A Novel Handover Algorithm with Load Balancing for Next Generation HetNet

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Abstract—The demand for wireless resources is increasing at high pace. Heterogeneous networks (HetNets), i.e., network composed by base stations (BSs) with different coverage area, are useful solutions to cope with this increased demand. Previously, we proposed a handover (HO) algorithm based on users velocity, users place, users received power strength from BSs and traffic load of BSs. Due to difficulties in obtaining the information for users velocity and users position, in this paper, we improve our former research and propose an HO algorithm which is only based on received power strength and traffic load. In the first step of the HO algorithm, user equipments’ (UEs’) received power and its estimation are employed to determine the necessity of HO. This phase, i.e., HO necessity estimation phase (HONEP), helps reducing the unnecessary HOs and consequently save more energy. After HONEP, in the second step UEs select the new BS based on received power, received power estimation and average traffic load of BSs which is advertised through beacon signals. A game-theoretic sleep mode algorithm is executed parallel to HO algorithm in BSs. The performance of the new algorithm, such as system power consumption and BSs’ average traffic load is evaluated by means of computer simulation.

Index Terms—HetNet, handover, base station sleep mode algorithm, game theory, energy efficiency, mobility

I. INTRODUCTION

The demand for wireless resource is increasing at high pace. Video streaming and social media [1] are mainly responsible for this increase. Consequently, traffic load and energy consumption in wireless cellular system is increasing accordingly and this urges the necessity of designing more energy and spectral efficient systems.

Heterogeneous networks (HetNets), consisting of macro cell base stations (MBSs) and small cell BSs (SBSs), are proven to be highly effective in increasing the wireless resources [2]–[4]. The total consumption energy in HetNets reduces when combined with sleep mode algorithms which adapt to traffic conditions in the network. In [3], a centralized sleep mode algorithm is proposed. It is shown that this algorithm can improve the energy efficiency in HetNets. However, if centralized approaches are used, the number of control signals increases with an increased information exchange between BSs. On the other hand, connecting all BSs to data processing centers, e.g. cloud radio access network (cloud-RAN), through high capacity backbone links, is an expensive solution and probably not yet suitable for some geographic areas. Sleep mode algorithms which rely on self-distribution control, do not need any information exchange through backhaul communication. In such algorithm, each BS decides independently to turn ON or OFF depending on its traffic load and consumption power.

In this paper, we use the similar sleep mode algorithm as in [1], in which a non-cooperative, mixed strategy, game is used to decide the ON, OFF condition of each BS. Here, OFF mode refers to idle condition in which BS consumes power only for detecting user equipments (UEs). In strategic form games [5], each player, i.e., BS, selects its strategy (action) only to maximize its utility, i.e., a function which evaluates each player’s outcome. In non-cooperative games, players decide their strategies independently without negotiating with other players. Later, we propose a handover (HO) algorithm for UEs, in combination with the aforementioned sleep mode algorithm. Previously we employed velocity, the received signal strength (RSS), traffic load and distance parameters for HO decision in UEs [6]. However, due to technical difficulties in obtaining information for UEs position and velocity, in this paper, we propose another HO algorithm, which is only based on received power strength and BSs traffic load. The HO algorithm comprises of two different phases, i.e., HO necessity estimation phase (HONEP) and HO execution phase (HOEP). In the first phase, only, the UE’s RSS and its time average are checked. If certain conditions are met, then the algorithm goes into the second phase and decides about the best target BS. First phase is important for reducing the number of unnecessary HOs. In the second phase UEs select the new BS based on the RSS, its estimate and average traffic load of BSs which is advertised periodically through beacon signals.

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.

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and the evaluation of our algorithm. Sections V concludes the paper.

II. SYSTEM MODEL

In this paper, we focus on the downlink transmission in HetNet, consisting of a MBS and several SBSs, $S = \{1, \ldots, S\}$, which are distributed uniformly within the macro cell. Fig. 1 shows an example realization of such HetNet scenario. Each BS chooses its strategy (transmission power level) from Table I.

Transmission power of $sth$ BS is given according to:

$$P_s(t) = \xi_s(t) \cdot P_{sMAX}^{TX},$$

(1)

where $\xi_s(t)$ is the transmission power level and $P_{sMAX}^{TX}$ is the maximum transmission power of $sth$ BS.

A. Consumption power

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

$$P_{s}^{\text{All}}(t) = \begin{cases} \frac{P_{\text{radio}} + P_{\text{base}}}{\eta \chi_t} + P_s^{\text{Back}} & \text{for OFF mode} \\ \frac{P_{s}^{\text{idle}}}{\eta \chi_t} + P_s^{\text{Back}} + P_s^{\text{TDC}} & \text{for ON mode} \end{cases},$$

(2)

with

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

(3)

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

B. Traffic load

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

$$\varsigma_s(z) = \frac{P_s(t)g_s(z)}{\sum_{s' \notin S} P_{s'}(t)g_{s'}(z) + N},$$

(4)

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:

$$D_s(z) = \nu_s(z) \log_2(1 + \varsigma_s(z)),$$

(5)

where $w$ is the channel bandwidth.

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

$$\vartheta_s(z) = \frac{\kappa_s(z)\nu_s(z)}{D_s(z)},$$

(6)

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

Traffic load is given by:

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

(7)

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

C. Utility

The smaller a BS’s consumption power $P_{s}^{\text{All}}(t)$ and traffic load $\nu_s(t)$ are, the better condition for the BS is. Therefore, utility of $sth$ BS consists of its consumption power $P_s^{\text{All}}(t)$ and traffic load $\nu_s(t)$ according to:

$$u_s(t) = - (\phi \cdot P_s^{\text{All}}(t) + \varphi \cdot \nu_s(t)), $$

(8)

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

III. ALGORITHM

We use the similar BS sleep mode algorithm in [1], as shown in Algorithm 1. The proposed algorithm, which is executed at UE is shown in Algorithm 2, where $\gamma$ is learning rate and indicates the impact of instantaneous received power $P_s^{RX}(t)$. Received power estimation is used instead of distance in [6]. UE decides whether to implement HO or not based on $P_s^{RX}(t)$ and $P_s^{RX}(t)$.
Algorithm 1 : Sleep mode algorithm at BS [1].

1: Input: $\hat{u}_{s,i}(t), \hat{r}_{s,i}(t), p_{s,i}(t)$
2: Output: $a_{s}(t+1)$
3: Initialization: $S = \{1, ..., S\}$;
4: while do
5: $t - 1 \rightarrow t$,
6: BS’s strategy selection: $a_{s}(t) = f(p_{s,i}(t - 1))$
7: Calculation of traffic load estimation $\hat{v}_{s}(t)$ and transmission to all UEs
8: Calculation of traffic load $\nu_{s}(t)$, power consumption $P^{\text{All}}_{s}(t)$ and utility $u_{s}(t)$
9: Update of utility estimation $\hat{u}_{s,i}(t)$, regret $\hat{r}_{s,i}(t)$ and probability distribution $p_{s,i}(t)$
10: end while

Algorithm 2 : Algorithm at UE.

1: Input: $\hat{v}_{s}(t)$ and $P^{RX}_{s}(t)$
2: Output: $s(z,t)$
3: if UE isn’t currently connected to any BS then
4: UE chooses a new BS , $s(z,t)$, based on $\hat{v}_{s}(t)$ and $P^{RX}_{s}(t)$
5: else
6: Decide whether to HO or not with Algorithm 4
7: if HO is necessary then
8: UE chooses a new BS, $s(z,t)$, based on $\hat{v}_{s}(t)$ and $P^{RX}_{s}(t)$
9: else
10: UE doesn’t change its BS
11: end if
12: end if

Algorithm 3 : Strategy selection at BS.

1: Input: $p_{s,j}(t - 1)$ ($j = 1, 2, 3, 4$)
2: Output: $i$
3: Select $r$ ($0 < r < 1$) randomly
4: if $p_{s,i}(t - 1) > r$ then
5: $i = 1$
6: else
7: if $\sum_{j=1}^{2} p_{s,j}(t - 1) > r$ then
8: $i = 2$
9: else
10: if $\sum_{j=1}^{3} p_{s,j}(t - 1) > r$ then
11: $i = 3$
12: else
13: $i = 4$
14: end if
15: end if
16: end if

A. BS’s strategy selection

Each BS has a set of strategies $A_{s} = \{a_{(s,1)}, ..., a_{(s,A_{s})}\}$ and $a_{s}(t)$ is the strategy chosen by $s$th BS at time $t$. It selects its strategy with their strategies probability distribution $p_{s,i}(t-1)$ at time $t$ according to:

$$a_{s}(t) = f(p_{s,i}(t-1)),$$

where $f$ is the conversion function from probability distribution to strategy and is elaborated in Algorithm 3. As previously described, strategies define transmission power levels of BSs, $\xi_{s}(t)$. It should be noted that MBS selects its strategy only from $i = 1$ and $i = 4$.

B. Traffic load estimation

Each BS calculates its load estimation, i.e., traffic load time average, according to:

$$\hat{v}_{s}(t) = \hat{v}_{s}(t-1) + n(t) \cdot (\nu_{s}(t-1) - \hat{v}_{s}(t-1)),$$

where $n(t)$ is the learning rate and indicates the impact of instantaneous value of load on load estimation. $n(t)$ is chosen in a way to make computation of traffic load estimation adequately slower than the UE association speed. If traffic load estimation changes rapidly, UEs change connected BS frequently. In this case, it may result in destabilizing the algorithm.

C. Computation of probability distribution

For $i$th strategy of $s$th BS, utility estimation, $\hat{u}_{s,i}(t+1)$, regret estimation, $\hat{r}_{s,i}(t+1)$, and probability distribution, $p_{s,i}(t+1)$, are updated according to [1]:

$$\hat{u}_{s,i}(t+1) = \hat{u}_{s,i}(t) + u_{b}(t+1) \cdot 1(t) \cdot (u_{s}(t) - \hat{u}_{s,i}(t)),$$

$$\hat{r}_{s,i}(t+1) = \hat{r}_{s,i}(t) + \tau_{s}(t+1) \cdot (\hat{u}_{s,i}(t) - u_{s}(t) - \hat{r}_{s,i}(t)),$$

$$p_{s,i}(t+1) = p_{s,i}(t) + \varrho_{s}(t+1) \cdot (G_{s,i}(\hat{r}_{s,i}(t)) - p_{s,i}(t)),$$

with

$$1(t) = \begin{cases} 1 & \text{if } a_{s}(t+1) = a_{s}(t) \\ 0 & \text{if } a_{s}(t+1) \neq a_{s}(t) \end{cases},$$

and

$$G_{s,i}(\hat{r}_{s,i}(t)) = \frac{\exp(\varepsilon_{s}\hat{r}_{s,i}(t))}{\sum_{i' \in A} \exp(\varepsilon_{s}\hat{r}_{s,i'}(t))},$$

where $G_{s,i}(\hat{r}_{s,i}(t))$ is the Boltzmann distribution and $\varepsilon_{s}$ is the temperature parameter. $\tau_{s}(t)$, $\varrho_{s}(t)$ and $\varrho_{s}(t)$ are learning rates.
Algorithm 4: HO necessity estimation algorithm at UE.

1: if UE is connected to MBS then
2:   Search for a new BS
3: else
4:   (UE is connected to SBS)
5:   if  \( \hat{P}_{sRX}(t) < P_{1}^{TH} \) (\( P_{1}^{TH} \): received power threshold 1) then
6:     Search for a new BS
7:   else
8:     if  \( \hat{P}_{sRX}(t) < P_{2}^{TH} \), \( \hat{P}_{sRX}(t) < \hat{P}_{sRX}(t - 1) \) and \( P_{sRX}(t) < P_{2}^{TH} \) (\( P_{2}^{TH} > P_{1}^{TH} \): received power threshold 2) then
9:       Search for a new BS
10:   else
11:     Do not change current connected BS
12:   end if
13: end if
14: end if

which follow a form like \( 1/t^c \) (\( c \): power parameter) and should meet the following criterion.

\[
\begin{align*}
\lim_{t \to \infty} \sum_{m=1}^{t} \tau_s(m) &= +\infty, \\
\lim_{t \to \infty} \sum_{m=1}^{t} \varrho_s(m) &= +\infty, \\
\lim_{t \to \infty} \sum_{m=1}^{t} \varrho_s^2(m) &= +\infty, \\
\lim_{t \to \infty} \sum_{m=1}^{t} \varphi_s(t) &= 0, \\
\lim_{t \to \infty} \varphi_s(t) &= 0.
\end{align*}
\]

\[(14)\]

D. HO Algorithm

Each UE receives the traffic load estimation, \( \hat{v}_s(t) \), through beacon signals and received power, \( P_{sRX}(t) \), from all BSs in the macro cell. Later, UE computes each BS’s received power estimation according to:

\[
\hat{P}_{sRX}(t) = \hat{P}_{sRX}(t - 1) \cdot (P_{sRX}(t) / \hat{P}_{sRX}(t - 1))^\gamma,
\]

\[(15)\]

UEs estimate HO necessity using algorithm 4. UEs which are not connected to any BS or UEs needing HO in point \( z \), selects BS \( s(z, t) \) to connect to based on the following criteria:

\[
s(z, t) = \arg\max_{s \in S} (\hat{v}_s(t) + \varsigma_s)^{-\varpi} \cdot \hat{P}_{sRX}(t) \cdot \hat{P}(t),
\]

\[(16)\]

with

\[
\hat{P}(t) = \begin{cases} 
    P_a & (BS \ s \ is \ SBS \ and \ \hat{P}_{sRX}(t) > \hat{P}_{sRX}(t - 1)) \\
    1 & (Other \ case)
\end{cases}
\]

\[(17)\]

and

\[
P_a > 1,
\]

\[(18)\]

where \( \varsigma_s \) is an offset and \( P_a \) is an inflating value.

IV. COMPUTER SIMULATION

Simulation parameters are summarized in Table 2. Users velocities are Gaussian distributed. Total simulation time is 10000 s. Time interval of Sleep mode algorithm and HO algorithm are 1 s. Time interval for calculating received power estimation is 0.1 s. In this part, we compared our proposed HO algorithm with the one in [6]. Fig. 2 shows the total consumption power in HetNet vs different number of UEs. In this graph, total consumption power in our proposed HO algorithm is smaller than the one in [6] by 40 UEs. This is mainly due to the effect of RSS in proposed HO algorithm which is bigger than that in [6]. Therefore, UEs select BSs with higher RSS more frequently. However, in 50 SBSs, total consumption power in our proposed HO algorithm is bigger than the one in [6]. This is because the effect of RSS in the proposed HO algorithm is small.

Fig. 3 shows the average traffic load per BS vs different number of UEs. The average traffic load per BS in the proposed algorithm and the one in [6] is almost the same. Here, we deduce that the HO algorithm is not dependent to traffic load of the BSs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Network</strong></td>
<td></td>
</tr>
<tr>
<td>Noise Variance ( N )</td>
<td>(-168 ) dBm/Hz</td>
</tr>
<tr>
<td>Arrival Rate ( \kappa_s(z) )</td>
<td>180 kbps</td>
</tr>
<tr>
<td><strong>MBS</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum Transmission Power ( P_{sM\text{MAX}}^{TX} )</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Minimum MBS-SBS Distance</td>
<td>75 m</td>
</tr>
<tr>
<td>Cell radius ( r_{MBS} )</td>
<td>250 m</td>
</tr>
<tr>
<td><strong>SBS</strong></td>
<td></td>
</tr>
<tr>
<td>Number of SBSs</td>
<td>7</td>
</tr>
<tr>
<td>Maximum Transmission Power ( P_{s\text{MAX}}^{TX} )</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Minimum SBS-SBS Distance</td>
<td>40 m</td>
</tr>
<tr>
<td>Cell radius ( r_{SBS} )</td>
<td>40 m</td>
</tr>
<tr>
<td><strong>Path loss (d):Distance of BS and user (m)) (unit: dB)</strong></td>
<td></td>
</tr>
<tr>
<td>MBS - UE</td>
<td>15.3+37.6log_{10}(d) [1]</td>
</tr>
<tr>
<td>SBS - UE</td>
<td>27.9+36.7log_{10}(d) [1]</td>
</tr>
<tr>
<td><strong>Algorithm Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Weighting Coefficients for Power Consumption and Traffic Load, ( \phi, \varphi )</td>
<td>10, 5</td>
</tr>
<tr>
<td>Learning Rate of Load Estimation ( \tau(t) )</td>
<td>( 1/P_s^{TH} )</td>
</tr>
<tr>
<td>Learning Rate Exponents ( c ) for ( \tau_s, \varphi_s )</td>
<td>0.6, 0.7, 0.8</td>
</tr>
<tr>
<td>Boltzmann Temperature ( \varepsilon_s )</td>
<td>10</td>
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<tr>
<td>Power Threshold ( P_s^{TH}, P_s^{2TH} )</td>
<td>(-60 ) dBm, (-50 ) dBm</td>
</tr>
<tr>
<td>Learning Rate of Power Estimation ( \gamma )</td>
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<tr>
<td>Weighting Exponent of Traffic Load for BS Selection ( \varpi )</td>
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<tr>
<td>Offset ( \varsigma_s )</td>
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</tr>
<tr>
<td>Inflating Value ( P_a )</td>
<td>7 dB</td>
</tr>
</tbody>
</table>
V. CONCLUSION

In this paper, a handover (HO) algorithm using only received signal strength (RSS) and traffic load is proposed. A BS sleep mode algorithm is coupled with the HO algorithm, which helps reducing the energy consumption in HetNet. In the first stage, each UE estimates the necessity of HO based on RSS of the current connected BS. If HO is needed, in the second stage, UE selects the BS to be connected to based on only RSS and BSs’ traffic load. Simulation result indicates that the benchmark outperforms the proposed algorithm. However, the proposed algorithm is more feasible to be implemented in practical scenarios due to simplicity.

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