cell zooming method and a coordinated multipoint (CoMP) method have been mainly considered [5]–[7]. However, these methods have several drawbacks as follows. Cell zooming method needs an additional *optimization* on transmit power and antenna tilt angle and an additional *transmit power* to support users in the other cells. On the other hand, CoMP needs an additional *information exchanges* for data, control signal, and channel state information, among the cooperating BSs.

For energy saving of long-term evolution (LTE) systems, discontinuous transmission (DTX) is considered without coordination among BSs [8]. Note that an operational cycle of DTX is much shorter than the above BS deactivation

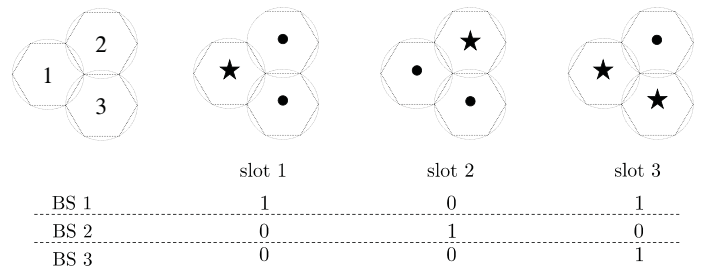


Fig. 1. An example of BS flickering over three time slots. ‘★’ and ‘●’ represent transmit mode (TM) and nap mode (NM), respectively.

methods. Time domain inter-cell interference coordination (ICIC) is introduced for heterogeneous network in LTE Rel-10 to increase the spectrum efficiency. Recently, the impact of coordinated sleep of LTE cell on EE is studied under *full traffic load* condition [9]. It is shown that coordination of BS sleep can bring additional improvement in EE due to the inter-cell interferences.

In this paper, we propose a time-slot-based transmission, termed by *coordinated napping (CoNap)*, to save the network energy consumption. The napping is equivalent to the subframe-based sleeping in [9], yet it represents well the behavior of BS which transmits after very short non-transmission time (e.g., 1ms for subframe of LTE). In the CoNap networks, multiple neighboring BSs form a *cluster*, and each BS in a cluster selects a transmit mode (TM) or a nap mode (NM) at each time slot according to a binary pattern. In TM, the pattern is one and the BS transmits a signal to its corresponding users as usual, while in NM, the pattern is zero and the BS stands by for the immediate transition from NM to TM. For example, in Fig. 1, CoNap is illustrated with a cluster consisting of three BSs. BS1 is in TM at time slots 1 and 3, and in NM at time slot 2, i.e., a binary pattern vector for BS1 is $(1\ 0\ 1)^T$. Since each BS alters its mode over time, we call this BS a *flickering BS* and the binary pattern is called a *flickering pattern*. The implicit coordination within the cluster is realized by a binary flickering pattern matrix including all flickering pattern vectors and a mapping matrix including all mapping pattern vectors. The mapping matrices will be designed later. In contrast to the existing BS deactivating approaches [5]–[7], BSs in CoNap cooperate *implicitly* and is neither in deactivate nor sleep mode. Different from [9], CoNap supports arbitrary number of cooperating BSs and flexible flickering pattern assignment

through a general flickering pattern matrix and a mapping matrix introduced later. The purpose of the CoNap is to reduce the energy consumption when a traffic load is low, while that of the time domain ICIC is to increase SE by controlling the subframe allocation under the heavy traffic load condition.

The instantaneous transmission rate during TM needs to be increased compared to the conventional approaches as each BS transmits during only TM. Hence, the transmit power or the required frequency domain resource blocks (RBs) may be increased to satisfy the QoS requirement. However, since the neighboring BSs in NM are not interference sources anymore, additional power or resources may not be significant. To verify this conjecture, we model the BS power consumption in the networks and evaluate the energy saving gain of CoNap. The simulation results show that as high as 50% energy saving can be achieved by CoNap without significant QoS degradation.

II. TRANSMISSION SYSTEM MODEL

Consider a downlink cellular system with B_{total} BSs. The numbers of total time slots and of total frequency domain RBs are denoted by S and M , respectively. The lengths of one transmission cycle and of one time slot are t_{cycle} and $t_{\text{ts}} (= t_{\text{cycle}}/S)$, respectively. Let us denote the whole BS set by $\mathcal{B}_{\text{total}}$, i.e., $|\mathcal{B}_{\text{total}}| = B_{\text{total}}$ with $|\mathcal{X}|$ being the cardinality of $\mathcal{X}$.

A. Received Signal Power at Users

In the proposed CoNap, each BS switches between TM and NM at each time slot according to the flickering pattern, which will be explained later. However, the inter-cell interference can not be reduced effectively if each BS randomly selects the flickering pattern. It motivates us to consider a BS clustering. The BSs in a cluster share the assignment information of flickering pattern. The cluster is formed by taking the same procedure as the well-known orthogonal frequency reuse, in which BSs are allocated to its own orthogonal frequency band. The BSs are divided into non-overlapping clusters, where each cluster is formed by B BSs. We refer to B as cluster size.

In the following, let us focus on the one cluster and denote the BS set within that cluster by $\mathcal{B}$ and the other BS set by $\bar{\mathcal{B}}$. Hence, $\mathcal{B} \cup \bar{\mathcal{B}} = \mathcal{B}_{\text{total}}$ and $\mathcal{B} \cap \bar{\mathcal{B}} = \emptyset$. The user set within the cluster is denoted by $\mathcal{U}$. The average received signal-to-interference plus noise ratio (SINR) of BS b during time slot s at user $u \in \mathcal{U}$, is calculated as

$$\gamma_{u,b,s} = f_{b,s} P_t G_{u,b} (I_{u,b,s} + \sigma_n^2)^{-1}, \quad (1)$$

where $f_{b,s} \in \{1, 0\}$ indicates that BS b is in TM if $f_{b,s} = 1$ and in NM if $f_{b,s} = 0$, P_t is the transmit power spectrum density, $G_{u,b}$ is the channel gain between user u and BS b which is assumed to be constant during one transmission period, $I_{u,b,s}$ is the interference from neighboring BSs, and σ_n^2 is the additive white Gaussian noise (AWGN) power density.

The channel gain, $G_{u,b}$, is given by

$$10 \log_{10} G_{u,b} = A(\psi_{u,b}) + L_{u,b} + \eta_{u,b}, \quad (2)$$

where $A(\psi_{u,b})$ is the antenna gain with $\psi_{u,b}$ being the elevation angle of user u from the main-beam direction of the antenna of BS b , $L_{u,b}$ is the distance dependant path-loss, and $\eta_{u,b}$ is the log-normally distributed shadowing-loss between user u and BS b with the standard deviation of σ^2 (dB).

The interference $I_{u,b,s}$ can be decomposed into two terms as

$$I_{u,b,s} = I_{u,b,s}^{\text{intra}} + I_{u,b,s}^{\text{inter}}, \quad (3)$$

where $I_{u,b,s}^{\text{intra}}$ represents the interferences from other BSs in the same cluster (intra-cluster interferences) and $I_{u,b,s}^{\text{inter}}$ represents the interferences from other clusters (inter-cluster interferences), and they are modeled as

$$\begin{cases} I_{u,b,s}^{\text{intra}} = P_t \sum_{b' \in \{\mathcal{B} \setminus b\}} f_{b',s} G_{u,b'} \\ I_{u,b,s}^{\text{inter}} = P_t \sum_{b' \in \bar{\mathcal{B}}} f_{b',s} G_{u,b'} \end{cases}. \quad (4)$$

B. Frequency Domain RB Allocation and Traffic Load

In this paper, only the large scale fading effects, i.e., path-loss and shadowing-loss, are considered to verify the potential benefit of the proposed CoNap. Here, the target rate is taken as a QoS requirement. Since there is no explicit cooperation among BSs, the RB allocation information at each BS cannot be shared among the BSs. Hence, each BS allocates sufficient number of RBs to each user such that the target rate can be achieved even under the intra-cluster and inter-cluster interferences. For frequency domain user scheduling, round robin (RR) scheduler is used (Note that any existing user scheduling algorithm can be incorporated into the CoNap).

Let $m_{u,b,s} \in \{0, 1, \dots, M\}$ indicate the number of RBs at BS b allocated to user u during time slot s , which satisfies

$$R_u^{\text{tar}} \leq S^{-1} \sum_{b \in \mathcal{B}} \sum_{s \in \mathcal{S}_{\text{TM},b}} m_{u,b,s} R_{u,b,s}, \quad (5)$$

where $\mathcal{S}_{\text{TM},b}$ denotes the set of time slots with $f_{b,s} = 1$, R_u^{tar} is the target rate of user u , and $R_{u,b,s}$ is the achievable rate per RB of user u by connecting to BS b during time slot s . The achievable rate is obtained as

$$R_{u,b,s} = W_{\text{total}} M^{-1} \log_2(1 + \gamma_{u,b,s}), \quad (6)$$

where W_{total} is the total system bandwidth.

Since the number of RBs is M , some users may be *blocked*, i.e., some user may not be allocated to sufficient number of RBs to satisfy (5). The blocking probability of the system is defined as $P_{\text{block}} \triangleq |\mathcal{U}_{\text{block}}|/|\mathcal{U}|$ with $\mathcal{U}_{\text{block}}$ being the user set who are blocked.

The traffic load, which represents the fraction of the RBs occupied at BS b during time slot s , is calculated as

$$\rho_{b,s} = M^{-1} \sum_{u \in \mathcal{U}} m_{u,b,s}. \quad (7)$$

Obviously, $0 \leq \rho_{b,s} \leq 1$. If $\rho_{b,s} = 0$, it is equivalent to $f_{b,s} = 0$, i.e., BS b is in NM.

C. Total Energy Consumption

The total energy consumption of a cluster during one transmission period is given as

$$E_c(\rho_{b,s}) = t_{ts} \sum_{b \in \mathcal{B}} \sum_{s \in \mathcal{S}_{TM,b}} P_{TM}(\rho_{b,s}) + t_{ts} P_{NM} \sum_{b \in \mathcal{B}} (S - |\mathcal{S}_{TM,b}|), \quad (8)$$

where $P_{TM}(\rho_{b,s})$ and P_{NM} are the total power consumption for given traffic load $\rho_{b,s}$ during TM and the power consumption during NM, respectively, which will be explained in the following.

A realistic total power consumption model at a BS is proposed as follows. The RF transmit power can be expressed as a function of the traffic load $\rho_{b,s}$ as [2]

$$P_{RF}(\rho_{b,s}) = \underbrace{(P_{\max} - P_{\text{over}})}_{W_{\text{total}} P_t} \rho_{b,s} + P_{\text{over}} \kappa(\rho_{b,s}), \quad (9)$$

where $P_{\text{over}} = p_{\text{over}} P_{\max}$ is the fixed overhead of the radiated power related to reference signal with $P_{\max}$ being the maximum transmit power and

$$\kappa(\rho_{b,s}) = \begin{cases} 1, & \text{if } \rho_{b,s} > 0 \\ 0, & \text{otherwise} \end{cases}. \quad (10)$$

The drain efficiency of a Doherty amplifier, that is defined as a ratio of output RF power to required DC power, is expressed as [10]

$$\eta(P_{RF}(\rho_{b,s})) = \begin{cases} \frac{\pi}{2} \sqrt{\frac{c P_{RF}(\rho_{b,s})}{c P_{RF}(\rho_{b,s}) - 1}} & 0 < c P_{RF}(\rho_{b,s}) \leq \frac{1}{4} \\ \frac{\pi}{2} \frac{c P_{RF}(\rho_{b,s})}{3 \sqrt{c P_{RF}(\rho_{b,s}) - 1}} & \frac{1}{4} < c P_{RF}(\rho_{b,s}) \leq 1 \end{cases}, \quad (11)$$

where $c = 1/(P_{\max} \times 10^{\text{OBO}/10})$, i.e., the inverse of the peak output power. Since the peak-to-average power ratio (PAPR) of current cellular system using orthogonal frequency division multiplexing (OFDM) is generally larger than 6 dB, output backoff (OBO) is set to more than 6 dB. Hence, the drain efficiency is always obtained from the first equation in (11).

By denoting the amplification gain of the PA by g , the input signal power to PA is given by $P_{\text{in}} = P_{RF}/g$. Then, the total required power of the PA for output power of $P_{RF}(\rho_{b,s})$ is

$$P_{PA}(\rho_{b,s}) = (g^{-1} + (\eta(P_{RF}(\rho_{b,s})))^{-1} P_{RF}(\rho_{b,s})) P_{RF}(\rho_{b,s}). \quad (12)$$

The total power consumption of BS for given traffic load $\rho_{b,s}$ is calculated as

$$P_{TM}(\rho_{b,s}) = (P_{\text{fix}} + \rho_{b,s} P_{\text{dyn}} + P_{PA}(\rho_{b,s})) P_{\text{loss}}, \quad (13)$$

where P_{fix} and P_{dyn} denote the power consumption at small-signal RF transceiver and base band interface, respectively, and P_{loss} is the total power loss due to AC-DC and DC-DC converters and cooling equipment. Each value of the consumed power is given as $P_{\text{fix}} = 10.8$ Watt, $P_{\text{dyn}} = 14.8$ Watt, and $P_{\text{loss}} = 27.9\%$ [2].

The total power consumption during NM is given as

$$P_{NM} = P_{\text{tx}}(0) = P_{\text{fix}} P_{\text{loss}}. \quad (14)$$

Remark 1: $P_{TM}(\rho_{b,s})$ is a concave function over $\rho_{b,s}$.

III. CONAP THROUGH FLICKERING PATTERN MATRIX AND MAPPING MATRIX

In contrast to the BS deactivating approaches, no BS is deactivated and there is *no explicit cooperation among BSs* in CoNap. The CoNap is realized by two matrices: a *binary flickering pattern matrix* and a *binary mapping matrix*. The number of time slots during one transmission period is referred to flickering pattern cycle as the same flickering pattern is repeated every S time slots.

A. Binary General Flickering Pattern Matrix

A *general binary flickering pattern matrix* is a Q -by- S binary matrix and denoted by $\mathbf{F}_G$, which captures the operation of BSs during flickering pattern cycle S . Since $\mathbf{F}_G$ is a binary matrix, the whole pattern can be covered by setting $Q = 2^S$, which denotes the total number of flickering patterns. $\mathbf{F}_G$ is expressed as

$$\mathbf{F}_G = \begin{pmatrix} \mathbf{f}_1^T \\ \vdots \\ \mathbf{f}_q^T \\ \vdots \\ \mathbf{f}_Q^T \end{pmatrix} = \begin{pmatrix} f_{1,1} & \cdots & f_{1,s} & \cdots & f_{1,S} \\ \vdots & \ddots & \vdots & & \vdots \\ f_{q,1} & \cdots & f_{q,s} & \cdots & f_{q,S} \\ \vdots & & \vdots & \ddots & \vdots \\ f_{Q,1} & \cdots & f_{Q,s} & \cdots & f_{Q,S} \end{pmatrix}, \quad (15)$$

where $\mathbf{f}_q = (f_{q,1} \cdots f_{q,s} \cdots f_{q,S})^T$ is the S -by-1 flickering pattern column vector and the element $f_{q,s} \in \{1, 0\}$ denotes the operation of BS at time slot s . If $f_{q,s} = 1$, the BS is in TM at time slot s , and otherwise it is in NM.

For example, the general binary flickering pattern matrix $\mathbf{F}_G$ with $S = 3$ is given by

$$\mathbf{F}_G = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{pmatrix}^T. \quad (16)$$

B. Mapping Matrix

Let us define a flickering pattern matrix of BSs in a cluster as

$$\mathbf{J} \triangleq (\mathbf{j}_1 \cdots \mathbf{j}_b \cdots \mathbf{j}_B)^T, \quad (17)$$

where $\mathbf{j}_b$ is a length S binary column vector which represents the flickering pattern assigned to BS $b \in \mathcal{B}$. A B -by- Q binary mapping matrix $\mathbf{M}_G$ is defined as

$$\mathbf{M}_G \triangleq (\mathbf{e}_{i_1} \cdots \mathbf{e}_{i_b} \cdots \mathbf{e}_{i_B})^T, \quad (18)$$

where $\mathbf{e}_i$ is a Q -by-1 column vector with a 1 at the i th element and 0's elsewhere.

Using the general binary flickering matrix in (15) and the binary mapping matrix in (18), we can determine the flickering pattern matrix in (17) as follows:

$$\begin{aligned} \mathbf{J} &= \mathbf{M}_G \mathbf{F}_G \\ &= (\mathbf{e}_{i_1} \cdots \mathbf{e}_{i_b} \cdots \mathbf{e}_{i_B})^T (\mathbf{f}_1 \cdots \mathbf{f}_q \cdots \mathbf{f}_Q)^T \\ &= (\mathbf{f}_{i_1} \cdots \mathbf{f}_{i_b} \cdots \mathbf{f}_{i_B})^T. \end{aligned} \quad (19)$$

The flickering pattern $\mathbf{f}_{i_b}$ is assigned to BS b .

C. Flickering Pattern Assignment

As shown in (19), any flickering pattern can be assigned to BSs from the general binary flickering pattern matrix $\mathbf{F}_G$ through the mapping matrix $\mathbf{M}$. In this subsection, we give several examples of the mapping matrix and resulting flickering pattern matrix assigned to BSs when $B = 3$ and $S = 3$ (i.e., $Q = 8$).

- 1) *Orthogonal Pattern Assignment*: Only one element of each column of the flickering pattern matrix is one, and remaining elements are zero as follows:

$$\begin{aligned} \mathbf{J}_{\text{orth}}^{(1)} &= (\mathbf{e}_2 \ \mathbf{e}_3 \ \mathbf{e}_5)^T \mathbf{F}_G = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix}, \\ \mathbf{J}_{\text{orth}}^{(2)} &= (\mathbf{e}_1 \ \mathbf{e}_2 \ \mathbf{e}_7)^T \mathbf{F}_G = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}. \end{aligned} \quad (20)$$

Remark 2: The intra-cluster interferences are completely eliminated as long as the same flickering pattern is not assigned to more than one BS.

Remark 3: The inter-cluster interferences become smaller as the number of BSs in other clusters becomes less, which is in TM during the same time slot, is less.

Remark 4: For the orthogonal flickering, the number of time slots and the cluster size should satisfy $S \geq B$.

- 2) *Random Pattern Assignment*: Each row can be randomly extracted from the rows of $\mathbf{F}_G$.

$$\begin{aligned} \mathbf{J}_{\text{rand}}^{(1)} &= (\mathbf{e}_2 \ \mathbf{e}_5 \ \mathbf{e}_8)^T \mathbf{F}_G = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 1 \end{pmatrix}, \\ \mathbf{J}_{\text{rand}}^{(2)} &= (\mathbf{e}_6 \ \mathbf{e}_6 \ \mathbf{e}_3)^T \mathbf{F}_G = \begin{pmatrix} 1 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}. \end{aligned} \quad (21)$$

Remark 5: For fixed S , the intra-cluster interferences become larger while the inter-cluster interferences become smaller as B increases.

IV. NETWORK ENERGY SAVING BY CONAP

In this section, we propose a network energy saving method by using the CoNap.

A. Orthogonal Flickering Pattern Assignment

As mentioned in Remarks 2 and 3, the orthogonal flickering pattern can completely eliminate the intra-cluster interferences and reduce the inter-cluster interferences, thus we use the orthogonal flickering pattern. Furthermore, for simplicity, we set $S = B$ to satisfy the condition for the orthogonal flickering pattern assignment in Remark 4, i.e., $S \geq B$. Accordingly, the length of each time slot is $t_{\text{ts}} = t_{\text{cycle}}/S$. As it is explained in Section III, every flickering pattern can be generated from the general binary flickering pattern matrix $\mathbf{F}_G$ and mapping matrix $\mathbf{M}_G$. To avoid to assign the same orthogonal flickering pattern to multiple BSs in the same cluster, we use the 2^S -by- S

general binary flickering pattern matrix $\mathbf{F}_G$ and the following mapping matrix $\mathbf{M}_{\text{fix}}$.

$$\mathbf{M}_{\text{fix}} = (\mathbf{e}_{i_1} \cdots \mathbf{e}_{i_b} \cdots \mathbf{e}_{i_B})^T, \quad (22)$$

where $i_b = 1 + 2^{S-b}$. For example, when $S = B = 4$ and $Q = 2^4$, we have the following flickering pattern matrix:

$$\mathbf{J}_{\text{orth}} = \underbrace{(\mathbf{e}_9 \mathbf{e}_5 \mathbf{e}_3 \mathbf{e}_2)}_{\mathbf{M}_{\text{fix}}} \underbrace{(\mathbf{f}_1 \cdots \mathbf{f}_q \cdots \mathbf{f}_Q)}_{\mathbf{F}_G}^T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \quad (23)$$

B. Network Energy Saving by Orthogonal Flickering Pattern

To minimize the total energy consumption per cluster, we formulate the optimization problem for a given flickering pattern $\mathbf{J}_{\text{orth}}$ as follows:

$$\min_{m_{u,b,s} \in \{0, \dots, M\}} E_c(\rho_{b,s}) \quad (24a)$$

$$\text{s.t.} \quad R_u^{\text{tar}} \leq \sum_{b \in \mathcal{B}} \sum_{s \in \mathcal{S}_{\text{TM},b}} m_{u,b,s} R_{u,b,s}, \quad \forall u \quad (24b)$$

$$\sum_{u \in \mathcal{U}} m_{u,b,s} \leq M, \quad \forall b, s \quad (24c)$$

$$\sum_{b \in \mathcal{B}} q \left(\sum_{s \in \mathcal{S}_{\text{TM},b}} m_{u,b,s} \right) \leq 1, \quad \forall u \quad (24d)$$

where $q(x) = 0$ when $x = 0$, otherwise $q(x) = 1$.

Constraint (24b) guarantees that each user's target rate, (24c) guarantees that the number of allocated RBs during each time slot at each BS is less than the total number of RBs, and (24d) follows the fact that there is no cooperation among BSs, i.e., each user is supported by a single BS.

Since the above problem is a combinatorial problem with the complexity $O(B^{|\mathcal{U}|})$, we develop a suboptimum algorithm to solve (24). To this end, we use the following observation. While satisfying (24b), $m_{u,b,s}$ is minimized by connecting to the BS with the highest $\gamma_{u,b,s}$ as it is a decreasing function over $\gamma_{u,b,s}$. Then, the following suboptimum algorithm to solve the optimization problem (24) is developed. First, each user is associated with the BS with highest SINR and the required number of RBs to satisfy the target rate is calculated using (6). Next, each BS checks whether the associated user can be accommodated. If there are enough number of RBs remained, the RBs are allocated to the user and move to next user. Otherwise, the user is considered to be blocked.

V. SIMULATION RESULTS

In this section, the energy consumption of the proposed CoNap is evaluated. The simulation parameters are summarized in Table I. In total $|\mathcal{U}|$ users are uniformly and randomly distributed within the cluster so that $\max_{b \in \mathcal{B}, s \in \mathcal{S}_{\text{TM},b}} \gamma_{u,b,s} \geq \gamma_{\text{th}}$ with γ_{th} being a predetermined threshold. Each user is equipped with two receive antennas. The interferences from neighboring six clusters are taken into account. The distance dependant path-loss is calculated as $L_{u,b} = 128.1 + 37.6 \log_{10}(d_{u,b})$ where $d_{u,b}$ (km) is the distance between user u and BS b . Antenna gain $A(\psi_{u,b})$ is calculated as in [11].

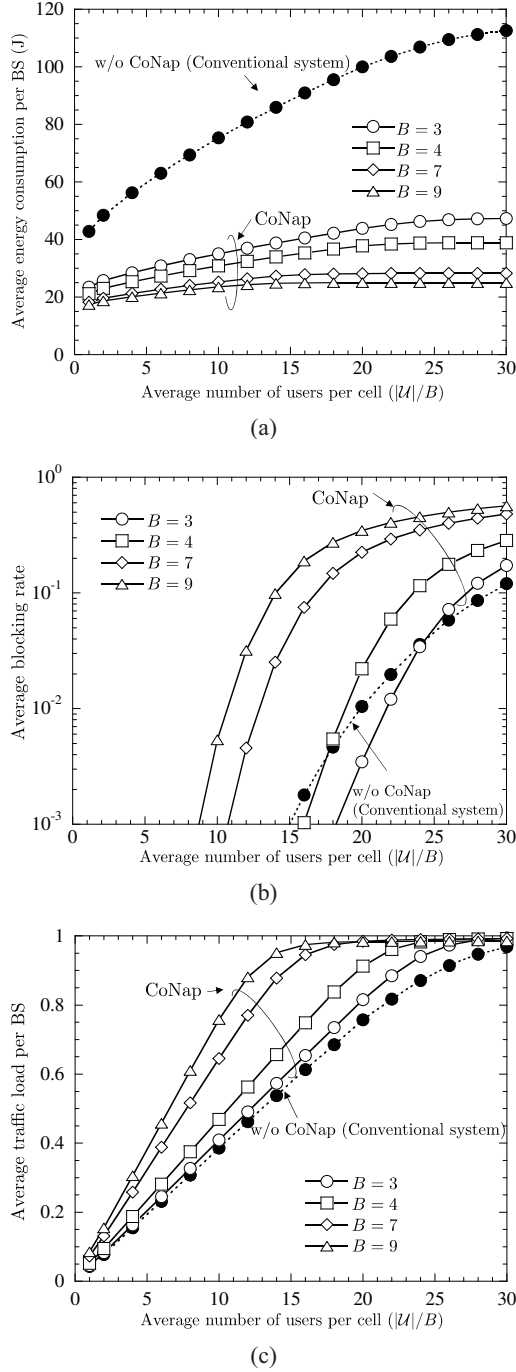


Fig. 2. Impact of average number of users per cell ($|U|/B$) with $R_u^{\text{tar}} = 1$ (Mbps): (a) Average energy consumption per BS (J) (b) Average blocking rate (c) Average traffic load per BS during TM.

TABLE I
SIMULATION PARAMETERS

Cluster size	B	3, 4, 7, 9
Cell radius	r_{cell}	290 (m)
Total bandwidth	W_{total}	10 (MHz)
Number of RBs	M	50
Maximum transmission power	P_{max}	46 (dBm)
Overhead of radiated power	p_{over}	0.1
Shadowing standard deviation	σ^2	8 (dB)
AWGN power density	σ_n^2	-174 (dBm/Hz)
SINR threshold	γ_{th}	-5 (dB)

The impact of the average number of users per cell ($|U|/B$) on the system performance is shown in Fig. 2 with the cluster size B being parameterized. The average energy consumption per BS, average blocking rate, and average traffic load per BS are taken as performance metrics. The target rate is fixed to $R_u^{\text{tar}} = 1$ (Mbps). Fig. 2 (a) clearly shows that the proposed CoNap provides significant energy saving gain irrespective of the number of users. When $B = 3$, up to 50% energy saving is achieved. This is because each BS is in NM during 2/3 of total transmission period. Furthermore, the intra-cluster interference is completely eliminated by the orthogonal flickering pattern. However, from Fig. 2 (b), the average blocking rate is severely degraded as B becomes larger. The blocking rate of the proposed CoNap with $B = 7$ and 9 is quite high. This is because the time slot duration becomes less and accordingly the transmission rate during TM needs to be higher. However, the number of frequency domain RBs and the transmission power are limited, the sufficient number of frequency domain RBs cannot be allocated to each user to support the QoS requirement. This can be seen from Fig. 2 (c) as the traffic load approaches 1 when B is larger and the number of users per cell becomes larger.

VI. CONCLUSION

In this paper, we propose a coordinated napping (CoNap), in which a non-transmission mode, so called napping mode, is realized by an implicit coordination among BSs according to a general binary flickering pattern matrix and a mapping matrix. As a consequence, significant reduction of the energy consumption can be obtained as verified by numerical results. Since the proposed CoNap requires only implicit coordination among the BSs, it can be implemented with low complexity and backhaul overhead.

REFERENCES

- [1] L. M. Correia, et al, "Challenges and enabling technologies for energy aware mobile radio networks," *IEEE Commun. Mag.*, vol.48, no.11, pp.66–72, Nov. 2010.
- [2] INFOS-ICT-247733 EARTH Deliverable D2.3 "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown", available@https://www.ict-earth.eu, Jan. 2012.
- [3] J. Joung, et al, "Tradeoff of spectral and energy efficiencies: Impact of power amplifier on OFDM systems," in *Proc. IEEE Globecom*, Anaheim, USA, Dec. 2012.
- [4] D. Willkomm, et al, "Primary user behavior in cellular networks and implications for dynamic spectrum access," *IEEE Commun. Mag.*, vol.47, no.3, pp.88–95, Mar. 2009.
- [5] Z. Niu, et al, "Cell zooming for cost-efficient green cellular networks," *IEEE Commun. Mag.*, vol.48, no.11, pp.74–79, Nov. 2010.
- [6] D. Cao, et al, "Energy saving performance comparison of coordinated multi-point transmission and wireless relaying," in *Proc. IEEE Globecom 2010*, pp.1-5, Miami, USA, Dec. 2010.
- [7] S. Han, et al, "On the energy efficiency of base station sleeping with multicell cooperative transmission," in *Proc. IEEE PIRMC 2011*, pp.1536–1540, Toronto, Canada, Sept. 2011.
- [8] P. Frenger, et al, "Reducing energy consumption in LTE with cell DTX," in *Proc. IEEE VTC'11-spring*, pp.1–5, Budapest, Hungary, May 2011.
- [9] K. Abdallah, et al, "Energy-efficient coordinated sleep of LTE cells," in *Proc. IEEE ICC'12*, pp.6760–6764, Ottawa, Canada, Jun. 2012.
- [10] S. C. Cripps, *RF Power Amplifiers for Wireless Communications*, Second Edition, Artech House Microwave Library, 2006.
- [11] 3GPP TR 36.814 V9.0.0, "Further advancements for E-UTRA physical layer aspects", 2010.