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Energy- and Spectral-Efficiency Tradeoff in HetNet with Non-Uniform 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.

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 [1] 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.

We focus on only the downlink transmission in dense HetNet. Each SBS chooses its strategy, i.e., transmission power level, independently. MBS always communicates with maximum transmission power in order to cover the whole area. Transmission power of sth BS is given by:

$$P_s(t) = \xi_s(t) \cdot P_{sMAX}^{TX} \quad (\xi_s(t) = 0,\ \ 1/3,\ \ 2/3,\ \ 1), \quad (1)$$

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

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TABLE I
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) [1]
SBS - UE	27.9+37.6log$_{10}$(d) [1]

A. Traffic load

Signal-to-noise-interference ratio (SINR) of UE at point z is given by:

$$\varsigma_s(z,t) = \frac{P_s(t) g_s(z)}{\sum_{\forall s' \in \mathcal{S}/s} P_{s'}(t) g_{s'}(z) + \omega N}, \quad (2)$$

where $\mathcal{S}$, $g_s(z)$ and ω are the set of BSs, the channel gain from sth BS to UE at point z and the channel bandwidth, respectively. N is the noise variance. Traffic load, i.e., the

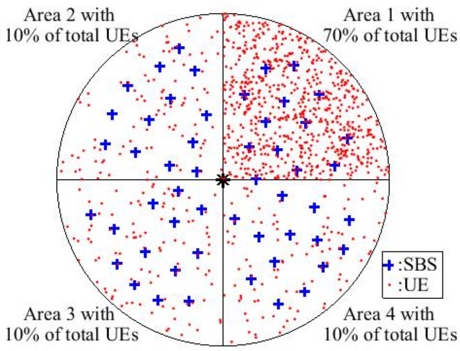

Fig. 1. Scenario 1: Non-uniform UE and uniform BS distribution.

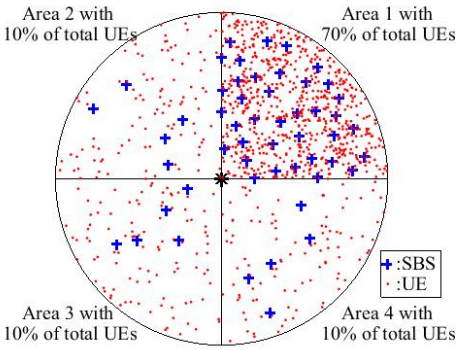

Fig. 2. Scenario 2: Non-uniform UE and BS distribution.

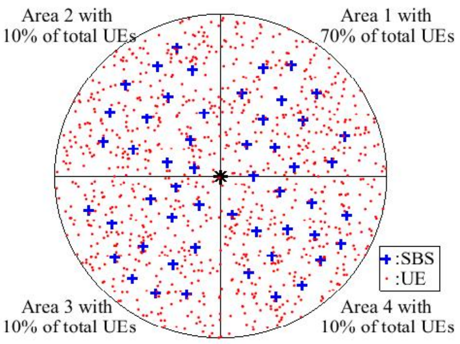

Fig. 3. Scenario 3: Uniform UE and BS distribution.

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

$$\nu_s(t) = \sum_{z \in \mathfrak{L}_s} \frac{\kappa_s(z)\rho_s(z)}{\omega \log_2 (1 + \varsigma_s(z,t))}, \tag{3}$$

where $\kappa_s(z)$, $\rho_s(z)$ and $\mathfrak{L}_s$ are the average packet size, the packet arrival rate of UE at point z and the set of all UEs connected to sth BS, respectively.

B. Utility

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

$$u_s(t) = -\left(\phi \cdot P_s^{All}(t)/P_{sMAX}^{All} + \varphi \cdot \nu_s(t)\right), \tag{4}$$

where ϕ and φ ($\phi > 0, \varphi > 0$) are weight parameters of power consumption and traffic load, respectively. P_{sMAX}^{All} is the maximum power consumption. Later, the game-theoretic algorithm in [1] is used for each SBS to evaluate the utility function in (1) and decide its transmission power level.

II. Computer Simulation

Three scenarios are considered, i.e., (1) Non-uniform UE and uniform BS distribution (Fig. 1), (2) Non-uniform UE and BS distribution (Fig. 2) and (3) Uniform UE and BS distribution (Fig. 3). We assume all UEs are stationary throughput the simulation time. In this simulation, fading, shadowing and interference between BSs are not considered. Table I shows the simulation parameters. Fig. 4 shows the total

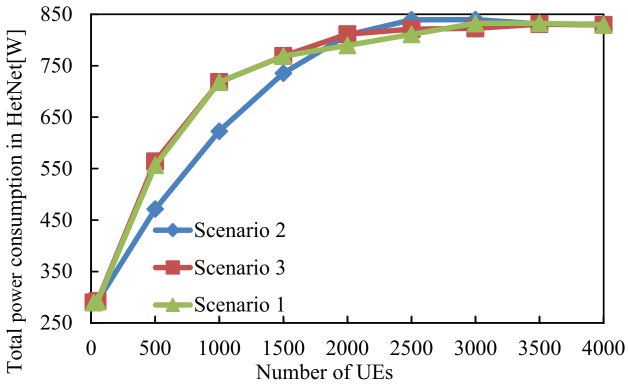

Fig. 4. Total power consumption *vs* different number of UEs for 52SBSs.

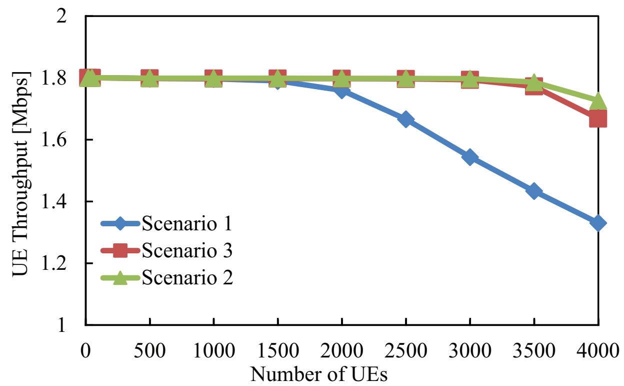

Fig. 5. UE throughput *vs* different Number of UEs for 52SBS.

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. 5 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.

III. 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.

References

[1] S. Samarakoon, M. Bennis, W. Saad, and M. Latva-aho, "Opportunistic sleep mode strategies in wireless small cell networks," in *IEEE International Conference on Communications 2014 - Mobile and Wireless Networking Symposium (ICC'14-MWS)*, June 2014, pp. 2707–2712.