Coverage Planning and Resource Allocation in Broadband Cellular Access - Optimization Models and Algorithms

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Abstract

The last two decades have witnessed a booming in the use of cellular communication technologies. Billions of people are now enjoying the benefits of mobile communications. This thesis deals with planning and optimization of broadband cellular access network design and operation. The problem types considered include coverage planning, power optimization, and channel assignment. Mathematical modeling and optimization methods have been used to approach the problems.

Coverage planning is a classical problem in cellular network deployment. A minimum-power covering problem with overlap constraints between cell pairs is considered. The objective is to minimize the total power consumption for coverage, while maintaining a necessary level of overlap to facilitate handover. For this coverage planning problem, the thesis develops two integer programming models and compares the models’ strength in approaching global optimality. In addition, a tabu search algorithm has been developed for solving the problem in large-scale networks.

For High Speed Downlink Packet Access (HSDPA) networks, transmission power is a crucial factor to performance. Minimizing the power allocated for coverage enables significant power saving that can be used for HSDPA data transmission, thus enhancing the HSDPA performance. Exploring this potential power saving, a mathematical model targeting cell-edge HSDPA performance has been developed. In determining the optimal coverage pattern for maximizing power saving, the model also allows for controlling the degree of soft handover for Universal Mobile Telecommunications System (UMTS) Release 99 services. In addition to the mathematical model, heuristic algorithms based on local search and repeated local search are developed.

For Orthogonal Frequency Division Multiple Access (OFDMA), which is used in Long Term Evolution (LTE) networks, inter-cell interference control is a key performance engineering issue. The aspect is of particular importance to cell-edge throughput. Frequency reuse schemes for mitigating inter-cell interference at cell-edge areas have received an increasing amount of research attention. In the thesis, a generalization of the standard Fractional Frequency Reuse (FFR) scheme is introduced. The generalization addresses OFDMA networks with irregular cell layout. Optimization algorithms using local search have been proposed to find the frequency reuse pattern of generalized FFR that
maximizes the cell-edge area performance.

For the problems considered in the thesis, computational experiments of the optimization models and algorithms using data sets representing realistic planning scenarios have been carried out. The experimental results demonstrate the effectiveness of the proposed solution approaches.
Acknowledgement

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Norrköping, December 2010
Lei Chen
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>1G</td>
<td>First Generation</td>
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<td>2G</td>
<td>Second Generation</td>
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<td>3G</td>
<td>Third Generation</td>
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<td>3GPP</td>
<td>3rd Generation Partnership Project</td>
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<td>4G</td>
<td>Fourth Generation</td>
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<tr>
<td>AMC</td>
<td>Adaptive Modulation and Coding</td>
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<td>AMPS</td>
<td>Advanced Mobile Phone Service</td>
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<td>BS</td>
<td>Base Station</td>
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<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<tr>
<td>CoMP</td>
<td>Coordinated Multi-Pointing T/R</td>
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<td>D-AMPS</td>
<td>Digital AMPS</td>
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<tr>
<td>DC-HSPA</td>
<td>Dual-carrier HSPA</td>
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<tr>
<td>DCA</td>
<td>Dynamic Channel Allocation</td>
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<tr>
<td>DCH</td>
<td>Dedicated Channel</td>
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<tr>
<td>E-DCH</td>
<td>Enhanced Dedicated Channel</td>
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<tr>
<td>EDGE</td>
<td>Enhanced Data rate for GSM Evolution</td>
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<td>EUL</td>
<td>Enhanced Uplink</td>
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<td>FAP</td>
<td>Frequency Assignment Problem</td>
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<td>FDMA</td>
<td>Frequency Division Multiple Access</td>
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<td>FFR</td>
<td>Fractional Frequency Reuse</td>
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<td>Acronym</td>
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<tr>
<td>FH</td>
<td>Frequency Hopping</td>
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<td>GPRS</td>
<td>General Packet Radio Service</td>
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<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<td>HARQ</td>
<td>Hybrid Automatic Repeat Request</td>
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<td>HS-DSCH</td>
<td>High Speed Downlink Shared Channel</td>
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<tr>
<td>HSCSD</td>
<td>High-Speed Circuit Switched Data</td>
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<td>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
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<tr>
<td>HSUPA</td>
<td>High Speed Uplink Packet Access</td>
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<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
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<td>LS</td>
<td>Local Search</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<td>LTE-A</td>
<td>LTE Advanced</td>
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<td>MI-FAP</td>
<td>Minimum Interference Frequency Planning Problem</td>
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<td>MIMO</td>
<td>Multiple Input and Multiple Output</td>
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<tr>
<td>Min-GBR</td>
<td>Minimum Guaranteed Bit Rate</td>
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<td>NMT</td>
<td>Nordic Mobile Telephone</td>
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<tr>
<td>NP-hard</td>
<td>Non-deterministic Polynomial-time hard</td>
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<td>OFDMA</td>
<td>Orthogonal Frequency Division Multiple Access</td>
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<td>OPEX</td>
<td>Operational Expenditure</td>
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<td>OR</td>
<td>Operational Research</td>
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<td>PC</td>
<td>Power Control</td>
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<td>PDC</td>
<td>Personal Digital Cellular</td>
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<td>PF</td>
<td>Proportional Fair</td>
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<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
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<tr>
<td>QoS</td>
<td>Quality of Service</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>RB</td>
<td>Resource Block</td>
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<tr>
<td>RNC</td>
<td>Radio Network Controller</td>
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<td>RRM</td>
<td>Radio Resource Management</td>
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<td>SAE</td>
<td>System Architecture Evolution</td>
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<td>SC-FDMA</td>
<td>Single Carrier Frequency Division Multiple Access</td>
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<td>SFR</td>
<td>Soft Frequency Reuse</td>
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<td>SHO</td>
<td>Soft Handover</td>
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<tr>
<td>SINR</td>
<td>Signal-to-Interference-plus-Noise Ratio</td>
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<tr>
<td>SIR</td>
<td>Signal Interference Ratio</td>
</tr>
<tr>
<td>TACS</td>
<td>Total Access Communication System</td>
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<tr>
<td>TD-SCDMA</td>
<td>Time Division Synchronous Code Division Multiple Access</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
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<tr>
<td>TS</td>
<td>Tabu Search</td>
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<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunication Systems</td>
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<tr>
<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
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<tr>
<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
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Part I

Introduction and Overview
1 Evolution of Cellular Networks

The concept of cellular communications was introduced by Bell Laboratories in 1947 to increase the communication capacity of mobile phones. In the 1970s, commercial mobile communications based on cellular technology began to appear all over the world. Systems deployed in this period are referred to as the first generation (1G) cellular networks. NTT launched the first commercial cellular network in the metropolitan area of Tokyo in 1979. Soon after, commercial cellular systems became available in Europe and America. Representative systems include the nordic mobile telephone system (NMT) in Scandinavia, the total access communication system (TACS) in UK, and the advanced mobile phone service system (AMPS) in America. Being analog-based, 1G networks suffered from many limitations such as low frequency utilization, limited service, poor communication quality, high equipment cost, and low security.

To overcome the limitations and meet the demand of mobile communications, the second generation (2G) cellular systems were developed. 2G cellular systems adopted digital transmission that is fundamentally different from the 1G cellular technology. Besides frequency division multiple access (FDMA), which is also used in 1G networks, 2G networks use more advanced access technologies such as time division multiple access (TDMA) and code division multiple access (CDMA), as well as hierarchical cell structure.

Representative 2G standards include the global system for mobile communications (GSM), interim standard 136 (IS-136, aka Digital AMPS, or D-AMPS), IS-95 (aka CDMAone), and the personal digital cellular (PDC) system. Both GSM and D-AMPS were based on TDMA. GSM was firstly introduced in Europe to provide a single and unified 2G standard in European countries. Later, GSM was implemented in many countries in the rest of the world. D-AMPS evolved from AMPS and was used in America, Israel and some of the Asian countries. IS-95 systems were based on CDMA, which allowed users to simultaneously access the same frequency band using different codes. As the only commercial CDMA standard of that time, IS-95 had been mostly implemented in North America and Asia. PDC was a TDMA-based standard and was available in Japan only.

The primary service in 2G networks was voice communication. To meet the emerging demand for data communication, a number of upgrades were introduced to 2G systems as low-cost, intermediate solutions for data services,
while developing the third generation (3G) systems. The intermediate steps in the transition from 2G to 3G were called 2.5G and 2.75G. One such step was high-speed circuit switched data (HSCSD) for GSM. HSCSD was easy to implement and required low cost in deployment. However, since it was still based on circuit switching, it suffered from inefficient frequency utilization. Another technology was the general packet radio service (GPRS). Using packet switching, GPRS had better frequency utilization in handling best-effort data communication. GPRS utilizes dynamically free TDMA channels in GSM systems, and can provide a speed of up to 114 kbps. Later, with the introduction of 8PSK encoding, GPRS evolved to enhanced data rate for GSM evolution (EDGE), aka enhanced GPRS. EDGE increased the data rate to 384kbps and was backward-compatible. At the same time, within the CDMA family of standards, IS-95 evolved to the CDMA2000 1 times radio transmission technology (CDMA2000 1xRTT), which supported a data rate of 153kbps.

Soon after the commercialization of 2G networks, development of 3G cellular communication systems started. The goal of 3G was to provide high data rate and multimedia data services for mobile Internet. Three major families of specifications, namely CDMA2000, wideband CDMA (WCDMA), and time division synchronous CDMA (TD-SCDMA) were accepted as 3G standards by the international telecommunications union (ITU). CDMA2000 was developed from IS-95 and mostly used in North America and South Korea. WCDMA, aka universal mobile telecommunication systems (UMTS) was developed from GSM, with efforts in Europe and Japan. Since GSM dominated the 2G commercial markets, the evolution path GSM-GPRS-EDGE-WCDMA was very natural. At present, WCDMA is the most widely implemented 3G technology. TD-SCDMA was China’s 3G standard, proposed by Datang Telecom and was mostly used in China.

Since the first release by 3rd generation partnership project (3GPP), referred to as release 99 (R99), WCDMA has evolved rapidly. In 2002, Release 5 (R5) was finalized to include high speed downlink packet access (HSDPA). In 2005, Release 6 (R6) became available, supporting high speed data services on the uplink by introducing enhanced uplink (EUL), aka high speed uplink packet access (HSUPA). In 2007, Release 7 (R7) introduced evolved high-speed packet access, aka HSPA+, to support higher order modulation, e.g., 64QAM and multiple input and multiple output (MIMO) technology. In Release 8 (R8), which was finalized in 2008, developments of two standards were specified, HSPA+ and long term evolution (LTE). HSPA+ was enhanced by a dual-carrier HSPA (DC-HSPA) which doubled the throughput by combining
two WCDMA radio channels. HSPA+ was a backward-compatible standard, allowing operators that have heavily invested in WCDMA to offer new features to their subscribers with legacy UMTS terminals. At the same time, the first release of LTE was specified in R8. LTE represented a new evolution path. The LTE standards adopted orthogonal frequency division multiple access (OFDMA) for downlink and single carrier FDMA (SC-FDMA) for uplink, to provide higher peak data rate and flexible bandwidth usage. Additional features, such as femto-cell, were introduced in Release 9 (R9) in 2009.

The ultimate goal of LTE is to pave the way for the fourth generation (4G) systems. Peak data rate of LTE targets 100 Mbps at downlink and 50 Mbps at uplink with a 20 MHz bandwidth and 2×1 MIMO antenna. In comparison to R6, average user throughput of LTE is expected to be 3-4 times higher at downlink, and 2-3 times higher at uplink. In LTE, spectrum utilization is scalable over blocks of 5, 10, 15, and 20 MHz. Blocks smaller than 5 MHz are also supported. As LTE is not supposed to be backward-compatible, it enjoys the freedom of implementing the latest transmission technologies. Besides the new air interface, advanced antenna solutions such as MIMO, beam-forming are also utilized. A flat all IP core network, namely system architecture evolution (SAE), is designed to replace the GPRS core network and to support high throughput with low latency in the radio access network (RAN). Despite the economic crisis in 2008 and 2009, trials of LTE networks have not been interrupted. The first commercial LTE service was provided by TeliaSonera in Stockholm and Oslo in 2009. The network delivers a downlink speed between 20 Mbps and 80 Mbps.

To meet the future demand of mobile broadband, the research on LTE-advanced (LTE-A), which represents a 4G standard, is also underway. LTE-A specifications will be part of Release 10 (R10). LTE-A will include more advanced technologies like clustering SC-FDMA, relaying, coordinated multi-pointing transmission/reception (CoMP), higher order MIMO transmission, etc., to take the peak data rate up to 1 Gbps for low mobility scenarios.

The above discussion applies to the development of standards in 3GPP. Besides LTE, worldwide interoperability for microwave access (WiMAX), specified in IEEE 802.16 series of standards, is also evolving towards fulfilling the requirement of 4G systems. An illustration of the evolution of cellular networks is given in Fig. 1. More detailed discussions can be found in [1, 15, 26, 27, 28, 42, 58].
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Network planning and optimization play a key role in reducing the capital expenditure (CAPEX) and operational expenditure (OPEX) for deploying and expanding cellular systems. Typically, radio network planning begins with a definition and dimensioning stage, which includes traffic estimation, service definition, coverage and capacity requirements, etc. It is traditionally considered as a static process. Some of the main tasks are site selection for base station location, location area and routing area planning, and radio resource management (RRM) strategies. Besides fulfilling the initial requirements such as coverage and capacity, radio resource has to be acquired in a way that the cost is minimized. Optimization is a long-term process before and after the launch of a network. The process applies various methods to maximize the system performance by optimally configuring the network and utilizing its resources. Traditionally, a large amount of manual tuning has been used in the optimization process. Nowadays, advanced optimization tools have been developed to automatically optimize the parameters for maximizing system performance, making the optimization process much more efficient.

Figure 1: Evolution of cellular technology.

2 Cellular Network Planning and Optimization

Network planning and optimization play a key role in reducing the capital expenditure (CAPEX) and operational expenditure (OPEX) for deploying and expanding cellular systems. Typically, radio network planning begins with a definition and dimensioning stage, which includes traffic estimation, service definition, coverage and capacity requirements, etc. It is traditionally considered as a static process. Some of the main tasks are site selection for base station location, location area and routing area planning, and radio resource management (RRM) strategies. Besides fulfilling the initial requirements such as coverage and capacity, radio resource has to be acquired in a way that the cost is minimized. Optimization is a long-term process before and after the launch of a network. The process applies various methods to maximize the system performance by optimally configuring the network and utilizing its resources. Traditionally, a large amount of manual tuning has been used in the optimization process. Nowadays, advanced optimization tools have been developed to automatically optimize the parameters for maximizing system performance, making the optimization process much more efficient.

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Analog-based 1G cellular networks did not pose much requirement to planning and optimization. Having low capacity requirement, the key problem is to provide a satisfied degree of coverage. With the success of 2G networks and the increasing amount of voice and data demand, cellular systems have become more and more complex. New radio access technologies also introduce new challenges to the planning and optimization processes. In the following, we outline some representative planning and optimization problems in cellular networks. More detailed discussions can be found in, for example, [40, 47, 48, 51].

2.1 Base Station Location

A very fundamental planning task in cellular networks is the base station (BS) location. To deal with the increasing user demand, more and more base stations are needed to provide satisfactory services. A resulting optimization problem is to determine how many and where base stations should be located in order to meet coverage and capacity requirements. An illustration of the problem is shown in Fig. 2. In the figure, the red spots require BS installed while the blue spots do not.

![Figure 2: An illustration of base station location.](image)

In general, the base station location problem is NP-hard [7, 46] in problem complexity. For 2G networks, to a large extend, the task can be regarded as a type of set covering problem, the performance is mainly coverage-driven and mostly depends on the propagation model. In this case, BSs are located among the candidate locations so that signal strength is high enough for the areas to
be covered. For 3G networks with WCDMA, this is however not enough as the single-to-interference ratio (SIR) needs to be taken into account. Besides the location of BS, coverage itself is heavily influenced by the traffic distribution. Thus, BS location in UMTS networks has to consider power control which in its turn is tightly connected to traffic distribution. In the past years, BS location has been extensively studied for both 2G and 3G networks [5, 6, 20, 35, 46, 59, 61, 64]. Both mathematical modeling and heuristic algorithms have been proposed for problem solution.

2.2 Frequency Planning

Along with BS location, another vital issue in 2G GSM networks is to deal with the frequency assignment problem (FAP). To avoid interference in GSM networks, neighboring cells should use different frequencies, see Fig. 3 for an illustration.

Figure 3: An illustration of frequency assignment.

Due to the high site density and the scarcity of the spectrum resource, frequency allocation has to be carefully planned so that high spectral efficiency and low interference can be achieved. Many optimization methods and algorithms have been proposed for FAP in GSM networks [3, 4, 10, 17, 18, 21, 25, 37, 50]. Planning strategies for more advanced frequency use, such as frequency hopping (FH) [2, 52] and dynamic channel allocation (DCA) [55, 56], have also been proposed.

In WCDMA networks, the frequency reuse factor is one, so FAP is not present. For the new radio interface OFDMA adopted in LTE networks, frequency op-
timization becomes again a key issue. LTE is designed to scale well in the spectrum availability. The spectrum is divided into a large number of sub-carriers which are orthogonal to each other. This enables a higher flexibility in respect to resource allocation. With OFDMA, intra-cell interference does not exist because of the orthogonality, but inter-cell interference may become the performance-limiting factor, especially for cell-edge users with poor radio signal condition. Sub-carrier allocation has to be done carefully to mitigate inter-cell interference. To this end, fractional frequency reuse (FFR) [19, 43, 60] and soft frequency reuse (SFR) [31] schemes have been proposed. With the evolution from 3G to 4G networks, inter-cell interference mitigation is attracting more and more research attention.

2.3 Radio Resource Management (RRM)

RRM is fundamental in cellular networks. Many optimization problems involving allocation strategies of various types of resource appear in RRM. The aforementioned FAP can be regarded as part of RRM, since frequency is a highly valuable resource in cellular networks. Another key resource type is transmission power. Transmission power plays an important role in interference management, energy consumption, as well as service quality. Thus power control (PC) mechanisms have been considered. PC can be located at user equipment (UE), BS, or radio network controller (RNC). It is a key component in IS-95 CDMA systems because of the near-far effect. GSM networks also has PC mechanism, although the need for PC is not as high as IS-95.

For 3G and 4G systems, more advanced PC mechanisms have been explored. Rather than considering a fixed SIR as in 2G systems, the achievable SIR varies, and is usually jointly controlled and optimized in the PC mechanism in 3G systems. Furthermore, PC algorithms also need to closely cooperate with other RRM procedures (e.g. scheduling) to maximize the network performance. Due to the rapid growth of cellular networks, extensive research has been done on PC algorithms with fixed SIR and variable SIR, opportunistic PC, PC based on game theory, joint PC and beamforming, joint PC and BS location, etc. A survey can be found in [14].

In addition to PC, scheduling is an important component of RRM since packet switching became supported in cellular networks. Scheduling means usually to allocate resource among users along the time dimension, to maximize target metrics (e.g. throughput, quality of service (QoS), fairness, etc). Typical
scheduling strategies include round robin (RR), maximum throughput, proportional fair (PF), minimum guaranteed bit rate scheduling (min-GBR), minimum bit rate scheduling with proportional fairness (min-GBR+PF), as well as maximum delay scheduling. For UMTS R99, which is based on a dedicated channel (DCH), scheduling is done at RNC. HSDPA introduces a high speed downlink shared channel (HS-DSCH). Instead of placing the packet scheduler at RNC, HSDPA utilizes a fast scheduler at Node B, giving Node B the ability to rapidly adapt to the channel conditions of the users. Similar to HSDPA, HSUPA introduces an enhanced DCH (E-DCH) for uplink which also supports fast scheduling. At present, HSPA is the most widely used cellular technology for mobile broadband, and a vast amount of literature has been devoted to its scheduling algorithms and RRM strategies [8, 9, 12, 23, 24, 29, 30, 33, 36, 53, 63].

With OFDMA, the flexibility in radio resource allocation grows. The downlink resource grid in LTE consists of resource blocks (RBs), each consists of 12 sub-carriers and 7 OFDM symbols. Depending on the available bandwidth, up to 100 RBs (with a bandwidth of 20 MHz) can be allocated. Power is jointly allocated with RBs. Moreover, information can be transmitted and combined by multiple antennas, which add one more dimension of freedom. Thus resource allocation in LTE involves several dimensions. Because of the flexibility, the performance of scheduling algorithms is crucial in OFDMA-based networks. Numerous articles investigated resource allocation strategies for OFDMA [13, 22, 32, 34, 45, 57, 67, 68], and more specifically for LTE [11, 16, 38, 39, 41, 44, 49, 54, 65, 66].

Additional functionalities, such as admission control and load control, are also needed in RRM. It is worth mentioning the RRM components are not independent of each other, and the overall performance is a joint effect of the various RRM functionalities.

3 The Present Thesis

This thesis consists of three research papers in coverage planning in cellular networks, power optimization in HSPA networks, and sub-carrier allocation in LTE networks, respectively. The objectives and contributions of the thesis work along with a summary of future research are give below.
3.1 Objectives

The main objective of the thesis is to investigate some optimization problems arising in coverage planning and resource allocation of cellular networks. Two types of resource parameters are considered. The first is the transmission power that determines coverage, where coverage is defined in terms of receiving sufficiently well the signal announcing network presence. The second resource parameter is the frequency band to be allocated in LTE networks. The planning objectives in the optimization problems range from the power consumption for coverage, the power requirement for achieving performance threshold for HSDPA service, to LTE network capacity in terms of cell-edge throughput.

For the planning problems, the research targets developing optimization models and time-efficient methods that are capable of delivering high-quality solutions. The research is also aimed to use realistic planning scenarios to demonstrate the benefit of the optimization approaches.

3.2 Thesis Summary and Contribution


The papers are co-authored with Di Yuan. The author of this thesis has contributed to the papers by major involvement in the research planning, the modeling and simulation work, the analysis of the results, along with taking a significant part in authoring the papers.

Paper I: Solving a minimum-power covering problem with overlap constraint for cellular network design

This paper deals with coverage planning in cellular network design. Given the locations of BSs, the problem amounts to determining cell coverage at minimum cost in terms of power usage. Minimum-power coverage tends to
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make cell size as small as possible; such a solution may have negative impact on handover performance. To tackle this issue, the objective is to perform power minimization with the requirement of having sufficient overlap between cells.

Two integer linear models are presented. The strength of their respective continuous relaxations as well as the numerical performance of the two models are thoroughly investigated. For large-scale networks, a tabu search (TS) algorithm is developed. The algorithm is able to obtain close-to-optimal results within short computation time. Simulation results are reported for both synthesized networks and networks originating from real planning scenarios.

The paper has been published in European Journal of Operational Research.

Paper II: Coverage planning for optimizing HSDPA performance and controlling R99 soft handover

This paper deals with a coverage planning problem for the currently common network deployment scenario of having co-existing HSDPA and R99 services. By utilizing the power saving resulted from power minimization in coverage planning, the throughput of HSDPA can be improved. The focus is to bring up the HSDPA performance at cell edge, for which improved data throughput is more perceived in comparison to cell center. At the same time, the level of soft handover (SHO) for R99 is taken into account in determining the coverage pattern.

An integer linear model is developed for the problem. The model can be used to find global optimum for small-sized networks. For large-scale planning scenarios, a heuristic algorithm is developed. The algorithm is based on local search and repeated local search. Performance benchmarking on small test networks shows that the algorithm gives close-to-optimality results. In addition, simulation results from the model and the use of the heuristic algorithm demonstrate significant power saving and HSDPA performance improvement in comparison to the reference solution.

The paper has been accepted for publication in Telecommunication Systems. Parts of the paper have been published in the following conferences:

- L. Chen and D. Yuan. Automated planning of CPICH power for enhancing HSDPA performance at cell edges with preserved control of
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**Paper III: Generalizing and optimizing fractional frequency reuse in broadband cellular radio access networks**

This paper deals with inter-cell interference mitigation in OFDMA-based networks. With OFDMA, inter-cell interference is the main performance-limiting factor for cell-edge users due to their high level of sensitivity to interference. FFR is one of the schemes used for inter-cell interference mitigation by frequency separation. Standard FFR uses a fixed number of sub-bands and a fixed reuse factor. This works well for a regular, hexagonal cell layout. However, for networks with irregular cell patterns, standard FFR can not be directly applied, and the performance is far from being optimal.

In the paper, the standard FFR is generalized to enable a high flexibility in the total number of OFDMA sub-bands and the number of sub-bands allocated in the cells’ edge areas. Two power assignment strategies are considered in sub-band allocation. Solution algorithms using local search are developed to optimize the sub-band allocation for generalized FFR. Performance evaluations are conducted for large-scale networks with realistic radio propagation conditions. The results demonstrate the applicability and benefit of applying and optimizing generalized FFR in performance engineering of OFDMA networks.

Parts of the paper have been published in the following conferences:


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3.3 Future Research

Cellular network planning and optimization form a complex engineering process, involving many resource types, network elements, and decision variables. The constant evolution of radio access technologies offers new opportunities to efficient radio resource utilization, and at the same time poses challenges to the planning and optimization process. To master the complexity, the planning and optimization algorithms have to become more advanced, efficient, and automatic. The latter means that the optimization process should become an integrated part of the network, and the work of manual tuning must be reduced as much as possible.

The work presented in the thesis contributes to dealing with some planning and optimization problems in cellular networks. The development of optimization tools integrating the models and algorithms for the problems will be a natural follow-up to the thesis work. There are several additional potential lines for future research. First, there are many problems that are beyond the scope of the thesis, but highly relevant to the research field. One example is modeling and solving the problem of optimally locating BSs of OFDMA networks. Second, network optimization problems accounting for recent technological advances such as MIMO, relay stations, and heterogeneous radio networks, warrant thorough research. Third, approaches that effectively integrate optimization and system-level simulation give rise to a very interesting topic for automated network planning. Fourth, within the network self-optimization paradigm, the development and implementation of distributed algorithms for resource allocation in broadband mobile access open up new research horizons.
Bibliography


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