VITALITY AND SUPERNATURAL EFFICIENCY IN CELLULAR NETWORKS CONSIDERING FADING, PATH LOSS, AND INTERFERENCE

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ABSTRACT:

Due to the increase of energy consumption in wireless systems, energy-efficient cellular planning concept has become an important concern in designing cellular networks. In this paper, energy efficiency (EE) and spectral efficiency (SE) analysis for single and multi-cell cellular systems are presented and investigated. The efficiency analysis is studied under the influence of Nakagamim multi-path fading superimposed on path loss, and co-channel interference for three base station (BS) antenna configurations which are omni, and 120o and 60o directive antennas. The downlink SE and EE are derived and simulated concerning the random users' location, normalized reuse distance, cell radius, and random channel gain. Theoretical and simulation results show that, as expected, single cell scenario provides higher efficiency than multi cell; however, antenna directivity improves both efficiency metrics. The analysis provides insight contribution for the SE-EE tradeoff issue in cellular networks for which most of the network and propagation parameters are included in the analysis.

Keywords—Cellular Networks, Energy Efficiency, Spectral Efficiency, Fading Channel, Co-channel Interference

I. INTRODUCTION:New applications and use cases, introduced in the context of 5th generation (5G) mobile networks, come along with unprecedented and challenging requirements, of which especially high availability is an important cornerstone [1]. Availability is related to various layers, components, and metrics of wireless communication systems; however, one vital performance indicator, that strongly affects other metrics as well, is the signal-to-interference-and-noise ratio (SINR). In contrast to existing studies of the SINR distribution, where typically 5th or 50th percentiles are evaluated, investigations of the left tail of the SINR distribution are required to address the needs of 5G applications, which in turn cause new challenges for system analysis and design. At the left tail of a probability distribution, e.g., at an outage probability of 10−7 or below, it is difficult to efficiently obtain statistically reliable simulation results. Here, abstract modeling of asystem can help address open questions with reasonable complexity. In this work, we present astochastic SINR model where shadow fading is described by random variables (RVs) shaping the final SINR distribution. The model presented characterizes all parts of the probability distribution in detail, also the leftmost tail. In this context, user association is an aspect that complicates modeling of the exact SINR distribution. If shadow fading is characterized by RVs, it is non-deterministic which link provides the highest receive power, and hence, the user association is random as well. This is an aspect that is most frequently simplified or neglected in related works. In [2] and [3], the authors utilize an approximation for the sum of log-normal RVs and simplify the SINR to a single lognormal RV, but the user association is assumed to be predefined or fixed. Another commonly used simplification is that the serving base station (BS) is chosen based on smallest path loss or shortest distance, see e.g., [4]. The latter assumption was also quite common in stochastic geometry; until 2014, when, in [5], Dillon et al. utilized a displacement theorem in order to incorporate shadowing into the user association process. Outside the field of stochastic geometry, there exist only a few approaches that consider shadowing in the user association. In [6], Muhleisen et al. present an analysis of the SINR distribution for the Long Term Evolution (LTE) uplink, but it is restricted to only two links. Furthermore, in [7], Kelif et al. numerically evaluate the impact of the best server association and show that in certain scenarios it is sufficient to neglect shadowing and connect the users to the closest BS. Another related work can be found in [8], where an approximation of the SINR distribution for hexagonal cellular networks is presented. The main idea is to connect the user to a specific BS and then truncate the corresponding SINR distribution below a certain threshold because it is likely that the user connects to another BS. The work in [9] extends the model from [8] by shadowing cross-correlation and noise. Although the approaches in [8] and [9] are simple and sufficiently accurate for many purposes, e.g., estimating the 50^{th}percentile of the SINR, they are not capable to model the left tail of the SINR distribution with high accuracy Our contribution is a new model for analyzing the SINR distribution at specific user locations or over a larger area of an arbitrary but defined cellular deployment. Important features of typical system evaluations such as shadowing cross-correlation and antenna sectorization are considered. We incorporate shadowing into the user association by considering different association options and modification of the power distributions of the interfering links. To elaborate, their distributions are truncated above the power value of the serving link since the latter is always stronger than the interferers. Then, the distributions are summarized to a single SINR distribution by using logarithmic convolution [10]. Most importantly, there is no approximation involved and hence, the model is suited to investigate the left tail of the SINR distribution which can, for instance, be of interest for high availability studies. Finally, we substantiate the accuracy of the model by comparison to Monte Carlo simulations. With the massive deployment of mobile cellular networks, corresponding energy consumption is also escalated. Wireless base station (BS) is regarded as a huge contributor in the total energy consumption of the cellular networks. D. Lister has reported [1] that energy bill of BS accounts for about 18% of the Operation Expenditure in European cellular market. This rise of energy consumption leads to an increase in greenhouse gas emission that ultimately contributes to the global CO2 emissions [2]. Studies in [3] and [4] have shown that power-peruse in mobile networks is rapidly increasing and the demand for electrical energy in wireless communication has annually increased by 20%. In this sense, energy efficiency (EE) and spectral efficiency (SE) have recently gained considerable attention from government, academia, and industry not only to reduce the energy bills, but also to minimize the effect of global warming and increase sustainable development. Optimizing SE was the main concern for most of the research efforts and EE was not regarded as a significant performance metric until recently. However, these efficiency metrics must be considered jointly instead of separately in the efficient design of mobile cellular systems. Maximizing one metric

(EE or SE) contradicts with other one and hence, balance between them is necessary for designing future wireless networks. In [5], fundamental trade-off between SE and EE was introduced for green wireless networks in AWGN without considering the fading channel effects. Power versus bandwidth efficiency analysis has been done for a simple interference model and considering Rayleigh fading channel in [6]. For interference-limited wireless network, the EE and SE trade-off problem was studied in [7] with iterative power allocation algorithm; also, further analysis has been done for the same problem considering the shadowing and frequency reuse factor effects in [8]. The average SE and EE between two user equipment's in cellular network have been obtained under Rayleigh fading channel; moreover, the optimal transmission power was also derived in [9]. These metrics have been also investigated in [10] for wireless body sensor network considering the interference effect and distance power control strategy was also implemented to improve the spatial energy efficiency. D. Tsilimantos et al. have introduced a simple theoretical framework for analyzing the SE-EE trade-off problem in cellular networks. In their paper [11], an optimal resource allocation approach and traffic repartition scheme have been presented to reduce the complexity trade-off problem. To the best of our knowledge, the aforementioned efficiency metrics are not extensively investigated when the transmission environment are fully considered. In this paper, a thorough efficiency study for a cellular network is done under the effect of wireless channel, path loss, and co-channel interference.

II. CELLULAR NETWORK AND CHANNEL MODELS The negative effects of interference and channel impairments are manifested as the multi-cell network becomes huge. A large scale cellular network is considered here which consists of homogeneous macro-cells with hexagonal tessellation as shown in Fig.1a. The base stations (BSs) are located on the center of each cell and the users are assumed to be served by the closest BS. The system resources such as power and bandwidth are equally assigned to the all cells, which makes the SE-EE analysis valid for the whole cellular network. The downlink, BS to users, analysis is our interest in this work. Three different BS antenna configurations are implemented in our analysis: omni, and 120o and 60o directional antenna. Fig.1 shows an example of the hexagonal cellular network with the main network parameters included in our analysis and simulation which are the cell radius (R), the frequency reused distance (D), and the interfering distance (Dj,i). As we can see, the same frequency is reused for more than one cell and hence, the network experiences

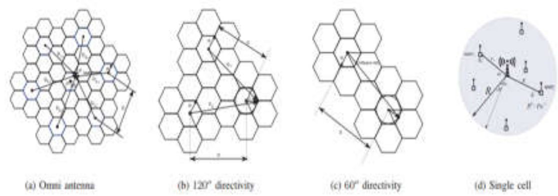


Fig. 1: Single cell and Multi-cell hexagonal tessellation with network parameters for omni and directional antennas

IMPLEMENTATION

- The SINR distribution as a function of traffic load is derived firstly. Then sufficient condition for ignoring thermal noise and simplifying the SINR distribution is investigated. Based on the simplified SINR distribution, the network spectral and energy efficiency as functions of network traffic load are derived.
- It is shown that the network spectral efficiency increases monotonically in traffic load, while the optimal network energy efficiency depends on the ratio of the sleep-mode power consumption to the active-mode power consumption of base stations. If the ratio is larger than a certain threshold, the network energy efficiency increases monotonically with network traffic load and is maximized when the network is fully loaded.
- Otherwise, the network energy efficiency firstly increases and then decreases in network traffic load. The optimal load can be identified with a binary search algorithm.

Driven by the increasing usage of smart devices and mobile applications, the traffic of cellular networks has grown dramatically and this trend would continue in the future. It is forecasted that the global mobile traffic would increase by nearlytenfold from 2014 to 2019. Therefore network densification has been proposed to increase the network capacity by increasing the reuse of radio resources . However, deploying more base stations (BSs) would lead to soaring energy consumption,which not only incurs severe environmental problems but also increases operation cost. It is therefore critical to increase the energy efficiency of cellular networks.

As indicated in the energy consumption of BSs accountsfor almost 60% of all the energy consumed by cellular networks. Different approaches have been proposed to reducethe energy consumption of BSs. One is to develop low-energy consuming hardware and the other is to operate BSs to traffic demand. The latter is motivated by the fact that the existing BSs are deployed and operated to cater for the maximum traffic demand while the network traffic may vary in time.

DRAWBACKS:

- The long-term traffic variation, for which the time scale is at level of hours.
- The average traffic intensity varies from hour to hour.
- Incoming traffic request in certain slots and then switched into micro sleep mode during idle slots.

PROPOSED SYSTEM:

In this paper, we investigate the impact of traffic load on network performance and endeavor to discover the explicit relationship between traffic load and spectral and energy efficiency of cellular networks using cell DTX.

1) Derive the network SINR distribution while considering network traffic load. Then we further derive network spectral and energy efficiency.

2) Present a sufficient condition for a cellular network to be interference-limited.

3) Analyze the impact of network traffic load on network spectral and energy efficiency.

4) Run numerical simulations to further confirm the analyticresults.

BLOCK DIAGRAM:

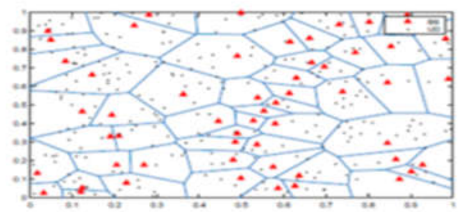


Figure 1. Distribution of base stations (BS) and user devices (UD) in a cellular network

DESCRIPTION:

In this section, we first describe the system model and the necessary assumptions for the performance analysis. Thenthe network traffic load and power consumption model are explained. In the end, the performance metrics are described.

Network Model

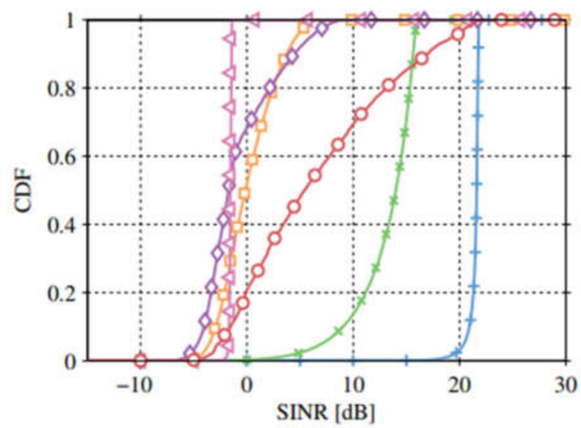
We consider the downlink transmission in a network whereboth BSs and users are randomly distributed. The network isassumed to be homogeneous in terms of both traffic demand and BS distribution. The distribution of BSs is modelled with an ergodic PPP _B with density λB. Note that we consider homogeneous networks and the case of heterogeneous network is beyond the scope of this paper. Each user is associatedtoits closest BS. Thus the coverage area of each BS canbemodelled using the Poisson Voronoi Tessellation (PVT)method. Fig. 1 illustrates an example of such a network. All theBSs are assumed to support DTX. The BS stays in active modeand transmits when there is any traffic request. Otherwise, it switches into sleep mode and does not transmit. The universal frequency reuse is applied and the system bandwidth is W.The users within each cell equally share the resources inan orthogonal manner. Only path loss and fast fading areconsidered. The link between a BS and a user is modeled as follows:

wherePr, Pt, C, K, r, and α denote the receive power, thetransmit power, the antenna gain, the path loss constant at unitdistance, the distance between the BS and the user and the path loss exponent respectively.

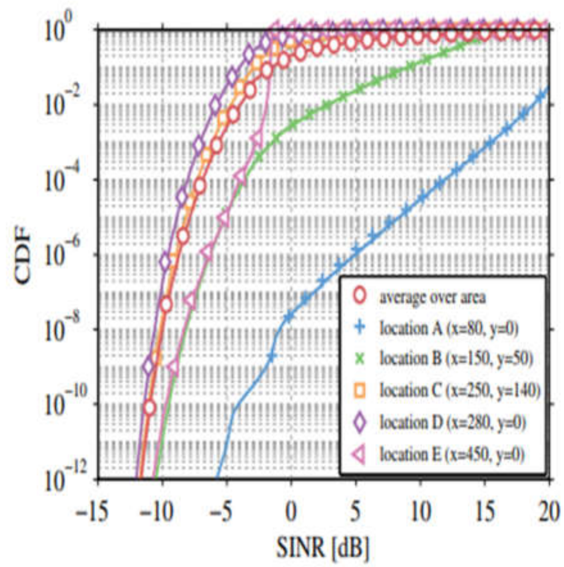
ADVANTAGES:

- The network is analyzed with theories of stochastic geometry.
- Simplified SINR distribution, analytical expressions are obtained to describe the impact of the network load on the performances, including link spectral efficiency, network spectral and energy efficiency.
- The average link spectral efficiency decreases while the network spectral efficiency increases

SIMULATION RESULTS:



(a) CDF of the SINR in linear scaling.



(b) CDF of the SINR in logarithmic scaling.

Fig Numerical evaluation of the SINR model: Model (solid lines) and Monte Carlo simulations (markers). The legend of Fig.(b) also applies to Fig. (a)

CONCLUSION: This paper has presented a general framework for investigating the SE and EE in the cellular networks. An evaluation based on theoretical derivations and simulation has been done for both single a multi-cell systems where omni and sectorized antenna systems are implemented on the BSs. Our study has considered multi path fading, signal propagation path loss, and co-channel interference. The downlink SE and EE have been derived and analyzed in terms of cell radius, reused frequency distance, path loss exponent, users' location, fading parameter, and signal to noise ratio. The results have shown that, based on the worst interference case, single cell achieves higher SE and EE than the multi-cell. BS antenna sectorization technique improves the overall efficiencies of cellular system; however, more BS antenna system complexity is expect

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