System Level Performance Evaluation of Broadband Wireless Access Networks

Abstract

Cellular networks are undergoing a rapid growth in terms of both number of subscriptions and per user data rate requirements. It has been estimated that by 2020, there would be 10 billion mobile devices thereby resulting an 11 fold increase in capacity compared with what they are experiencing today. The principal challenge for service providers is to cater to this ever increasing traffic demand within the limited radio spectrum available. Therefore, one of the main objectives of cellular system design is to improve Area Spectral Efficiency (ASE). To connect the growing number of mobile devices, the number of Base Stations (BSs) worldwide has doubled from 2007 to 2012. The number of BSs has reached more than 4 million as of today. This large number of BSs has tremendously increased energy consumption which is expected to increase further in coming years. The energy consumption significantly increases operational expenditure (OPEX) and impact the environment negatively due to increased CO_2 emissions. Therefore, energy efficient network design has also become the need of the hour for cellular network service providers. Therefore, the focus of this thesis work is to investigate ASE and Area Energy Efficiency (AEE) performance of cellular systems.

Heterogeneous Network (HetNet) deployment consists of low-power BSs (also termed as small cells) along with macro/micro BSs is being considered as a promising approach to meet future traffic demand requirements. The different types of small cells are pico cells, femto cells, and relays. Particularly, the deployment of femtocells is expected to solve indoor coverage problem and enhance the capacity of cellular systems several folds. However, uncontrolled interference generated by unplanned femtocell deployment would limit the achievable capacity gain particularly in single frequency systems. Accordingly, in the first part of this thesis work, the outage performance of co-channel deployed macrocell-femtocell network under fractional network load conditions is investigated considering uniformly distributed femtocells. Next, the minimum and the maximum transmit power settings for femto BSs that satisfy outage requirements of macrocell and femtocell users under different macro load conditions are obtained. It is seen that the outage performance in the co-channel deployment highly depends on the load condition of the macrocell network. Further, it is found that, in a multi-cell scenario the macrocell users located at the edge of the cell are significantly affected by the femtocell transmissions during medium and peak macro load conditions. It is also shown in this work that the outage performance can be improved by controlling femtocell load (activity status of subchannels) along with transmit power.

In the second part of the work on small cells, the ASE of co-channel deployed macrocell-femtocell networks is obtained from the Signal to Interference-plus-Noise Ratio (SINR) distributions. The effect of femtocell radio parameters, such as transmit power, load, and femtocell density, as well as macrocell transmit power on the ASE is investigated under different macrocell network load conditions. It is seen that the macrocell load has a significant impact on the ASE performance. The highest ASE gain is achieved during low load conditions in macrocells, and the maximum number of femtocells is supported during medium load conditions. Further, an inverse relationship has been observed between the macrocell load and the femtocell load. It is also seen that the ASE performance is sensitive to the macrocell power. It is found that in co-channel femtocell deployment, the ASE gain can be improved significantly by using appropriate femtocell radio parameters in a centralized manner without degrading macrocell network performance. Further, achievable offloading gain is also investigated in terms of number of supportable users for varying femtocell density. It is seen that the offloading gain can be achieved with large number of femtocells by increasing macro BS transmit power.

Co-channel interference analysis is essential for better planning and performance evaluation of cellular systems. For example, energy efficient network management requires accurate interference modeling especially under low traffic conditions. The SINR is an important metric of link quality in cellular systems.

It is affected by the radio resource occupancy in neighbouring cells due to varying co-channel interference pattern. The radio resource occupancy in the neighbouring cells is dependent upon the offered traffic load in those cells. In practice, non-uniform BS locations and Radio Access Network (RAN) parameter configurations and inhomogeneous traffic load lead to non-uniform interference scenarios across the network. Therefore, better estimate of system performance metrics such as coverage and capacity is required to exploit full potential of the radio resources. A cell load model that relates the offered traffic load to the radio resource utilization (subcarrier occupancy) is developed in this thesis. The model incorporates the characteristics of streaming and elastic traffic, and the propagation characteristics such as path loss, shadowing, and small scale fading. With this model, better estimate of system capacity can be achieved which would help to exploit full potential of the radio resources during radio network planning and management.

As energy efficiency is an important factor for cellular network design, the last part of the thesis deals with the network level energy saving. Though the BSs are deployed considering peak traffic demand and future traffic growth, most of the time the BSs are largely underutilized due to spatial and temporal traffic variations. Therefore, putting under-utilized BSs to sleep mode during non-peak traffic conditions is being considered as a promising approach for potential energy savings, thereby increasing AEE. In this thesis, the possibility of energy saving through BS sleep mode is investigated using multi-objective optimization. The inter-relationships between different system objectives are studied and guidelines are proposed to find the appropriate BS and RAN parameter configuration that provides the best achievable trade-offs. The multiple objectives considered are coverage maximization, ASE maximization, overlap minimization, and energy minimization. Genetic Algorithm based evolutionary approach is used to obtain the optimal solution (i.e. set of active BSs and RAN parameters) with fast convergence rate and minimal computational complexity. It is shown that by selecting the solutions based on different objectives, at 20%, 50%, and 80% network traffic load, it is possible to achieve energy saving between 60% to 85%, 30% to 60%, and 10% to 40%, respectively.

The focus of this thesis work has been on the performance evaluation of system-level metrics such as ASE and AEE due to femtocell deployment and BS sleep mode. It is concluded that by appropriately controlling femtocell radio parameters according to network load condition, the maximum ASE gain due to femtocell deployment can be achieved. It is also concluded that by using the proposed multi-objective optimization framework for BS sleep mode, maximum energy saving can be achieved while maintaining good trade-offs between other system design objectives such as coverage and overlap. In practice, dynamic network management for varying traffic conditions is essential for ensuring better utilization of the network resources. Therefore, the system level analysis presented in this thesis would be helpful in designing algorithms and improving system-level performance of current and future wireless broadband access networks under dynamic environments.

Keywords: Cellular networks, Radio access network, Small cells, Femtocell, Base station, Sleep mode, Fractional load, Streaming traffic, Elastic traffic, Orthogonal Frequency Division Multiple Access, Blocking probability, Co-channel interference, Signal to Interference-plus-Noise Ratio, Interference management, Area spectral efficiency, Area energy efficiency.