Cellular networks have undergone a sea change since their inception especially through the last decade which saw the arrival of 3G and 4G networks. A fundamental change is that these networks are designed for packet data services. Also, several technical enhancements such as Orthogonal Frequency Division Multiple Access (OFDMA), Multiple Input Multiple Output (MIMO), Frequency Domain Link Adaptation (FDLA), Packet Scheduling (PS) etc. have come into play which help in achieving better performance and reliability for best effort (BE) services. At the same time there has been a growing demand for real-time (RT) services, which are not intrinsically supported by packet switched networks. With more availability of broadband services user satisfaction has become a key issue in network design. This work is focused on user satisfaction in modern cellular networks.

User satisfaction is driven by both link level and system level techniques employed in these networks. First, we look at link level enhancements such as MIMO. MIMO offers great theoretical performance benefits such as high spectral efficiency (SE) and reliability (low bit-error rate). However, it incurs a lot of complexity. In this thesis we propose a low complexity MIMO antenna selection (AS) algorithm which works under a combination of diversity and spatial multiplexing to make MIMO based devices easier to realize. The proposed algorithm provides high SE which is within 3% of that provided by optimal AS while being almost an order of magnitude simpler to implement. Low symbol-error rate is an additional benefit with this algorithm. This helps in improving user satisfaction at the link layer compared to a single input single output (SISO) link. This is independent of the higher layer services be it BE or RT traffic. Since these networks are designed for BE with packet switching, the gains of MIMO are expected to be transferred directly in their case. However, for RT traffic there are several important performance metrics that need to be considered.

RT traffic has strict Quality of Service (QoS) requirements. To ensure QoS of both existing and new users, we need to look at the blocking probability (P_b) or the admission probability ($P_a = 1 - P_b$) of arriving calls. In modern cellular systems Erlang capacity is defined as the maximum offered traffic intensity in Erlangs for which the P_b is below a target threshold. Erlang capacity analysis is important for cell dimensioning. It is shown in this thesis that due to Orthogonal Frequency Division Multiplexing (OFDM) with adaptive modulation and coding in physical layer, and the use of dynamic resource allocation algorithms, the P_b varies within the cell (coverage area of a base station) often being very high at the cell-edge. This leads to variation of perceived user satisfaction within a cell.

Since there is a strong demand that the new networks support ubiquitous user satisfaction, the second part of this thesis concentrates on issues related to disparity of P_b between cell center and cell edge (implying an issue with P_b fairness). To begin with we need analytically tractable methods to analyze cell-wide and cell-average P_b. For such analysis we propose an improved Erlang approximation that is significantly more accurate in cell-average P_b evaluation (within 2% of exact) compared to the original method (which is >25% off from exact); we also propose two new algorithms for cell-wide P_b evaluation that involve closed form expressions and hence are mathematically tractable. These algorithms generate almost exact estimates of base station density requirement to support a given network load in case of voice traffic. These algorithms also provide useful insights into the nature of variation of P_b within a cell.

Thereafter, to quantify P_b fairness issues we propose to use certain metrics such as the min-max metric of fairness which is the ratio of the minimum value of P_a to its maximum value. Conventional Erlang capacity analysis and cell-dimensioning consider the peak supportable cell load as that value at which the cell-average P_b reaches 2%. However, as we show in this thesis, at such peak load the fairness and user satisfaction levels as quantified by appropriately selected metrics are too low. In this context we also show that the P_b fairness and user satisfaction both improve significantly in case of voice calls if the per-cell peak load is reduced by approximately 11% which may be a modest compromise.

Such system level tradeoffs can be achieved with higher precision when the link level performance is modeled with greater accuracy. In this context, we show that improved link SE models significantly impact the results of Erlang capacity analysis. For example, with the SISO antenna configuration, using improved link SE models yields a three-fold increase in Erlang capacity per cell. Again, using accurate link level models for MIMO techniques like 1x2 maximal ratio combining, 2x2 space-frequency block codes and 2x2 Bell Labs Layered Space-Time (BLAST) results in approximately another two-fold increase in Erlang capacity. An increase in Erlang capacity per cell translates into a corresponding reduction in required base station density for a given traffic demand. Thus it is seen that there is a significant impact of MIMO on cell-dimensioning for modern OFDMA cellular network design. Surprisingly, although MIMO is ubiquitously used to improve performance in such systems, it has been ignored in the conventional Erlang capacity analysis and cell dimensioning. MIMO is also shown to bring about an improvement in fairness of P_b.

Another method to improve intra-cell fairness of P_b is through appropriate call admission control (CAC) algorithms. In the final part of the thesis we introduce one such algorithm. This algorithm leverages the fact that the cell-center P_b is very low. Hence, users from the cell-center regions may be forcefully blocked at times of high bandwidth occupancy with appropriately chosen blocking rate in order to improve the overall fairness situation. The proposed CAC is shown to have a beneficial effect on the metrics of P_b fairness introduced earlier. Performance evaluation is carried out through analytical techniques and verified through discrete event simulations.

Keywords: Antenna Selection, Spatial Multiplexing, Diversity Multiplexing Tradeoff, BLAST, MMSE receiver, Resource Reuse, OFDMA Networks, Blocking Probability, Admission Probability, Grade of Service, Quality of Service, Call Admission Control, Fairness, User Satisfaction, Real-Time Traffic, Streaming Traffic.