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A Simulation Study of Hyper-Cellular Architecture with Dynamic Temporal and Spatial Traffic

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***Abstract*—To provide the paradigm shift of green cellular communications, Hyper Cellular Architecture (HCA), has been proposed, in which the common control functionalities are decoupled from the data service functionalities at base station (BS) level so that the traffic BSs can be more adaptive to the temporal and spatial traffic fluctuations. In this paper, we develop a system level simulator (SLS) for HCA to evaluate the HCA performance under temporal and spatial traffic fluctuations. The SLS enjoys low complexity, open interface and completed functions through the carefully tuned modeling on long-term large-scale traffic model, the separation architecture and the resource allocation strategies. Simulation results show that even with some basic BS sleeping algorithms, HCA can achieve up to 45% energy efficiency (EE) gain over conventional cellular architecture with macro BSs only or heterogeneous network during the low traffic period, and about 36% EE gain on average for a typical daily traffic pattern.**

***Keywords*—system level simulation; hyper-cellular architecture; dynamic traffic**

I. INTRODUCTION

The next generation 5G cellular network is committed to connect at least 100 billion devices, and achieve a 10 Gb/s individual user experience capable of extremely low latency and response times. [1]. Many innovatory technologies have been introduced from the aspects of higher spectral efficiency, denser cell deployment and so on [2].

However, as the capacity performance improves in 5G networks, the system energy consumption increase rapidly [3]. Hence, the EE (Energy Efficiency) of cellular system should be taken into account. In cellular networks, base stations (BSs) consume a large portion of energy. Consequently, when traffic load is low, it is necessary to reduce energy consumption by BS sleeping, i.e. adapting energy consumption to the dynamic traffic profile.

Hyper-cellular architecture (HCA), which separates control signaling and data service, provides possibility to dynamically schedule/coordinate the operation of BSs, according to the spatial and temporal fluctuations of the traffic demand [3]. The notion of separation architecture, proposed in [4], [5] and [6], focuses on the functional separation of control signaling and data service in BSs. HCA consists of two kinds of BSs to carry the control signaling and data traffic, namely the control BS (CBS) and the traffic BS (TBS), respectively. In HCA the common control functionalities are decoupled from the data service functionalities at BS level so that the TBSs can be more adaptive to the temporal and spatial traffic fluctuations. By introducing BS sleeping, the TBSs or part of it can be switched off [7]. Accordingly, HCA is expected to have the potential to increase the network EE by the utilization of separation architecture.

To quantitatively evaluate the EE gain brought by HCA, extensive simplifications have been done in traditional theoretical analysis, which can not reflect the whole picture of system performance. System simulation provides an effective way to analyze the system. To verify the feasibility of candidate resource management algorithms in real communication systems, many simulators have been developed to evaluate link level (LL) or system level (SL) performance. Simulators can be classified into two types: dynamic simulators (DS) and static simulators (SS). An SS based on snapshot intervals omits temporal correlation of 2-layers heterogeneous networks [8], while a DS consider network events continuously over time is able to model user mobility, traffic models, channel models and other network details. DSs possess advantages in accuracy with rational compromise in time complexity, when compared with SS. As far as concerned, there is exploration on LTE/LTE-A simulator, such as [9]-[12].

However, the simulators mentioned above can not analyze the EE metrics of the HCA separation architecture, and do not apply long-term large-scale traffic model to simulate the different granularities of traffic. In order to fulfill the comprehensive requirement for evaluating the performance of HCA, we develop an SL Dynamic Simulator. We decreases the complexity of theoretical analysis effectively through 2-layers simulation architecture explained in section III.

The main contributions of our work are listed as follows:

- We use dynamic system level simulation to model the function details of HCA. As a result, we can conduct power allocation strategy and radio resource management with conventional network metrics, such as throughput, outage probability and spectral efficiency.
- We implement the separation architecture for TBSs and CBSs in the simulator to support multi-CBS, multi-TBS and multi-user scenarios, where various BS sleeping algorithms can be applied to increase the energy efficiency under spatial and temporal traffic fluctuations with different granularities.

- We evaluate the energy consumption of HCA in comparison with Marco BS Only and Heterogeneous Network (HetNet), which contains macro BSs and micro BSs, by a combination of EARTH energy model and our HCA power consumption model in this paper.

The remaining parts of this paper are organized as follows. Section II describes the system and traffic model of the system level simulation, along with the detailed illustration of the channel and energy model. Section III introduces the methodology of system level simulation, including network elements generation, link level performance abstraction and scheduling. Section IV analyzes the simulation results from our simulator, which shows the energy efficiency gain from the HCA separation architecture. Finally, conclusions are given in Section V.

II. SYSTEM AND TRAFFIC MODEL

A. Hyper-Cellular Architecture

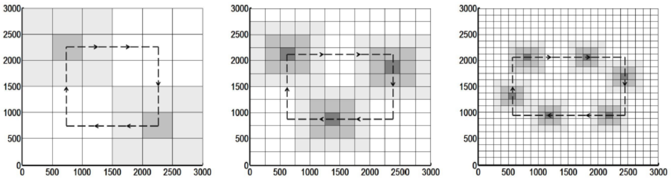
In our simulation, we implement two types of BSs (CBSs & TBSs) to serve a given geographic area. Specifically, we implement a standard hexagonal topology of 19 CBSs, while we deploy TBSs randomly according to Poisson Point Process (PPP) within a CBS cell.

A typical UE access procedure in separation architecture differs from that in a conventional cellular network. For a fresh UE coming to access to the network, it will choose a CBS firstly by the reference of Signal-to-Interference-plus-Noise Ratio (SINR) map. We still use SINR as a critical quality parameter to decide the connection between CBS and UE. According to [3], the probability that the SINR of a UE exceeds a threshold γ_0 is defined as the coverage constraint as $\mathbf{P}\{\text{SINR}(d) \geq \gamma_0\} \geq 0.95$, where d is the distance from the UE to the CBS.

After the establishment of the link between the UE and the CBS, the CBS will decide which TBS should offer data service to this UE by referring to all the available system information, such as channel condition between the UE and TBSs, traffic service requirements of the UE, traffic load distribution, new network layout after the implementation of BS sleeping algorithms and so on. In other words, our simulator is able to evaluate different assignment strategies on how UEs access to TBSs, which is an important characteristic in communication systems with separation architecture. In our simulator, the path loss and shadow fading are calculated separately for both CBSs and TBSs. Once the access between the UE and TBSs is established, the path loss map will be updated to reflect the channel condition change.

B. Traffic Model

In order to reflect the variations of daily traffic in different temporal scales, our simulator combines the Transmit Time Interval (TTI) with Long Term Interval (LTI), which provides flexibility to simulate the spatial and temporal traffic model.



Granularity: 6 × 6
$N_{hotspot} = 2$, $M_{traffic\_level} = 3$

Granularity: 12 × 12
$N_{hotspot} = 3$, $M_{traffic\_level} = 4$

Granularity: 24 × 24
$N_{hotspot} = 6$, $M_{traffic\_level} = 4$

Fig. 1. Non-uniformal traffic models with different granularities and THS traces.

1) Spatial and Temporal Traffic Model: When we analyze the traffic fluctuation in heterogeneous network, the assumption, that the traffic variation distributes evenly within a macro-cell, should be updated to model the non-uniformity of traffic. As a result, our simulator apply spatial coordinates mapping between network layout and traffic hot spots to define the traffic unit (TU) as the minimum geographic region where the traffic intensity holds a constant arrival rate $\lambda_l(T_{\text{LTI}}), l = 1, 2, ..., L$. L, regarded as a parameter to reflect the variation of traffic intensity, denotes the total number of traffic levels (TL). The traffic hot spot (THS) is part of TUs with the heaviest traffic load, and it will move along with the traces periodically. We apply different granularities in a same geographic area as shown in 1.

In each LTI, we use the daily traffic profile from EARTH [13] to generate the traffic intensity. The temporal model of traffic is performed in the time scale LTI by the mobility of traffic hot spots in TUs. We simulate the transmission process of data packets in different TTIs during which the traffic intensity is assumed not to change. According to [8] and [14], the mobility model of traffic hot spots can be configured as follows:

- For each LTI, the traffic arrival rate $\{\lambda_l(t)\}$ repeats with period $T = 24$h.
- The mobility traces of traffic hot spots also repeat periodically with period $T = 24$h.
- To model the spatial correlation of traffic hot spots in a LTI, we use the hot spots center model according to [14], where $\lambda_l(t) = \alpha_l \lambda_{\text{THS}}(t), l = 1, 2, ..., L$, and $0 \leq \alpha_L \leq ... \leq \alpha_2 \leq \alpha_1 \leq 1$.

2) Traffic Types: In continuous simulation in several TTIs, the traffic service of each UE will experience the procedures of data packets generation, transmission and acknowledgment. 3GPP standard group divides the traffic service types into two types best effort packet transmission and real time transmission, both supported by our simulator with a flexibility to change the proportion of mix traffic types. We apply the typical parameters of traffic models from [15].

C. Channel Model

WINNER II channel model [16] adapts to the simulation requirements of link level and system level when we conduct performance evaluation of wireless systems. We choose WINNER II channel model to describe the wireless channels

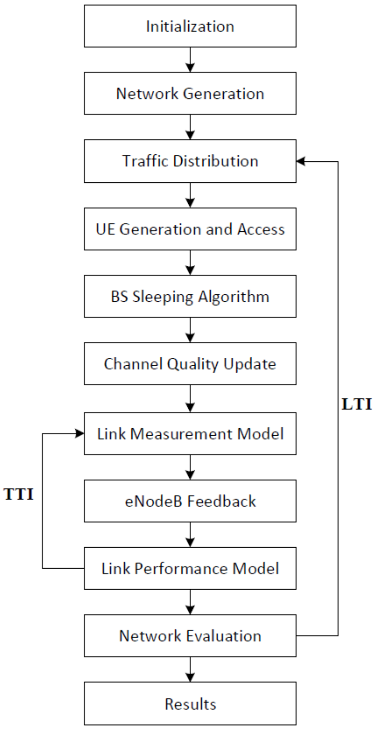


Fig. 2. Flow chart of HCA system level simulator.

between UEs and BSs (TBSs and CBSs) from both large-scale and small-scale parameters. As for various simulation scenarios, our simulator supports other channel models, such as free space, COST231 and so on, according to 3GPP documents [17]-[19].

D. Energy Model

In order to evaluate the energy consumption of HCA, we use this formula to describe the power consumption of HCA:

$$P = \alpha P_{\text{CBS,sig}} + (1-\alpha) P_{\text{CBS,idle}} + \sum_{j=1}^{N_{\text{TBS}}} I^{j}_{\text{sleep}} P^{j}_{\text{TBS,data}},$$

where α is the calibration value to model the signaling power, and $I^{j}_{\text{sleep}} = 0$ if TBS_j is in sleep mode, otherwise $I^{j}_{\text{sleep}} = 1$. $P_{\text{CBS,sig}}$ ($P_{\text{TBS,data}}$) stands for the power allocation of signaling (data) part in CBS (TBS), while $P_{\text{CBS,idle}}$ means the residual power of the vacant resource block. The power consumption of BSs is calculated according to EARTH model [20]. The EE is defined as $\text{Energy Efficiency}(t) = \frac{\text{Energy Consumption}(t)}{\text{Throughput}(t)}$.

III. METHODOLOGY OF SYSTEM LEVEL SIMULATION

A. Simulator Architecture

The flow chart of our simulator is illustrated in Figure 2. In each LTI, the dynamic system states are simulated for many definable TTIs, while the time granularities are adjustable. In our SLS, we use $T_{\text{TTI}} = 3\text{ms}, T_{\text{LTI}} = 1\text{h}$.The different system simulation behaviors are listed as follows.

- LTI (Long Term Interval, typical value is an hour): At the beginning of each LTI, UEs are re-generated according to a traffic map. Meanwhile, we perform the BS sleeping algorithms to re-construct the topology of network by controlling the on/off state of TBSs as well as the UE-TBS association relationship. The path loss and the shadow fading map will also be updated accordingly. During each LTI, network performance is evaluated in several TTIs by means of LL simulation.
- TTI (Transmission Time Interval, typical value is 1ms): At the beginning of each TTI, a UE walking mobility model is implemented to update the position of UEs and the association relationship. For each TTI, transmission process of data packets is simulated sequentially through the following module, UE link quality model, eNodeB feedback and UE link performance model, according to [9]. We can calculate system performance metrics including spectral efficiency, throughput, energy efficiency from the data recorded in simulation traces.

When the simulation starts, the network generation module will generate BSs, UEs, and traffic. At the same time, the pathloss map and the shadow fading map is calculated. Then the link level simulation runs for many TTIs to simulate the system under a prescribed traffic model.

B. Network Elements Generation

Aiming at a universal comparison standard, the layout of CBS obeys standard hexagonal topology containing 19 CBSs. A wrap-around technique is applied to improve the simulation accuracy. With consideration of the coverage of CBSs, we assume the CBSs use omni-directional antennas in 2×2 MIMO scenarios.

The deployment of TBS constitutes a homogeneous PPP of intensity λ_{TBS} in a CBS cell. The number of TBSs is denoted by N, which obeys Poisson distribution $Poi(\lambda_{\text{TBS}} S_{\text{CBS}})$, where S means the square of a CBS cell. However, there is not any slavery relationship between the CBS and the TBSs in the cell. For a given CBS, it has wire line linkage to all TBSs, from which CBS can gain a great deal of information of the system to make a rational decision on which TBS should serve a given UE. To satisfy various simulation requirements, our simulator retains the external interface to the real data about the distribution of TBSs.

As for UEs generation, our simulator provides two ways. One is constant number of UEs per cell, and the other is various number of UEs according to the traffic map. The spatial distribution of UEs is uniform in a given TU, while the number of UEs is calculated according to the traffic intensity from the spatial and temporal traffic model as the formula $N_{\text{UEs}} = \frac{\lambda_l(t)\times S_{TU}}{\text{TL}_{perUE}}$, where $\lambda_l(t)$ denotes the traffic intensity and S_{TU} means the area of the TU. TL_{perUE} stands for the traffic load per UE. Using the fluctuation of the number of UEs to represent the traffic intensity variation has been widely accepted in many papers [3] and [21].

Figure 3 shows the network layout of the simulator. The larger triangles refer to CBSs, while the smaller triangles show the location of TBSs. The position of each UE is given by dot.

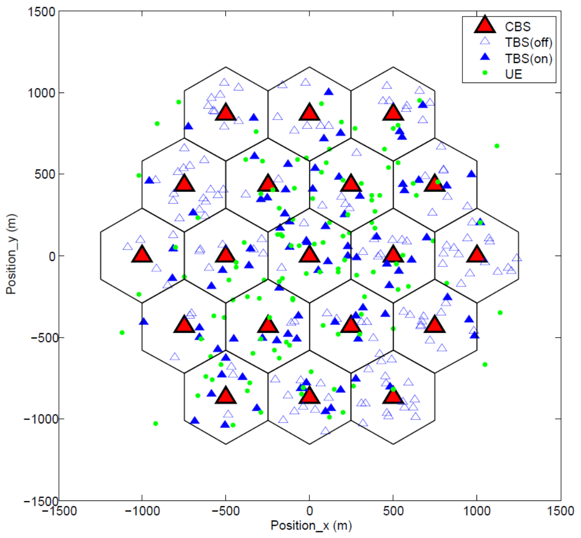


Fig. 3. Network layout in HCA simulator.

C. Link Level Performance Abstraction

Physical layer abstraction plays an important role in system level simulation, and Effective SINR Mapping (ESM) technology between link level and system level is applied. In multi-carrier transmission scenarios in LTE simulation, ESM has been implemented to combine the different SINRs of different sub-carriers into a single value, effective SINR, which can be used to check the performance curve between SINR and BLER. According to [22], Mutual Information Effective SINR Mapping (MIESM) is more robust to calibration errors. In our simulator, the effective SINR is given as $\mathrm{SINR}_{\mathrm{eff}} = \alpha_1 I^{-1}_{m,\gamma}(\frac{1}{N}\sum_{n=1}^{N} I_{m,\gamma}(\frac{\mathrm{SINR}_n}{\alpha_2}))$ where the mutual information is calculated as $I(m,\gamma) = \mathcal{I}_m(\gamma)$, which depends on the modulation alphabet m and the applied demodulator type. The symbols α_1 and α_2 are the calibration parameters in MIESM, and N means the number of sub-carriers.

D. Scheduling

The functionality of scheduling in BS provides flexibility to manage the Resource Block (RB) allocation, which is essential to system performance. For the sake of much clearer presentation of separation architecture in HCA, we take macro BS only network and heterogeneous network as benchmarks, whose RB allocation strategies are shown in Figure 4.

- Macro BS Only: There are only 19 macro-cells in the network without micro-cell or TBS. The macro-cells are responsible for coverage and data service, and parts of RBs are persisted to evaluate signaling overhead.
- HCA Separation Architecture: To specialize the separation architecture, RBs of CBSs are applied to transmit signaling only to ensure coverage, while the RBs of TBSs are held to transmit data without any control signaling.
- Heterogeneous Network: Based on the macro BS only scenario, we deploy micro BS randomly on the network with a minimum distance constraint between marco-cell and micro-cell. Both micro-cell and macro-cell have the functionalities of coverage and data service, meanwhile the RBs are used for signaling and data transmission.

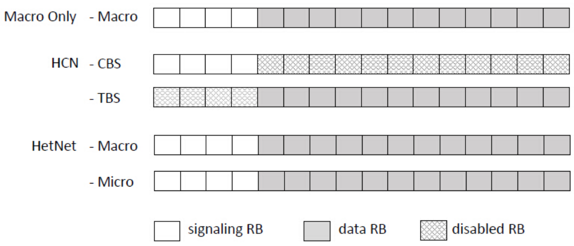


Fig. 4. RBs Allocation of Macro Only, HetNet, HCA.

IV. Simulator Verification of BS Sleeping Algorithms

A. BS Sleeping Algorithms

The temporal fluctuation of traffic load provides the opportunity to turn some TBSs into sleep mode in HCA when the traffic load is low [14]. Effective BS sleeping algorithms have been delivered in [23], [24]. In our simulator, we use a threshold-based BS sleeping algorithm, which turn TBSs off with probability $1 - \frac{N_{\mathrm{UE}}}{T_{\mathrm{UE,off}}}$, and turn on with probability $\frac{N_{\mathrm{UE}}}{T_{\mathrm{UE,on}}}$, where N_{UE} is the predicted number of UEs to access, and $T_{\mathrm{UE,off(on)}}$ is the control threshold.

B. Simulation Scenarios and Parameters

In order to evaluate the accuracy of our simulator, simulation has been done for Macro-only, HetNet and HCA scenarios, when variables are controlled except for network layout and RBs allocation. Detailed simulation parameters are listed in Table I.

TABLE I
SYSTEM LEVEL SIMULATION PARAMETERS.

Deployment scenario	Macro Only	HCA	HetNet
Total BS Tx power(W)	40	CBS 40 TBS 6.3	Marco 40 Micro 6.3
Carrier frequency(GHz)	2.0	2.0	2.0
Network Layout	19 hexagon	CBS 19 hexagon TBS PPP $\lambda = 10$	Macro 19 hexagon Micro PPP $\lambda = 10$
Inter-site distance(m)	500	500	500
User distribution	Hotspot+EARTH	Hotspot+EARTH	Hotspot+EARTH
Antenna configuration	2×2MIMO CLSM	2×2MIMO CLSM	2×2MIMO CLSM
BS antenna pattern	Omni-directional	Omni-directional	Omni-directional
Simulation bandwidth(MHz)	20	20	20
Channel Model	WINNER II	WINNER II	WINNER II
Pathloss Model	TS36.942	TS36.942	TS36.942
Scheduler	Round Robin	Round Robin	Round Robin

C. Results Analysis

The macro-only network is poor in network throughput, while the HetNet and HCA throughput is twice as large as macro only according to Figure 5. As a result, we omit macro only scenario in our following analysis. As the traffic load in each LTI increasing, all networks achieve their performance upper bound in throughput.

To analyze the gain brought by the BS sleeping algorithms in HCA, we use energy consumption as a critical metric to measure the performance in HCA and HetNet. Figure 6 reflects that energy consumption in HCA and HetNet is shaped by the traffic profile. Compared with HetNet, HCA can save more

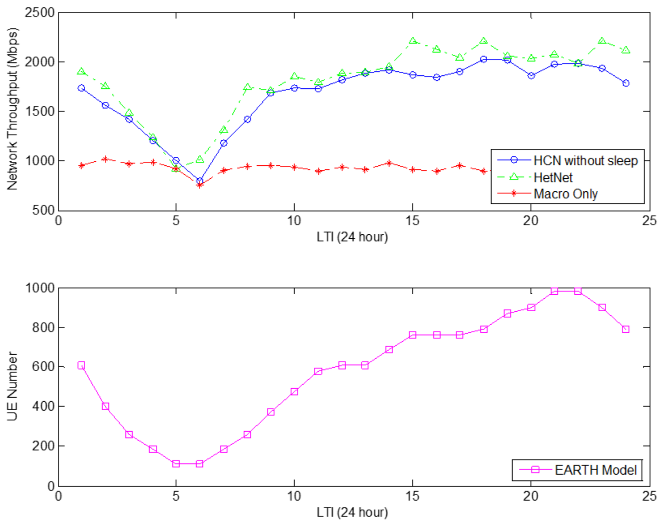


Fig. 5. Network throughput compared with traffic profile [13].

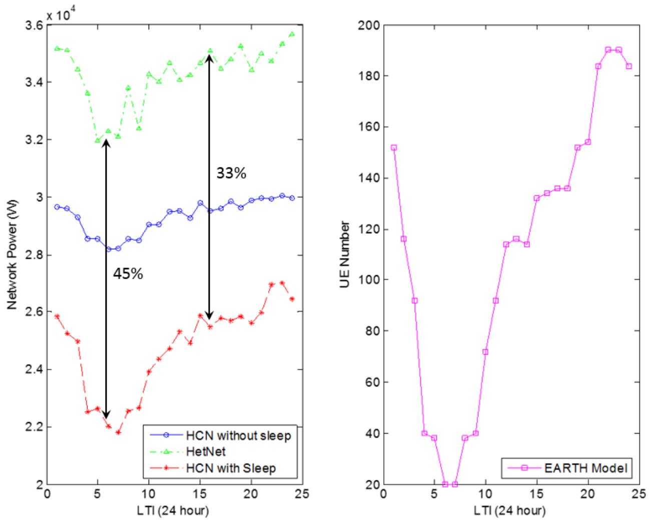


Fig. 6. Energy consumption in HetNet and HCA.

than 29% energy at 5% decline in throughput on average. In the vacant traffic period (5th&6th LTI), HCA with BS sleeping algorithms can increase more than 45% EE than normal HCA, even though a simple sleeping strategy is simulated. The advantages of BS sleeping are still maintained in the busy period of traffic profile (16th LTI) in 33% energy benefit.

The improvement on EE can be demonstrated in Figure 7.In this simulation scenario, HCA with BS sleeping algorithm shows 67% enhancement in energy efficiency, compared with HetNet, when the traffic load is low. Accordingly, the BS sleeping algorithms emerge natural adaptation to the traffic dynamic, which reveals the excellence of HCA separation architecture. The difference between normal HCA and HCA with BS sleeping algorithms attenuates along with the peak load of traffic coming. What's worse, the energy efficiency even deteriorates 10% in the peak hours.

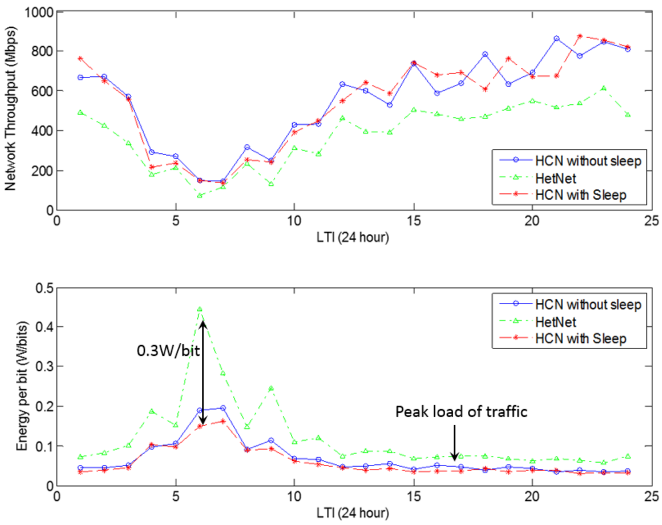


Fig. 7. Energy efficiency in HetNet and HCA.

V. CONCLUSION

In this paper, we develop a system level simulator for HCA, supporting the separation architecture of TBSs and CBSs, to evaluate the system performance within the consideration of temporal and spatial fluctuation of traffic. Detailed illustration of the implementation of HCA SLS has been introduced to explain the system model and simulation methodology. We design a new simulation flow chart with LTI and TTI, which can reduce the complexity of long term simulation effectively. Simulation results show that even with some basic BS sleeping algorithms, HCA can provide about 45% energy efficiency gain over conventional cellular architecture with macro BS only and heterogeneous network during the low traffic period, and about 36% EE gain on average for a typical daily traffic pattern.

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REFERENCES

[1] HUAWEI, "5G: A Technology Vision," Jan. 2014.
[2] Y. Wang, J. Xu, and L. Jiang, "Challenges of System-level Simulations and Performance Evaluation for 5G Wireless Networks," *IEEE, Access*, vol. 2, pp. 1553-1561, Jan. 2015.
[3] Z. Wang, W. Zhang, "A Separation Architecture for Achieving Energy-Efficient Cellular Networking," *IEEE Trans. Wireless Commun.*, vol. 13, no. 6, pp. 3113-3123, May 2014.
[4] Z. Niu, "TANGO: traffic-aware network planning and green operation," *IEEE Wireless Commun.*, vol. 18 no. 5, pp.25-29, Oct. 2011.
[5] X. Xu, et al., "On functionality separation for green mobile networks: concept study over LTE," *IEEE Commun.*, vol. 51, no. 5, pp. 82-90, May 2013.
[6] A. Capone, et al., "Looking beyond green cellular networks," in *IEEE WONS*, Courmayeur, Jan. 2012.
[7] X. Guo, et al., "Characterizing EnergyDelay Tradeoff in Hyper-Cellular Networks With Base Station Sleeping Control," *IEEE J. Sel. Areas Commun.*, vol. 33, no. 4, pp. 641-650, Jan. 2015.

[8] L. Du, J. Biaham, and L. Cuthbert, "A bubble oscillation algorithm for distributed geographic load balancing in mobile networks," in *IEEE INFOCOM*, Mar. 2004.

[9] JC. Ikuno, M. Wrulich, and M. Rupp, "System level simulation of LTE networks," in *IEEE VTC*, Taipei, May 2010.

[10] A. Virdis, G. Stea, and G. Nardini. "SimuLTE: a modular system-level simulator for LTE/LTE-A networks based on OMNeT++," in *IEEE SIMULTECH*, Vienna, Austria, Aug. 2014.

[11] G. Piro, L. Grieco, G. Boggia, F. Capozzi, and P. Camarda, "Simulating LTE cellular systems: an open-source framework," *IEEE Trans. Veh. Technol.* vol. 60, no. 2, pp. 498-513, Oct. 2010.

[12] N. Baldo, et al., "An open source product-oriented LTE network simulator based on ns-3," in *ACM MSWiM*, New York, NY, USA, Oct. 2011.

[13] M. Imran et al., "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown," EARTH Project Deliverable, vol. 2, no. 2.

[14] J. Gong, S. Zhou, Z. Niu, "A dynamic programming approach for base station sleeping in cellular networks," *IEICE Trans. Commun.*, vol. 95, no. 2, pp.551-562, Feb. 2012.

[15] Alliance N. "NGMN radio access performance evaluation methodology," *NGMN Technical Working Group Steering Committee*, vol. 1, no. 37,2008.

[16] P. Kysti, et al., "WINNER II channel models," 2008.

[17] 3GPP TR 36.942, "E-UTRA; LTE RF system scenarios," 3GPP, 2008-2009.

[18] 3GPP TR 36.814, "E-UTRA; further advancements for E-UTRA physical layer aspects," 3GPP, 2010.

[19] 3GPP TR 25.814, "Physical layer aspects for E-UTRA," 3GPP, 2006.

[20] G. Auer, et al., "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown." EARTH Project Deliverable, vol. 2, no. 3.

[21] D. Lee, et al., "Spatial modeling of the traffic density in cellular networks." *IEEE Wireless Commun.*, vol. 21, no. 1, pp. 80-88, Feb. 2014.

[22] K. Brueninghaus, D. Astly, T. Salzer, et al., "Link performance models for system level simulations of broadband radio access systems," *IEEE PIMRC*, Berlin, vol. 4, pp. 2306-2311, Sept. 2005.

[23] K. Son, et al., "Base station operation and user association mechanisms for energy-delay tradeoffs in green cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 8, pp. 1525-1536, Sept. 2011.

[24] J. Wu, S. Zhou, and Zhisheng Niu. "Traffic-aware base station sleeping control and power matching for energy-delay tradeoffs in green cellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 8, pp. 4196-4209, July 2013.