A Study of Energy- and Spectral-Efficiency for Dense HetNet Scenario with Non-Unifom BS and UE Distribution

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***Abstract*—In this paper, two remarkable challenges, i.e., energy-efficiency (EE) and spectral-efficiency (SE) in next generation wireless networks are addressed. Specifically, we have studied the effect of uniform and non-uniform user equipment (UEs) and base stations (BSs)' distribution in a dense heterogeneous network (HetNet) environment. An ON/OFF switching algorithm has been used for the purpose of improving the EE of base stations (BSs). Simulation results are provided to understand the percentage of EE and SE improvement, when BSs' distribution adapts to UEs' distribution.**

***Index Terms*—heterogeneous network; energy-efficiency; game theory.**

I. Introduction

Densification is the process of utilizing an abundant number of small base stations (SBSs) with reduced coverage in heterogeneous network (HetNet), in order to increase the network capacity. 5th generation (5G) of wireless networks is supposed to benefit from this process. Although now densification has become a reality with recent technological advancement, however still we face several challenges in designing radio resource management algorithms for dense HetNet, e.g., interference management and energy-efficiency (EE) issue [1]–[3].

In this paper, we consider a dense HetNet system model, consisting of one marcocell base station (MBS) and a variable number of SBSs. A learning-based game-theoretic algorithm is used to execute a distributed BS ON/OFF switching procedure similar to [4] with the aim of increasing the system EE. We have then simulated several scenarios in which user equipment (UEs) and BSs are distributed uniformly or non-uniformly in a 2-dimensional plain. Later, system performance in terms of EE and throughput is studied for the aforementioned scenarios.

The rest of this paper is organized as follows. In Section II, system model is described along with power consumption, load, and utility function models. Section III discusses our proposed algorithm, Section IV provides the simulation results and the evaluation of our algorithm. Section V concludes the paper.

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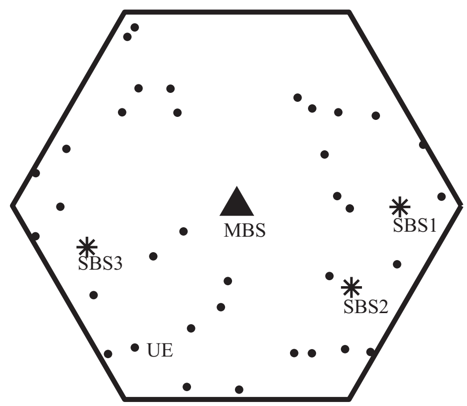

Fig. 1. An example of HetNet, consisting of a macro cell created by MBS and small cells created by SBSs

II. System Model

In this paper, we focus on the downlink transmission in HetNet, assuming one MBS and a variable set of SBSs, $\mathcal{S} = \{1, ..., S\}$, distributed uniformly within the MBS. MBS is on the center of a hexagonal shaped macro cell. Fig. 1 shows an example realization of such HetNet scenario. Each BS chooses it's strategy (transmission power level), using Table I.

TABLE I
TRANSMISSION POWER LEVELS

Identification Number of Strategy i	Transmission Power Level $\xi_s(t)$
1	0
2	1/3
3	2/3
4	1

Transmission power of sth BS is given according to:

$$P_s(t) = \xi_s(t) \cdot P_{s\,MAX}^{\,Transmitted}, \tag{1}$$

where $\xi_s(t)$ is the transmission power level and $P_{s\,MAX}^{\,Transmitted}$ is the maximum transmission power of sth BS.

A. Consumption power

When a BS is in OFF mode, the BS consumes power only for detecting UEs. The consumption power of sth BS in OFF mode at time t is given by [5]:

$$P_s^{All}(t) = \frac{P_{radio} + P_{base}}{\chi} = P_s^{Idle}, \tag{2}$$

with

$$\chi = (1 - \chi_{DC})(1 - \chi_{main})(1 - \chi_{cool}), \tag{3}$$

where P_{radio} and P_{base} are consumption power in radio frequency and baseband unit. χ_{DC}, χ_{main} and χ_{cool} are losses in AC-DC conversion, main supply, and cooling units.

Consumption power of sth BS in ON mode at time t is given by [5]:

$$P_s^{All}(t) = \frac{P_s(t)}{\eta\chi(1 - \chi_{feed})} + P_s^{Back} + P_s^{Idle}, \tag{4}$$

where η and P_s^{Back} are respectively, the power amplifier's efficiency and consumption power in backbone network. χ_{feed} models the loss in the feeder.

B. Traffic load

Signal to interference plus Noise Ratio (SINR) of UE at point z is given by:

$$\varsigma_s(z) = \frac{P_s(t) g_s(z)}{\sum\limits_{\forall s' \in \mathcal{S}/s} P_{s'}(t) g_{s'}(z) + N}, \tag{5}$$

where $g_s(z)$ is UE's channel gain at point z and connected to sth BS. N is the noise variance.

Data rate of UE at point z is given by:

$$D_s(z) = w \log_2(1 + \varsigma_s(z)), \tag{6}$$

where w is the channel bandwidth.

Traffic load density of UE at point z is given by [6]:

$$\vartheta_s(z) = \frac{\kappa_s(z) v_s(z)}{D_s(z)}, \tag{7}$$

where $\kappa_s(z)$ is the packet arrival rate and $v_s(z)$ is the average packet size of UE at point s.

Traffic load of BS is given by:

$$\nu_s(t) = \sum_{z \in \mathfrak{L}_s} \vartheta_s(z), \tag{8}$$

where $\mathfrak{L}_s$ is the coverage area of sth BS.

Algorithm 1 : Sleep mode algorithm at BS [4].

```
Input:   û_{s,i}(t), r̂_{s,i}(t), p_{s,i}(t)
Output:   a_s(t+1)
Initialization: S = { 1, ..., S };
while  do
    t − 1 → t,
    Strategy selection by BS:   a_s(t) = f (p_{s,i}(t − 1))
    Calculation of traffic load estimation ν̂_s(t) and transmission to all UEs
    Calculation of traffic load ν_s(t), power consumption P_s^{All}(t) and utility u_s(t)
    if ν_s(t) > 1 then
        Select connected UEs
    end if
    Update of utility estimation û_{s,i}(t),regret r̂_{s,i}(t) and probability distribution p_{s,i}(t)
end while
```

C. Utility

Utility of sth BS is formed by its consumption power $P_s^{All}(t)$ and traffic load $\nu_s(t)$ according to:

$$u_s(t) = -(\phi \cdot P_s^{All}(t) / P_{s\,MAX}^{\,Transmitted} + \varphi \cdot \nu_s(t)), \tag{9}$$

where ϕ and φ ($\phi > 0, \varphi > 0$) are weighting factors of consumption power and traffic load. These figures define the influence of consumption power and load.

III. Algorithm

We use the sleep mode algorithm in [4] as shown in Algorithm 1.

A. Strategy selection of BS

Each BS has a set of strategies $\mathcal{A}_s = \{a_{(s,1)}, ..., a_{(s,A)}\}$ and $a_s(t)$ is the strategy chosen by sth BS at time t. A probability is associated with the strategy set of each BS and is updated at each iteration. BS's next strategy is decided by probability distributions $p_{s,i}(t-1) \;\; \forall i = 1, 2, 3, 4$ according to:

$$a_s(t) = f(p_{s,i}(t-1)), \tag{10}$$

where f is the conversion function from probability distribution to strategy and is elaborated in Algorithm 2. As previously described, each strategy defines the transmission power level, $\xi_s(t)$, of BSs. Please note that MB selects its strategy only from $i = 1$ and $i = 4$.

B. Beacon Transmission and UE Association

Each BS estimates its traffic load, $\hat{\nu}_s(t)$, according to:

$$\hat{\nu}_s(t) = \hat{\nu}_s(t-1) + n(t) \cdot (\nu_s(t-1) - \hat{\nu}_s(t-1)), \tag{11}$$

where $n(t)$ is the learning rate and is selected in a way to make sure that the changes in traffic load estimation is slower than the UE association speed. If traffic load estimation changes rapidly, UEs change connected BS frequently, in which case

Algorithm 2 : Strategy selection at BS.

```
Input:   p_{s,j}(t-1) (j = 1,2,3,4)
Output:  i
Select r (0 < r < 1) randomly
if p_{s,1}(t-1) > r then
    i = 1
else
    if sum_{j=1}^{2} p_{s,j}(t-1) > r then
        i = 2
    else
        if sum_{j=1}^{3} p_{s,j}(t-1) > r then
            i = 3
        else
            i = 4
        end if
    end if
end if
```

it may result in destabilization of the algorithm. $\hat{\nu}_s(t)$ is then transmitted via periodic beacons to all UEs. UEs receive each BS's beacon and its estimated load and tend to choose the BS with highest received signal strength and lower load value.

C. Load Compensation

If traffic load of sth BS is larger than 1, it has to drop some of its connected UEs, such that the overall load again becomes equal or less than one. Please note that this phenomena causes un increase in network dropping probability and our proposed UE association and HO algorithm try to improve the network dropping probability by incorporating BSs' load information into the decision process.

D. Computation of probability distribution

For ith strategy of sth BS, utility estimation, $\hat{u}_{s,i}(t)$, regret estimation, $\hat{r}_{s,i}(t)$, and probability distribution, $p_{s,i}(t)$, are updated according to [4]:

$$\begin{aligned} \hat{u}_{s,i}(t+1) &= \hat{u}_{s,i}(t) + \iota_b(t+1) \cdot \mathbf{1}(t) \cdot (u_s(t) - \hat{u}_{s,i}(t)), \\ \hat{r}_{s,i}(t+1) &= \hat{r}_{s,i}(t) + \tau_s(t+1) \cdot (\hat{u}_{s,i}(t) - u_s(t) - \hat{r}_{s,i}(t)), \\ p_{s,i}(t+1) &= p_{s,i}(t) + \varrho_s(t+1) \cdot (G_{s,i}(\hat{r}_{s,i}(t)) - p_{s,i}(t)), \end{aligned} \tag{12}$$

with

$$\mathbf{1}(t) = \begin{cases} 1 & (if \quad a_s(t+1) = a_s(t)) \\ 0 & (if \quad a_s(t+1) \neq a_s(t)), \end{cases} \tag{13}$$

and

$$G_{s,i}(\hat{r}_{s,i}(t)) = \frac{\exp(\varepsilon_s \hat{r}_{s,i}(t))}{\sum_{i' \in \mathcal{A}_s} \exp(\varepsilon_s \hat{r}_{s,i'}(t))}, \tag{14}$$

where $G_{s,i}(\hat{r}_{s,i}(t))$ is the Boltzmann distribution and ε_s is the temperature parameter. $\iota_s(t)$, $\tau_s(t)$ and $\varrho_s(t)$ are learning rates which follow a form like $1/t^c$ (c: power parameter) and should meet the following criteria.

$$\begin{aligned} &\lim_{t\to\infty} \sum_{m=1}^{t} \iota_s(m) = +\infty, && \lim_{t\to\infty} \sum_{m=1}^{t} \tau_s(m) = +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s(m) = +\infty, && \lim_{t\to\infty} \sum_{m=1}^{t} \iota_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \tau_s^2(m) < +\infty, && \lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \frac{\tau_s(t)}{\iota_s(t)} = 0, && \lim_{t\to\infty} \frac{\varrho_s(t)}{\tau_s(t)} = 0. \end{aligned} \tag{15}$$

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Network	
Total time	10000s
Time interval of 1 iteration	1s
Noise Variance N	-174dBm/Hz
Arrival Rate $\kappa_s(z)$	1.8 Mbps
MBS	
Max. Trans. Power $P_{s\,MAX}^{Transmitted}$	46dBm
Minimum MBS-SBS Distance	75m
Cell radius r_{MBS}	250m
SBS	
Max. Trans. Power $P_{s\,MAX}^{Transmitted}$	30dBm
Minimum SBS-SBS Distance	40m
Cell radius r_{SBS}	40m
Path loss (d:Distance of BS and user (m)) (unit: dB)	
MBS - UE	15.3+37.6log$_{10}$(d) [4]
SBS - UE	27.9+37.6log$_{10}$(d) [4]

IV. COMPUTER SIMULATION

Three scenarios are considered, i.e., (1) Non-uniform UE and uniform BS distribution (Fig. 2), (2) Non-uniform UE and BS distribution (Fig. 3) and (3) Uniform UE and BS distribution (Fig. 4). We assume all UEs are stationary throughput the simulation time. In this simulation, fading, shadowing

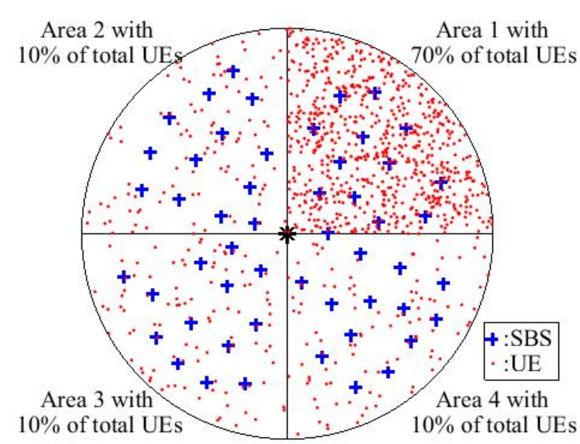

Fig. 2. Scenario 1: Non-uniform UE and uniform BS distribution.

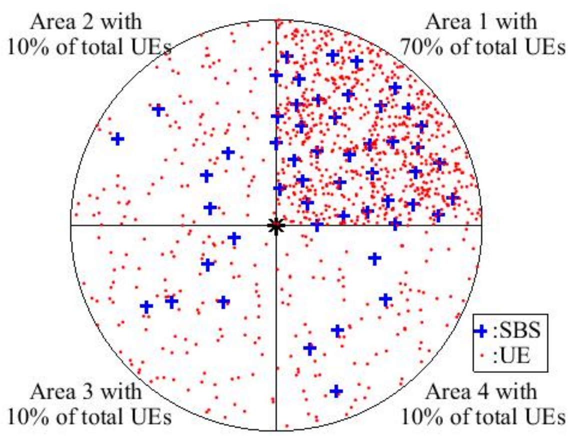

Fig. 3. Scenario 2: Non-uniform UE and BS distribution.

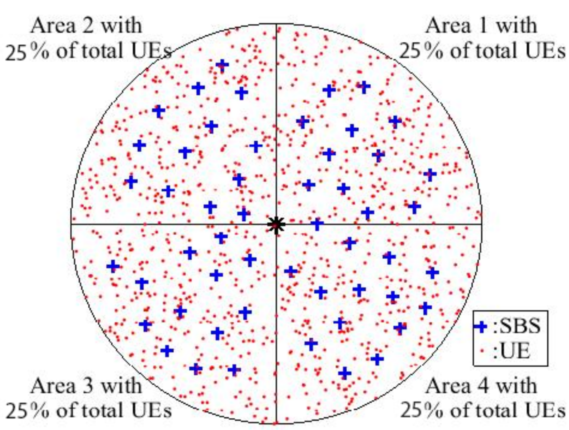

Fig. 4. Scenario 3: Uniform UE and BS distribution.

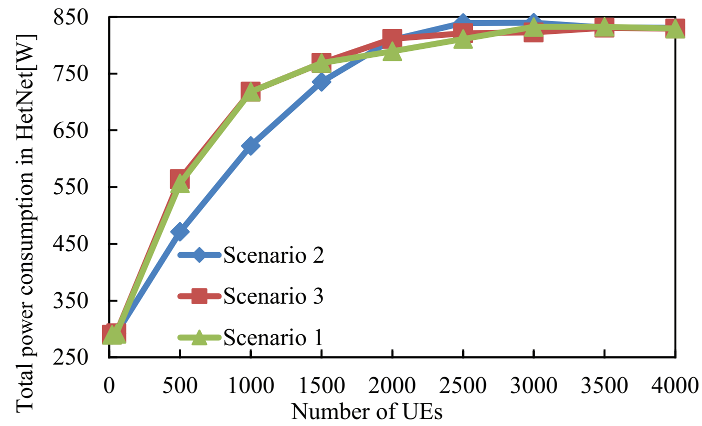

Fig. 5. Total power consumption *vs* different number of UEs for 52SBSs.

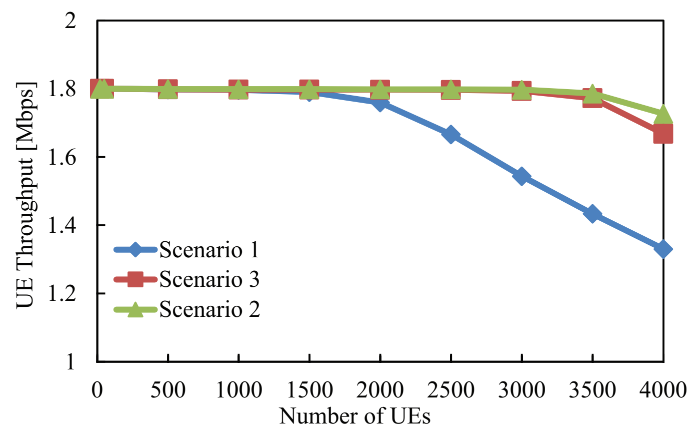

Fig. 6. UE throughput *vs* different Number of UEs for 52SBS.

and interference between BSs are not considered. Table II shows the simulation parameters. Fig. 5 shows the total power consumption *vs* different number of UEs and 52SBSs. Power consumption in non-uniform UE and BS distributions is smaller than other cases from 500 UEs to 1500 UEs. This is because SBSs in UE vacant areas, i.e., area 2, 3, 4, consume less energy. Fig. 6 shows the UE throughput *vs* different number of UEs and 52SBS. From 2000 UEs, throughput in non-uniform UE and BS distribution is smaller than other cases. This is because BSs in crowded area cannot accommodate all UEs. Therefore, it is showed that BSs have to be non-uniformly distributed when UEs are non-uniformly distributed from the point of throughput.

V. Conclusion

In this paper, we investigated the effect of BSs and UEs distribution on UE throughput and system energy consumption, assuming a dense HetNet model. A distributed BS ON/OFF switching algorithm was implemented to improve the system energy-efficiency. Computer simulation results show the importance of adapting the BSs' distribution with temporal and spatial behavior of UEs.

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