System Level Performance Evaluation for Ultra-Dense Networks

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Abstract. The ultra-dense network (UND) has been considered as an effective scheme to satisfy the growing demands on data rate in the wireless network. And it can easily improve the throughput by increasing the number of base stations. In this paper, the performance of UDN with various small cell densities is evaluated. And the throughput, spectrum efficiency and energy efficiency are taken into consideration to evaluate the performance of the deployment strategies. As can be seen from the simulation results, the throughput and area spectrum efficiency are obviously improved with the increasingly dense cells. However, as the network densification the positive influence on throughput and spectrum efficiency would be decreased.

Keywords: Ultra dense networks · Throughput · Spectrum efficiency · Energy efficiency

1 Introduction

The popularization of smart devices and rapid development of internet services lead to a prophecy that the traffic flow of mobile data traffic will increase a 1000-fold till the year of 2020 [1]. In order to meet future mobile communication systems under the conditions of the traffic demand, from the spectral efficiency and energy efficiency, the heterogeneous networks (HetNets) is a practical approach to maximize the spectral efficiency and minimize the energy consumption [2]. Moreover, the 5th generation mobile networks (5G) will provide support for a new kind of network deployment such as ultra-dense network [3]. And advanced small cell technology will be adopted in 5G systems to bring highly quality of experience of users.

The small cells, which including picocells, femtocells and microcells, have been attracting more and more attention to improve service coverage and system capacity. In order to make the best of spectrum, small cells usually adopt the same frequency as the macro cells. And they often have lower transmit power than macro cells to reduce co-channel interference. Currently, small cells are widely deployed in small commercial areas or at home. Indeed, small cells already have a larger number than macro cells. Meanwhile, green communication has been paid more attention in global scale. And the energy efficiency is one of the most importance parts of the performance. However, what problems the UDN will bring to spectrum and energy consumption have not been

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well known. This paper has evaluated the network performance in UND using several parallel metrics likes SINR distribution and throughput. Particularly, varieties of spectrum efficiencies and energy efficiencies are also considered for assessing the network performance in different dense network scenarios.

The organization of the paper is as follows. Section 2 provides an overview of system model. In Sect. 3 the main simulation results of performance evaluation in UND are discussed. Following that, some problems and challenges in UND are discussed in Sect. 4. Finally, in Sect. 5 the conclusions are presented.

2 System Model

2.1 Scenario and Parameter

In this paper the traditional 7 Macro layout of hexagonal deployment has been used as the base scenario for the simulation. And as shown in Fig. 1, in the center cell (Cell 0) a lot of Pico eNodeBs (PeNBs) are randomly deployed, but there are no PeNBs in the Macro cells locating around the center cell. The function of surrounding Macro eNodeBs (MeNBs) is providing interference, so that the scenario is realistic. And the number of Pico is increased from 20 to 120 with an interval of 20, which results in 97, 190, 282, 375, 468 or 560 cells per square km deployed in the scenario, respectively. It's worth noticing that all eNBs i.e. MeNBs and PeNBs are transmitting in the same frequency. And the specific simulation parameters can be found in Table 1.

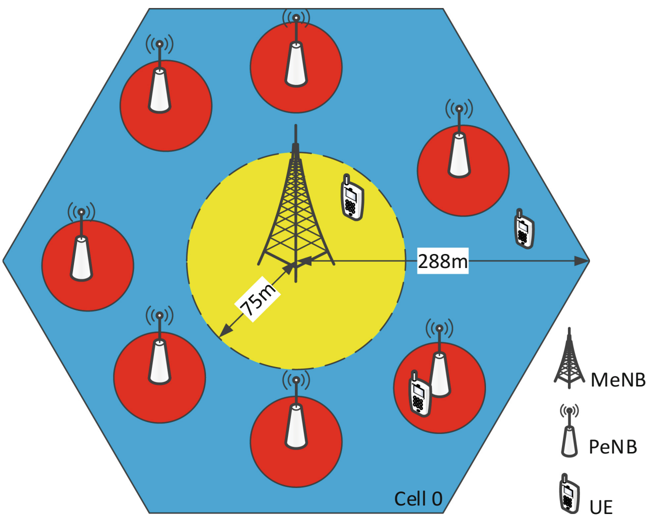

Fig. 1. Simulation scenario.

Table 1. Simulation parameters.

Parameters		Value
System configurations		
Frequency		2 GHz
Bandwidth		10 MHz (50RBs)
Duplex		FDD
Antenna configuration		DL: 2×2
ISD		500 m
Frequency reuse factor		1
Minimum distance between eNB and UE		35 m (MeNB)/10 m (PeNB)
Minimum distance between MeNB and PeNB		75 m
Minimum distance between PeNB and PeNB		40 m
Noise		−174 dBm/Hz
Fast fading		Jakes model
Number of UEs		30 (Macro)/5 (Pico)
Number of Picos		20/40/60/80/100/120
Scheduler		PF
eNB configurations		
MeNB	Transmit power	46 dBm
	Antenna gain	17 dBi
	Antenna height	25 m
	Channel model	3D-UMa
PeNB	Transmit power	30 dBm
	Antenna gain	5 dBi
	Antenna height	10 m
	Channel model	3D-UMi
UE configurations		
Transmit power		23 dB
Antenna height		1.5 m
Mobility type		Random walk
Speed		3 km/h
Traffic type		Full buffer

2.2 Channel Model

The channel model of the simulation handles packet transmission and models the propagation loss taking into account four different fields as suggested in [4]: (i) the penetration loss, (ii) the path loss, (iii) the fast fading, and (iv) the shadowing fading

[5]. And the propagation loss can be divided into two kinds of channel parameters. The first one is the large scale parameters including the path loss and shadow fading. The second one is the small scale parameters, like fast fading. And to meet the complex simulation scenarios in UND there are variety channel models can be chosen such as 3D channel, WINNER II and traditional channel models.

2.3 Antenna Model

A 3D antenna model is adopted for this simulation. The horizontal radiation pattern (1) and vertical radiation pattern (2) are both considered as well as the electrical down tilt [6]. The horizontal radiation pattern is given by:

$$A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] |[dB] \tag{1}$$

where $A_{E,H}(\varphi)$ is the antenna attenuation in the horizontal direction φ, the value of φ is from -180^{o} to 180^{o}, $\varphi_{3\mathrm{dB}}$ is the horizontal 3 dB beam width and the default is 65^{o}, and A_{m} = 30 dB is the maximum gain, and min [.] denotes the minimum function. The vertical radiation pattern is similar as the horizontal antenna pattern and it is given by:

$$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta - \phi_{tilt}}{\theta_{3dB}}\right)^2, SLA_V\right] |[dB] \tag{2}$$

where $A_{E,V}(\theta)$ is the relative antenna attenuation in the vertical direction θ, $-90^{o} \leq \theta \leq 90^{o}$, and $\theta_{3\mathrm{dB}}$ is the vertical 3 dB beam width corresponding to $\theta_{3\mathrm{dB}} = 65^{o}$. SLA_V = 30 dB, ϕ_{tilt} is electrical down tilt, and it may be assumed to be 90^{o}. And the combined antenna radiation pattern is computed as:

$$A(\theta, \varphi) = -\min\{-[A_{E,V}(\theta) + A_{E,H}(\varphi)], A_m\} \mid [dB] \tag{3}$$

2.4 Protocol Stack

The protocol stack has been set up as a container of Radio Resource Control (RRC), Radio Link Control (RLC), MAC and PHY entities. Generally speaking, the RRC contains a lot functions including broadcasting the relevant system information, operating the RRC connection between the UE and the E-UTRAN, managing the mobility and allocating the wireless resources etc.

The RLC entity provides interactions between the radio bearer and the MAC entity [7]. Besides, it models the unacknowledged data transmission at the RLC layer [8]. The most important functionalities of RLC are the segmentation and the concatenation of service data units. And the RLC entity comprises three different types of RLC: Acknowledged Mode (AM), Unacknowledge Mode (UM) and Transparent Mode (TM).

While the MAC entity provides all the most important procedures for the radio interface, such as scheduling requests and radio resource allocation [9]. Moreover, in this entity the Adaptive Modulation Coding (AMC) module is further defined.

Moreover, PHY provides reliable environment for the data transmission between transmission media and interconnection equipment. And it is directly facing the actual data transmission physical media to provide a transport raw bit stream over a physical media layer to the MAC.

3 Simulation Evaluation

As known the throughput and spectrum efficiency are two key performance indicators for evaluating the capacity in the 4G network. And the energy efficiency attracts more and more people's attention for the communication industry towards green development. In the following, all the performances are evaluated as well the SINR.

3.1 SINR

The performance of a cellular system in a certain environment is highly dependent on the radio propagation conditions. The quality of the radio propagation is determined by the transmission power of the eNB and the interference which set a limit on the maximum throughput, as defined by Shannon capacity bound.

Figures 2 and 3 respectively show the CDF of UE SINR and the SINR spatial distribution corresponding to 20, 40, 60, 80, 100 and 120 small cells deployments. It is evident that, the UE SINR is deteriorated as the density of Pico developments. And the reason can be easily owe to interferences from the other co-frequency eNBs except the serving eNB. As shown in Fig. 3, the coverage is becoming larger with the Pico cell density, and on the other side the percent of high UE SINR is becoming lower. That is because, with more and more Pico cells deployments, more areas are occupied by Pico cells. At the same time that leads to a problem, as mentioned earlier, the interference will be stronger.

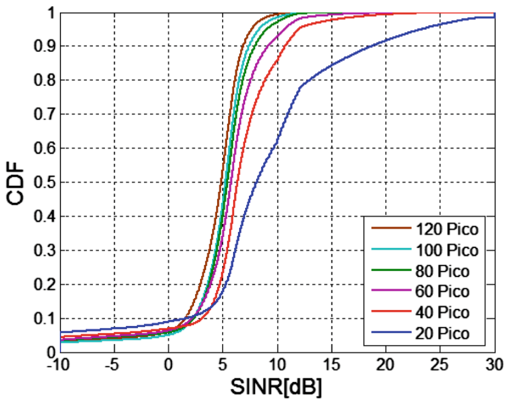

Fig. 2. CDF of UE SINR for different Pico densities.

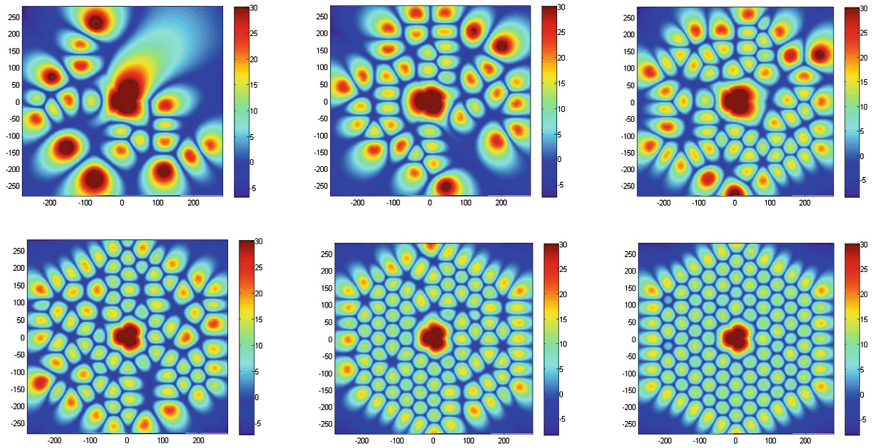

Fig. 3. SINR spatial distribution for different Pico densities.

3.2 Throughput

Network densification has the potential to linearly increase the throughput of the network with the number of deployed cells through spectrum reuse, and it is deemed to be the key technology to provide most of the throughput gains in future networks [10]. As shown in Fig. 4(a), increasing the number of Pico development will increase the throughput of the entire cellular networks. But the pace of increasing in throughput becomes slower. Moreover, Fig. 4(b) shows that the maximum rate is gradually decreased due to the increasing density of cells. As spectrum resources can be fully utilized in the same frequency network development, the same frequency is adopted in both Macro and Pico. Nevertheless, the interference will grow with the increasing of network nodes in the same frequency. That is the reason why the increasing of the throughput becomes slow.

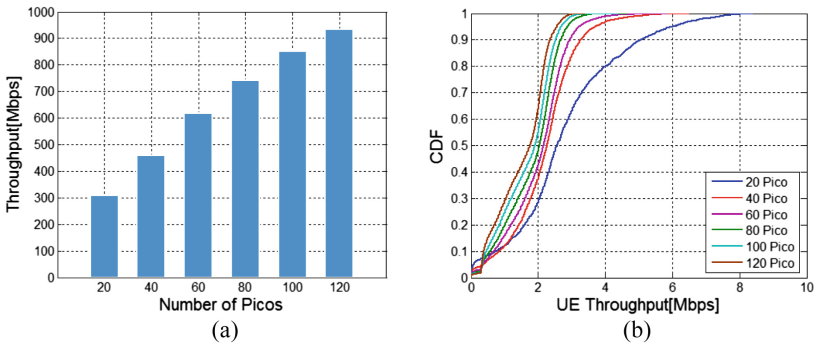

Fig. 4. The network throughput (a) and the CDF of UE throughput (b) for different Pico densities.

3.3 Spectrum Efficiency

Table 2 provides relevant spectrum efficiency such as cell spectrum efficiency (η_{cell}), area spectrum efficiency (η_{area}) and cell edge spectrum efficiency (η_{edge}) versus cell densities. As for cell spectrum efficiency, it is shown to decrease with the increasing of the cell density. Initially, the cell spectrum efficiency is at the level of 1.47 bps/Hz/cell and reduces to 0.77 bps/Hz/cell when network is densified from 97 cells/km^2 to 560 cells/km^2. Besides, the cell edge spectrum efficiency has the same trends as the cell spectrum efficiency, which reduces from the level of 0.158 bps/Hz/cell to 0.067 bps/Hz/cell. On the contrary, the high degree of resource reuse because of dense deployments with co-frequency leads to an increase of the area spectrum efficiency as shown in Table 2. On the other hand, the pace of increasing in area spectrum efficiency becomes slower due to the increasing interference from the other co-frequency eNBs.

Table 2. Various spectrum efficiencies for different Pico densities.

Pico number	ρ_{cell} [cells/km^2]	η_{cell} [bps/Hz/cell]	η_{edge} [bps/Hz/cell]	η_{area} [bps/Hz/km^2]
20	97	1.47	0.158	142.23
40	190	1.12	0.127	211.62
60	282	1.01	0.107	285.82
80	375	0.92	0.092	342.99
100	468	0.84	0.078	392.73
120	560	0.77	0.067	431.85

3.4 Energy Efficiency

The energy to bit ratio (λ_I) is one of the most common metric used for evaluating the energy efficiency of the performance in a network, especially in urban environments. And it is defined by the amount of power consumed in providing an aggregate network capacity. From other side, it also can be described as energy consumed for transmitting per bit information. This metric is appropriate for assessing the energy efficiency of a network with full loads [11].

In order to evaluate the impact of energy efficiency in a cell densification network, the area energy consumption (λ_A) by normalizing the total power consumption is also given in [12] to 1 km^2 area. The area energy consumption is usually used in a case where the network without full loads. Finally, taking into account the area spectrum efficiency and area energy consumption, the energy-efficiency is defined as following:

$$E_{eff} = \frac{\eta_{area}}{\lambda_A} | [bps / Hz / w] \tag{4}$$

where η_{area} is the area spectrum efficiency as mentioned in Table 2.

The energy efficiency is summarized in Table 3. It can be observed that, the area energy consumption is increasing as the network deployment densified. It increases from 276.898 w/km^2 to 739.861 w/km^2 when the network is densified from 97

Table 3. Various energy efficiencies for different Pico densities.

Pico number	ρ_{cell} [cells/km^2]	λ_I [w/bps] * 10e−6	λ_A [w/km^2]	E_{eff} [bps/Hz/w]
20	97	0.194	276.898	0.514
40	190	0.174	369.491	0.573
60	282	0.161	462.083	0.619
80	375	0.161	554.676	0.618
100	468	0.164	647.269	0.607
120	560	0.171	739.861	0.584

cells/km^2 to 560 cells/km^2. That is because the network coverage is constant, more and more power will be consumed with the increasing in the eNB density. From another aspect, increasing the eNB density will first increase the energy-efficiency E_{eff} and then decrease. The reason can be deduced from the growth trend of the area spectrum efficiency and the cell density. It can be observed that, the increment of the cell density is a constant i.e. the acceleration of the area energy consumption is a constant. However, due to the increasing interference with the increasing cell density the acceleration of the area spectrum efficiency is becoming smaller. That can lead to the E_{eff} increases from 0.514 bps/Hz/w to 0.619 bps/Hz/w when the network is densified from 97 cells/km^2 to 282 cells/km^2 and then decreases to 0.584 bps/Hz/w.

4 Challenges in Ultra Dense Networks

Although UDN is a promising technology to improve the throughput and meet the demand of the increasing traffic, there are also some issues in UDN like the intense co-frequency interference as mentioned before. Some researches consider the enhanced inter-cell interference coordination (eICIC) and the coordinated multi-point (CoMP) as feasible ways to overcome the interference. But how effectively they would perform in UDN is indeterminate so far. And as more and more small cell stations deployed the energy consumption is another hotspot in UDN. Moreover, the reduced Inter Site Distances (ISD) in UDN will raise the handover frequency and handover failure rate of mobile users. And UDN would bring some problems to the mobility management. Some new schemes of mobility management for example dual connectivity should be further explored. Also challenges of this network architecture could be the flexible connection to the core networks, dynamic on-off and the random deployment of small cells, and the flat system architecture of system.

5 Conclusions

In this paper, the network performance in different dense network scenarios has been evaluated. From the SINR distribution point of view, the SINR of the overall network deteriorates as the density of Pico deployments. From the throughput point of view, network densification can increase the throughput. But the acceleration of throughput is becoming smaller as the network densification. From the point of spectrum efficiency, the area spectrum efficiency is raised just like the throughput. However, for the cell spectrum efficiency and cell edge spectrum efficiency, they will decrease with the increasing of cell density. As for energy consumption, the area energy consumption is improved as the network deployment densified. On the other side, it can be found that the energy-efficiency defined above rises at first and then falls. And it could be also found that the UDN will cause some problems such as the intense inter-cell interference and more frequent handover.

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