Neuro-fuzzy admission control in mobile communications systems

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1. Introduction

1.1. Background

While wireless communication has existed in some form or another since the invention of the wireless receiver by Marconi in 1896, it was only in the last quarter of the 20th century that it witnessed an explosion in its growth. Wireless communication devices have become so common that they have become part of everyday life where hundreds of millions of people rely on them to perform their day to day jobs. Even more exciting is the fact that this only seems to be the beginning [RAP2002]. Wireless communication devices are set for higher growth over the foreseeable future as shown by many market studies [FORB2004] and the large number of technology co-operations that have invested billions of dollars in developing wireless devices and infrastructure [ECON2004].

So, why ‘Wireless’? Wireless devices enable the user to be mobile and communicate at the same time. With mobile wireless devices becoming ever smaller, down to the point of ‘wearable devices’, the concept of anywhere, anytime communications is truly possible. A popular concept that defines a whole range of wireless (mobile) communications devices is Personal
Communications Services (PCS) or Personal Communications Networks (PCN). PCS include Cordless Telephones, Cellular Mobile Systems, Wide Area Wireless Data Networks, High-Speed Wireless Local Area Networks, Paging/Messaging Systems and Satellite based Mobile Networks. While each of these technologies play its part in providing seamless wireless communications anywhere anytime, this thesis will focus on future cellular mobile networks.

New cellular mobile networks provide much higher bandwidth than currently available. Current popular cellular systems (such as GSM) are primarily voice services (with some support for short messaging and other low bandwidth applications), while the emerging third generation systems support both real and non-real time services, such as voice, video, Internet access (which includes streaming and multi-media applications), email and many other applications. In fact many of these applications are available over current GSM networks through GPRS. While currently most networks around the world are still 2G and thus only support slow speeds (13 kb/sec for GSM), 2.5G and 3G networks support tens (and beyond) of kbps. While the profitability of such networks is yet to be proven, the telecommunications industry sees 3G as an inevitable part of the evolution of mobile cellular systems. The industry is also pursuing license free bandwidth to add capacity to their networks. IEEE 802.11b/a/g [IEEE1999] networks are being deployed in hot spots to add capacity over short distances. 802.11b has a maximum nominal transmission rate of 11Mbps and is the wireless equivalent of Ethernet. Some companies have also proposed voice handsets to work with the 802.11b hotspots and hence the convergence between data and voice networks.

In fact, standards for short-range high capacity wireless LANs have evolved quite significantly over the course of this work. The IEEE 802.11b standard has
evolved over the years and a new OFDM physical layer was defined (with minor modifications to the original 802.11b MAC) and the result was the new 802.11a standard [STD802a] that can support a maximum nominal data rate of 54Mbps. Products are now available in the form of network interface cards that plug into mobile devices such as laptops. The IEEE 802.11 working group has also started a new task group to develop the next generation of Wireless LAN standards and speeds of between 100Mbps and 500Mbps have been proposed. Another emerging technology for short range wireless communications is IEEE 802.15.3 with a variety of physical layers, one of which is Ultra Wide Band (UWB) which is capable of wireless speeds of hundreds of Mbps.

In effect there is much more available bandwidth over short ranges, and WLANs are just an example. But the recent mobile technology evolution has not stopped there. Two recent working groups have recently started to look at wide area high capacity support for mobile networks [MBWA2003], [IEEE2003]. A new working group has started with the name of IEEE 802.20. This group will define a MAC and Physical layer that will enable the support of 1Mps sustainable data rate over network sizes and ranges that are similar to the current GSM/GPRS/3G networks. The main difference is that 802.20 will not be backwards compatible with 2G networks (as 3G is) and will aim to support IP data networks much as 802.11b has done. Hence mobile technology is evolving to support true multi-services from the real time applications of voice and video to all other non-real time data services.

Over the past ten years, advances in VLSI techniques, battery design and smaller cell sizes, have seen the rapid growth and acceptance of cellular mobile systems. But before cellular mobile networks can advance further, some problems need to be overcome. Of primary concern is bandwidth. While the price of bandwidth
has decreased in land-based networks (due to the use of fiber optics and other technologies), bandwidth in wireless communications remains relatively expensive. There are two primary reasons: one being the regulatory constraints placed by governments on the use of spectrum and the other being the high infrastructure cost of wide area cellular networks. This was highlighted by record amounts paid for spectrum licenses in Europe and the US by mobile carriers [ECON2001]. While the problem of efficient bandwidth usage applies to all network technologies, it is of primary importance when it comes to mobile wireless networks.

One solution that has been used in current mobile networks is to reduce the cell size to increase frequency reuse. While this allows the overall capacity of the cellular network to increase, it presents its own set of problems to be overcome before it could be realized. These problems include handover control, and the need for new analytical modeling techniques for performance prediction and robust algorithms for connection admission control.

1.2. Thesis Outline

Neuro-Fuzzy Control has been applied to the problem of admission control in the literature on a number of occasions (see Chapter 3). In most cases Neuro-Fuzzy logic is used to discriminate between different traffic types and requirements in order to reach an admission decision. In this thesis, we apply Neuro-Fuzzy control to the problem of admission control in mobile communications. Neuro-Fuzzy Logic is an excellent tool to apply to the problem of connection admission in cellular networks due to the complexity of the problem at hand.
The thesis first looks at bandwidth reservation in the multi-services case, before investigating methods of intelligent admission control using Neuro-Fuzzy admission controllers. The problem of Connection Admission Control for wireless cellular networks is highly complex with many variables as is shown by the literature reviewed in Chapter 2. The literature describes the problems of quantifying measurements such as user velocity, call holding time distributions, handoff arrival rate distributions and mobility models just to name a few. Such complex systems are well modeled using Neuro-Fuzzy Logic due to its “black box” approach to system modeling.

In Chapter 2 an overview of cellular mobile networks and technologies is given. Fundamental concepts such as cell reuse, mobile capacity, the handover process and a review of current mobile systems are described. Current mobile systems include 2, 2.5 and 4G systems. A review of connection admission control is also given in this chapter. Concepts such as multi-service and effective bandwidth are described. Finally the state of the art of connection admission control in mobile multi-service networks is reviewed.

Chapter 3 describes the fundamentals of fuzzy and neuro-fuzzy systems. The concepts of membership functions and IF-THEN rules are described. Neural network learning algorithms that are used for adapting the fuzzy logic membership functions are also given. The chapter ends with a review of current state of the art of fuzzy and neuro-fuzzy logic applications to wireless mobile communications.

Chapter 4 begins by introducing fixed bandwidth reservation to mobile multi-service networks. An analytical solution is derived and then the results of this solution are compared to a simulation model. Improvements to the analytical
solution are then described. The chapter ends by describing a sensitivity study of the simulation model. The analysis and simulation of admission control are continued in Chapter 5. This chapter focuses on the study of utilization by performing a number of case studies. The impact of cell capacity, traffic class ratios and the number of classes of traffic on utilization is described.

Chapter 6 describes the first heuristic fuzzy logic admission control. Several aspects of the problem are described in detail. This fuzzy logic algorithm is extended to include velocity based admission control. Chapter 7 describes the neuro-fuzzy admission controller. Analysis and simulation of the problem is provided. A number of results are generated and discussed. The thesis ends with Chapter 8 which described the results of this work and suggestions are made for further research.

1.3. Contributions

The main contributions of the thesis are listed below.

- Analysis of the multi-service admission control problem in the mobile domain. This approximate analysis is used to derive new and handover blocking probabilities for multi-service mobile networks. The approximation is further extended to cover the case of microcellular networks [Chapters 4 and 5][Raad2000a,c].

- Design and development of an event driven simulation model for multi-service mobile network [Chapter 4].
• Confirmation of the analysis results through extensive simulation. The analytical model derived is further validated by the use of general probability distributions for the cell dwell time which are more realistic. [Chapter 4] [Raad2000a, c]. Further Development and validation of the approximate analysis to further agree with simulation results [Section 4.5.1 and 4.6].

• Carried out a sensitivity study to input distribution and class load for multi-service mobile networks was carried out [Section 4.7][Raad2000b].

• Development of a heuristic for obtaining optimum utilization while meeting Grade of Service guarantees for a multi-service mobile network. This work looked at the mobile cell utilization while meeting the GoS guarantees. This result is useful when dimensioning such networks [Section 5.4][Raad2000a,c]. A study of optimum utilization for different cell size and different traffic loads and cell capacities was carried out [Chapter 5].

• A limits study was carried out that confirms the heuristic that was developed above. The result shows that for large cell sizes, optimum utilization is achieved when enough bandwidth is reserved to meet the bandwidth requirements of the largest traffic class while meeting the Grade of Service constraints of new and handover call blocking probabilities [Chapter 5].
• Designed and simulated an adaptive fuzzy logic admission controller with heuristics to meet GoS for a single class of service mobile network [Section 6.2].

• Designed and simulated an intelligent velocity based fuzzy logic admission controller was designed for a single class of service mobile network [Section 6.3].

• Derived a solution for single class bandwidth reservation for exponential cell dwell times with guard channels [Section 7.3.2][Raad2001].

• Proposed, designed and simulated a Neuro-Fuzzy logic admission controller for the single class case [Section 7.4][Raad2001].

• Proposed and simulated a training algorithm for the Neuro-Fuzzy logic controller allowing its extension to the general in-out distribution based on the exponential cell dwell time distribution [Section 7.4.2][Raad2001].

• Developed an automated algorithm that fine tunes the number of reserved channels by adjusting the input membership functions of the Neuro-Fuzzy Logic controller [Chapter 7].

• Developed an Automated algorithm that fine tunes the number of reserved channels by adjusting the training data through measured
data and a shaping function and retraining of the Neuro-Fuzzy
Controller.

- Development of an Event driven simulator for mobile network with
  a Neuro-Fuzzy Admission Controller [Chapter 7][Raad2001].

1.4. Publications

The following publications have resulted from this work

- [Raad2001] Raad Raad, Eryk Dutkiewicz and Joe Chicharo "Neuro-Fuzzy
  Dynamic Bandwidth Reservation in Micro-Cellular Mobile Networks", ITC
  Specialist Seminars On Access Networks, 2001. This paper is based on
  Chapter 7.

- [Raad2000a] Raad Raad, Eryk Dutkiewicz and Joe Chicharo, "Connection
  Admission Control in Micro-cellular Multi-service Mobile Networks", IEEE
  ISCC’ 2000, pp 600-606. This paper is based on chapters 4 and 5.

- [Raad2000b] Raad Raad, Eryk Dutkiewicz and Joe Chicharo,
  "Optimisation of Channel Utilisation for Multi-service Mobile Networks Using
  Fixed Bandwidth Reservation", ITC Specialist Seminar on Mobile Systems
  and Mobility, 2000, pp 337-348. The work of this paper based on
  Chapters 4 and 5.

- [Raad2000c] Raad Raad, Eryk Dutkiewicz and Joe Chicharo, “Connection
  Admission Control for micro-cellular Multi-service Mobile Networks”, accepted for
  presentation at the 5th INFORMS Telecommunications Conference, 2000. The work of this paper appears in Chapters 4 and 5. This paper
  was accepted for publication based on an extended abstract but could not
  be presented due to work commitments.
Publications submitted for review:

- Paper to be submitted to IEEE Transactions on Fuzzy Logic based on chapters 3, 6 and 7.

The papers listed below have been published or under review are direct extensions to the work described in this thesis but the work does not appear in this thesis.

