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負荷分散を行うヘテロジニアスネットワークにおける
ハンドオーバアルゴリズムの性能評価

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あらまし　無線リソース需要が急速に高まっている．小セルのみで構成されるネットワークでは，多数の小セル基地局（SBS）が必要であるためネットワークでのエネルギー消費が大きい．そのため，大セル基地局（MBS）と小セル基地局を組み合わせたヘテロジニアスネットワーク（ヘットネット）において，基地局 SleepMode アルゴリズムを用いることには，大きな期待が寄せられている．本アルゴリズムにおいて，基地局は 4 種類の SleepMode 戦略（送信電力強度決定）から自身の戦略を選択する．そのことにより，ヘットネットにおけるエネルギー消費量を大幅に低減できる．以前，我々は端末受信電力強度，基地局のトラヒック負荷に基づいて端末が接続基地局を決定するハンドオーバアルゴリズムを提案した．本稿では，基地局で算出したトラヒック負荷を基地局 SleepMode アルゴリズムとハンドオーバアルゴリズムの双方で利用するヘットネットについて，計算機シミュレーションによって，ヘットネット全体での消費電力，1UE あたりの平均スループット，端末の接続割合，基地局が取る SleepMode 戦略の割合について評価を行った．
キーワード　ヘテロジニアスネットワーク，ハンドオーバ，基地局 SleepMode アルゴリズム，ゲーム理論，エネルギー効率，ユーザモビリティ

An Evaluation of Handover Algorithms with Load Balancing for Heterogeneous Network

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Abstract　The demand for wireless resources increases at too high pace. In small cell networks, many small BSs (SBSs) are needed and the energy consumption in the network is very high. Therefore, heterogeneous network (HetNet) with sleep mode algorithm based on non-cooperative game, consisting of macro base stations (MBSs) and SBSs, is attracting a great attention. The algorithm has four sleep mode strategies, i.e., decision of transmission power level and reduces greatly the energy consumption in HetNets. Recently, we proposed hand over (HO) algorithm which is based on received power strength and traffic load. In this paper, we consider the HetNet with the sleep mode algorithm combined with the HO algorithm. The traffic load calculated by BS using sleep mode algorithm is used by the HO algorithm. We evaluate by computer simulation the following: 1. consumption power in HetNet, 2. average throughput per 1 UE in HetNet, 3. the rate of UE's connections and 4. the distribution of each sleep mode strategy. We consider the case without interference.
Key words　heterogeneous network, handover, base station sleep mode algorithm, game theory, energy efficiency, mobility

1. INTRODUCTION

The demand for wireless resources increases at a very high pace. Video streaming and social media are main factors of this increase [1]. Therefore, energy consumption and traffic load in networks increases and this needs to build energy and spectral efficient communication systems.

Heterogeneous networks (HetNets), i.e., networks comprising of macro cell base stations (MBSs) and small cell BSs (SBSs), are prominent in enhancing efficiency of utilization of the wireless resources [2] [3] [4]. Total consumption energy in HetNets is greater than conventional networks such as small cell networks or macro cell networks. Sleep mode algorithms can reduce energy consumption in HetNets. In [3], a centralized sleep mode algorithm is proposed. This algorithm can improve the energy efficiency in HetNets. However, if centralized approaches are used, the number of control signals increases because of an increased information exchange between BSs in networks. Sleep mode algorithms, which rely on self-distribution control, need no such information exchange. In such algorithm, BSs determine independently to switch between wake mode and sleep mode based on parameters such as their traffic load and consumption power.

In this paper, the similar BS sleep mode algorithm in [1], using a non-cooperative and mixed strategy game, is used. Sleep mode indicates the idle mode which power consumption in BS is mainly for detecting user equipments (UEs). In strategic form games [5], each player, i.e., BS, selects its strategy (action) only for maximizing its utility, i.e., a function for evaluating player's outcome. In non-cooperative games, each player decides its strategy independently and does not negotiates with other players.

Recently, we proposed a HO algorithm which is based on UE's received power strength (RSS) and traffic load of BSs [6]. The HO algorithm comprises of two different phases, i.e., HO necessity estimation phase (HONEP) and HO execution phase (HOEP). In HONEP, UE employs only UE's instantaneous RSS and average RSS to determine the necessity of HO. In HOEP, UE selects the new BS based on instantaneous RSS, average RSS and average traffic load.

In this paper, we consider the HetNet with the sleep mode algorithm combined with the HO algorithm. The traffic load calculated by BS using sleep mode algorithm is used by the HO algorithm. We evaluate by computer simulation following: 1. consumption power in HetNet, 2. average throughput per 1 UE in HetNet, 3. the rate of UE's connections and 4. the distribution of each sleep mode strategy. We consider the case without interference. We consider a scenario without interference.

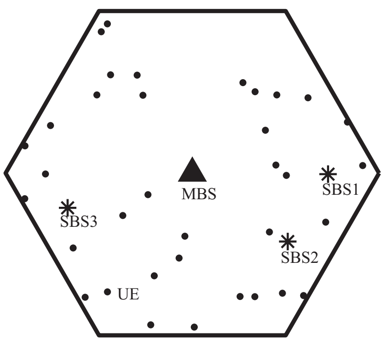

Fig. 1 HetNet topology.

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

2. SYSTEM MODEL

In this paper, we consider only downlink transmission. In HetNet, a MBS is on the center of macro cell and SBSs, $\mathcal{S} = \{1, ..., S\}$, are distributed in the macro cell. Fig. 1 shows an example of an arrangement of HetNet. SBSs select their strategies (transmission power levels) from Table 1. MBS always communicates with maximum transmission power.

2.1 Consumption power

When one BS is in sleep mode, the BS consumes power only for finding UEs in the macro cell. The consumption power of BS s at time t is given by [7]:

$$P_s^{All}(t) = \begin{cases} \frac{P_{radio}+P_{base}}{\chi} = P_s^{Idle} & (sleep\, mode) \\ \frac{P_s(t)}{\eta\chi(1-\chi_{feed})} + P_s^{Back} + P_s^{Idle} & (wake\, mode), \end{cases} \tag{1}$$

with

$$\chi = (1-\chi_{DC})(1-\chi_{main})(1-\chi_{cool}), \tag{2}$$

where P_{radio}, P_{base} and P_s^{Back} are consumption power in radio frequency, baseband unit and backbone network. χ_{DC}, χ_{main}, χ_{cool} and χ_{feed} are losses in DC-DC conversion, main supply, cooling units and the feeder. η is the power amplifier's efficiency.

2.2 Traffic load

Signal to Interference plus Noise Ratio (SINR) of UE on point z at time t is given by:

$$\varsigma_s(z,t) = \frac{P_s(t)g_s(z)}{\sum\limits_{\forall s' \in \mathcal{S}/s} P_{s'}(t)g_{s'}(z) + N}, \tag{3}$$

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

Data rate of UE on point z at time t is given by:

$$D_s(z,t) = w\log_2(1+\varsigma_s(z,t)), \tag{4}$$

where w is the channel bandwidth.

Table 1 Transmission power levels.

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

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

Initialization: $\mathcal{S} = \{1, ..., S\}$;
while do
  $t-1 \rightarrow t$,
  BS's strategy selection: $a_s(t) = f\,(p_{s,i}(t-1))$
  Calculation of average traffic load $\hat{\nu}_s(t)$ and broadcast to all UEs
  Calculation of traffic load $\nu_s(t)$, power consumption $P_s^{All}(t)$ and utility $u_s(t)$
  Update of average utility $\hat{u}_{s,i}(t)$, regret $\hat{r}_{s,i}(t)$ and probability distribution $p_{s,i}(t)$
end while

Algorithm 2 : Association algorithm at UE [6].

if UE isn't currently connected to any BS **then**
  UE chooses a new BS, $s(z, t)$ (HOEP)
else
  Decide whether to HO or not (HONEP)
  if HO is necessary **then**
    UE selects a new BS, $s(z, t)$ (HOEP)
  else
    UE doesn't change its BS
  end if
end if

Traffic load density of UE at point z at time t is given by [8]:

$$\vartheta_s(z, t) = \frac{\kappa_s(z) v_s(z)}{D_s(z, t)}, \tag{5}$$

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, which indicates the utilization rate of BS's cell capacity is given by:

$$\nu_s(t) = \sum_{z \in \mathfrak{L}_s} \vartheta_s(z, t), \tag{6}$$

where $\mathfrak{L}_s$ is the set of all UEs connected to BS s.

2.3 Utility

For the BS, smaller consumption power, $P_s^{All}(t)$ and smaller traffic load, $\nu_s(t)$ are better conditions. Because of this, utility of BS s consists of its consumption power, $P_s^{All}(t)$ and traffic load, $\nu_s(t)$ according to:

$$u_s(t) = -(\phi \cdot P_s^{All}(t)/P_{sMAX}^{TX} + \varphi \cdot \nu_s(t)), \tag{7}$$

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

3. ALGORITHMS

The similar BS sleep mode algorithm as shown in Algorithm 1 and association algorithm at UE as shown in Algorithm 2 are used.

3.1 Average traffic load

BSs calculate their average load, i.e., time average of traffic load, as follows:

$$\hat{\nu}_s(t) = \hat{\nu}_s(t-1) + n(t) \cdot (\nu_s(t-1) - \hat{\nu}_s(t-1)), \tag{8}$$

Algorithm 3 : HONEP at UE.

if UE is connected to MBS **then**
  Search for a new BS
else
  (UE is connected to SBS)
  if $\hat{P}_s^{RX}(t) < P_1^{TH}$ **then**
    Search for a new BS using (14)
  else
    if $\hat{P}_s^{RX}(t) < P_2^{TH}$, $\hat{P}_s^{RX}(t) < \hat{P}_s^{RX}(t-1)$ and $P_s^{RX}(t) < P_2^{TH}$ (P_2^{TH} ($P_2^{TH} > P_1^{TH}$): RSS threshold 2)) **then**
      Search for a new BS using (14)
    else
      Do not change current connected BS
    end if
  end if
end if

where $n(t)$ is the learning rate and indicates the weight of instantaneous traffic load on average load. $n(t)$ is a value making computation of average traffic load slower than the UE association. If average traffic load changes rapidly, UEs change their BSs to be connected to frequently and it may make the algorithm destabilizing .

3.2 Computation of probability distribution

For ith strategy of sth BS, average utility, $\hat{u}_{s,i}(t+1)$, regret, $\hat{r}_{s,i}(t+1)$, and probability distribution, $p_{s,i}(t+1)$, are updated as following [1].:

$$\begin{aligned} \hat{u}_{s,i}(t+1) &= \hat{u}_{s,i}(t) + \iota_b(t+1) \cdot \mathbf{1}(t) \cdot (u_s(t) - \hat{u}_{s,i}(t)), \\ \hat{r}_{s,i}(t+1) &= \hat{r}_{s,i}(t) + \tau_s(t+1) \cdot (\hat{u}_{s,i}(t) - u_s(t) - \hat{r}_{s,i}(t)), \\ p_{s,i}(t+1) &= p_{s,i}(t) + \varrho_s(t+1) \cdot (G_{s,i}(\hat{r}_{s,i}(t)) - p_{s,i}(t)). \end{aligned} \tag{9}$$

with

$$\mathbf{1}(t) = \begin{cases} 1 & (if \ \ a_s(t+1) = a_s(t)) \\ 0 & (if \ \ a_s(t+1) \neq a_s(t)), \end{cases} \tag{10}$$

and

$$G_{s,i}(\hat{r}_{s,i}(t)) = \frac{\exp(\varepsilon_s \hat{r}_{s,i}(t))}{\sum_{i' \in \mathcal{A}_s} \exp(\varepsilon_s \hat{r}_{s,i'}(t))}, \tag{11}$$

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 criterion.

$$\begin{aligned} &\lim_{t\to\infty} \sum_{m=1}^{t} \iota_s(m) = +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \tau_s(m) = +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s(m) = +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \iota_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \sum_{m=1}^{t} \tau_s^2(m) < +\infty, \quad \lim_{t\to\infty} \sum_{m=1}^{t} \varrho_s^2(m) < +\infty, \\ &\lim_{t\to\infty} \frac{\tau_s(t)}{\iota_s(t)} = 0, \quad \lim_{t\to\infty} \frac{\varrho_s(t)}{\tau_s(t)} = 0. \end{aligned} \tag{12}$$

3.3 HO Algorithms at UE

UEs receive the average traffic load, $\hat{\nu}_s(t)$, through beacon signals and RSS, $P_s^{RX}(t)$, from all BSs in the macro cell. UEs use strength of received beacon signals as RSS. The HO algorithm uses these information for the HO decision process. In the algorithm, at first, UEs calculate each BS's average RSS, i.e., time average of RSS from each BS, according to:

$$\hat{P}_s^{RX}(t) = \hat{P}_s^{RX}(t-1) \cdot (P_s^{RX}(t)/\hat{P}_s^{RX}(t-1))^{\gamma}, \quad (13)$$

where γ is learning rate and indicates the weight of instantaneous RSS, $P_s^{RX}(t)$. Next, UE implements HONEP as shown in Algorithm 3. In HONEP, UEs always search for new BSs if UEs are connected to MBS. The reason for this is that UEs should not keep connecting to MBS for long time. If UE is connected to SBS, UE implements HONEP as following. If condition, $\hat{P}_s^{RX}(t) < P_1^{TH}$, is met, UEs search for new BSs .to be connected to. This is because UE should not keep connecting to BS far from UE. If UEs are connected to SBSs and condition, $\hat{P}_s^{RX}(t) \geqq P_1^{TH}$, is met, UE implements HONEP as following; If conditions, $\hat{P}_s^{RX}(t) < P_2^{TH}$, $\hat{P}_s^{RX}(t) < \hat{P}_s^{RX}(t-1)$ and $P_s^{RX}(t) < P_2^{TH}(P_2^{TH}$ $(P_2^{TH} > P_1^{TH})$: RSS threshold 2)), are met, UEs search for new BSs to be connected to. If UE is not connected to any BS or UE need HO, UE at point z selects BS $s(z,t)$ to be connected to based on the following criteria:

$$s(z,t) = \arg\max_{s\in\mathcal{S}} (\hat{\nu}_s(t) + \varsigma_s)^{-\varpi} \cdot \hat{P}_s^{RX}(t) \cdot \acute{P}_s(t), \quad (14)$$

with

$$\acute{P}_s(t) = \begin{cases} P_a & if\ s\text{th}\ BS\ is\ SBS\ and\ \hat{P}_s^{RX}(t) > \hat{P}_s^{RX}(t-1) \\ 1 & Otherwise, \end{cases} \quad (15)$$

where $P_a > 1$, ς_s is an offset and P_a is the inflation constant. At last, UEs transmit the connection request signal to selected BS.

Table 2 Simulation Parameters.

Parameter	Value
Network	
Noise Variance N	-168 dBm/Hz
Arrival Rate $\kappa_s(z)$	180 kbps
MBS	
Maximum Transmission Power P_{sMAX}^{TX}	46 dBm
Cell radius r_{MBS}	250 m
SBS	
Number of SBSs	9
Maximum Transmission Power P_{sMAX}^{TX}	30 dBm
Minimum MBS-SBS Distance	75 m
Minimum SBS-SBS Distance	40 m
Path loss (d: distance of BS and UE (m)) (unit: dB)	
MBS - UE	15.3+37.6log$_{10}$(d) [1]
SBS - UE	30.6+36.7log$_{10}$(d) [1]
Algorithm Parameters	
Weighting Coefficients for Power Consumption and Traffic Load, ϕ, φ	10, 5
Learning Rate of Average Load $n(t)$	$1/t^{0.9}$
Boltzmann Temperature ε_s	10
Power Threshold P_1^{TH}, P_2^{TH}	-60 dBm, -50 dBm
Learning Rate of Average Power γ	0.93
Weighting Exponent of Traffic Load for BS Selection ϖ	1
Offset ς_s	0.5
Inflating Value P_a	7 dB

4. COMPUTER SIMULATION

We used MATLAB software for this computer simulation. In this computer simulation, all UEs move around the macro cell during the full simulation time. Simulation parameters are shown in Table 2. UEs' velocities have a Gaussian distribution. We do not consider interference, fading and shadowing. Total simulation time is 10000s. Time interval of sleep mode algorithm and HO algorithm are 1 s. This indicates that the algorithm runs totally 10000 times. Time interval for calculating average RSS is 0.1 s.

Fig. 2 shows the total consumption power in HetNet as a function of different number of UEs. We compare the result of case 1, i.e., sleep mode algorithm, case 2, i.e., all SBSs communicate in maximum transmission power and case 3, i.e., only MBS exists in macro cell. Total consumption power in case 1 is much smaller than that in case 2. However, case 1 and case 3 have small difference. This is because the sleep-mode algorithm reduces the transmission power of BSs.

Fig. 3 shows the average throughput per UE as a function of different number of UEs. The average throughput per UE in case 1 and that in case 2 have small difference. From 100 users to 160 users, the average throughput in these two cases is much bigger than when only MBS exists in the macro cell. We deduct that our algorithm can save energy with a small degradation of throughput from the results of 2 and 3.

Fig. 4 shows the average probability of each strategy in sleep mode algorithm as a function of different number of UEs. The more UEs are in the macro cell, the bigger probability of strategy 2 is and the smaller probability of strategy 1 is. This is mainly because more SBSs go to ON mode in order to provide the communication resources to UEs if there are many UEs.

Fig. 5 shows the rate of UE's connections as a function of different number of UEs. From 80 UEs, the more UEs are in the macro cell, the bigger the rate of UEs connected to SBS or dropped UEs are and the smaller the rate of UEs connected to MBS. This is because MBS can not afford to provide so many UEs and UEs which are not able to connect to MBS tend to connect to SBSs or are dropped.

5. CONCLUSION

In this paper, we evaluate by computer simulation consumption power in HetNet with the sleep mode algorithm combined with the HO algorithm, average throughput per 1 UE in HetNet, the number of UEs to connect to each BS, the distribution of each sleep mode strategy. We considered the case without interference. We can say that our algorithm can save energy consumption with small degradation of throughput from the results of consumption power and average throughput per 1 UE in HetNet. The more UEs are in the macro cell, the bigger probability of strategy 2 is and the smaller probability of strategy 1is. The reason for this

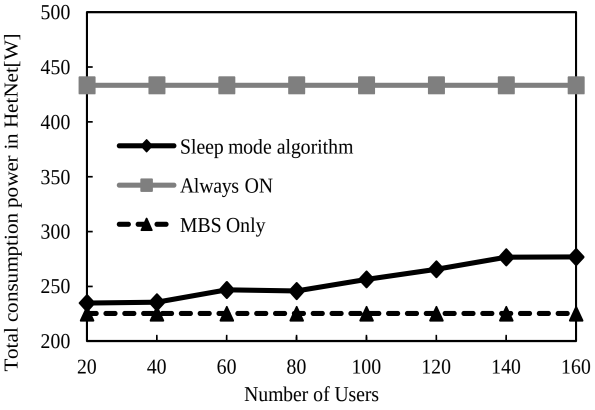

Fig. 2 The total consumption power in HetNet as a function of different number of UEs at an average velocity of 4 km/h.

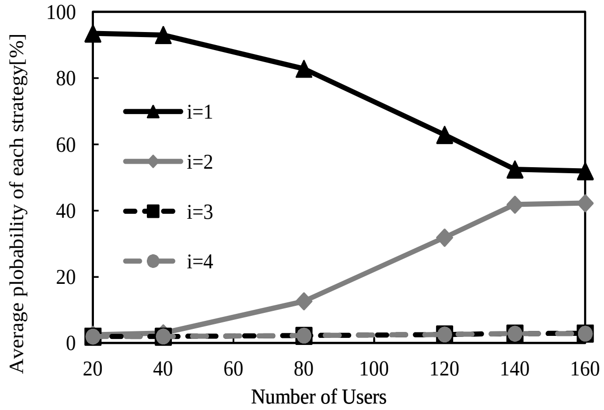

Fig. 4 Average probability of each strategy *vs* different number of UEs at an average velocity of 4 km/h.

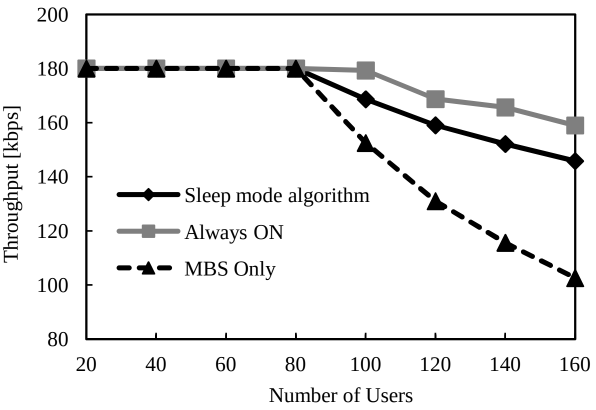

Fig. 3 The average throughput per UE *vs* different number of UEs at an average velocity of 4 km/h.

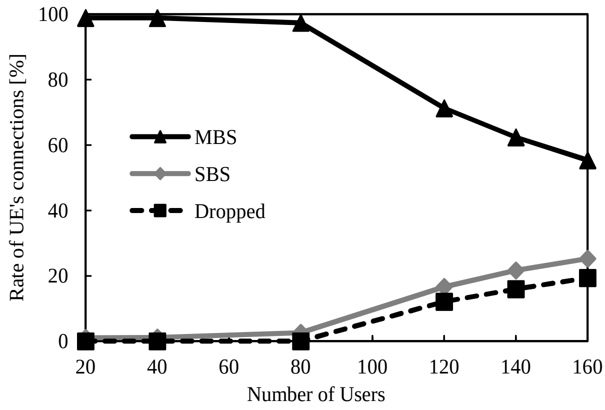

Fig. 5 Rate of UE's connections *vs* different number of UEs at an average velocity of 4 km/h.

is that many SBSs become ON mode in order to provide communication resources to UEs if there are many UEs.

In this paper, we assumed no co-channel interference. However, there exists the co-channel interference (CCI) since the same channel should be reused by spatially separated BSs. Therefore, we have to consider the case using a practical channel assignment. One of decentralized channel assignment algorithm is the channel segregation algorithm [9]. An investigation of handover algorithm for a HetNet using BS ON/OFF switching and channel segregation is our interesting future study.

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