A fuzzy logic based approach to Quality of Service In 802.11b wireless networks

Said David Soud El Maameri

A thesis submitted in partial fulfilment of the requirements of

London Metropolitan University

For the degree of

Doctor of Philosophy

July 2004

This project is dedicated to Azad and Margos with all my love

A special dedication to my mother and father and to all members of my family, who had to bear with me during the past three years

Acknowledgements

A work such as this is never an individual effort, many people contributed to its completion in various ways, though there are too many to mention here. A special debt of gratitude is owed to Dr Hassan Kazemian for his encouragement, support and advice without which this project would not have been completed

I would like to say thank you to all my friends who assisted me in many ways during this period of discovery, honourable mentions must go to :-

Howard and Christine Clifford, Scott Colson , Pete Coppola, Philip Burbidge, Angela and Tim, Peter Williams, Alastair Macdonald and the staff of AMV Supplies

Contents

Glossary

ATM	Asynchronous Transmission Mode.
AWGN	Additive White Gaussian Noise
CAC	Connection Admission Control.
CBQ	Class Based Queuing.
CSMA/CD	Carrier Sense Multiple Access with collision detection.
CSMA/CA	Carrier Sense Multiple Access with collision avoidance.
CTS	Clear to Send.
DECT	Digital Electronic Cordless Transmission.
DIFFSERV	Differential services.
ECN	Explicit Congestion Notification.
FTP	File Transfer protocol.
GOP	Group of Pictures.
IEEE	Institute of Electronic and Electrical engineers
IETF	Internet Engineering Task force
INTSERV	Integrated Services.
ISM	Industrial Scientific and Medical frequency
ITU	International telecommunications Union
LAN	Local Area network
MPC	Multi priority control.
MPEG	Motion picture Experts Group.
NTSC	National television System Committee
PAL	Phase Alternate Line.
PAN	Personal Area Network
PID	Proportional Integral Derivative
QoS	Quality of Service
RED	Random Early Detection
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RSVP	Resource Reservation Protocol
SNMP	Simple Network Management Protocol
TCP/IP	Transmission Control protocol/ Internet protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UEP	Unequal Error Protection
UMTS	Universal Mobile Transmission service
UPC	Usage Parameter Control.
WRED	Weighted Random Error Detection
WLAN	Wireless Local Area Network.
WAN	Wide Area network

Table of Figures

List of Tables

Abstract

A generally held view is that the bulk of the data transmitted across packet switched networks in the future will be video and audio traffic. In recent years public telecommunications carriers have replaced circuit switched networks with integrated service packet networks that support both multimedia and data. One challenge with sending multimedia data is that it is delay-sensitive. To encourage the widespread use of the INTERNET as a multimedia platform it is necessary to have a minimum level of service. Guarantees are required that ensure satisfactory end to end transmission of delay-sensitive multimedia data. In wired systems the mechanisms used to provide Quality of Service (QoS) are Connection Admission Control (CAC), Usage Parameter Control (UPC) and MultiPriority Control (MPC). An increasing number of users are connecting to the Internet through Wireless Local Area Networks (WLANs). The most widespread standard for WLANs is that defined in the Institute of Electrical and Electronic Engineers (IEEE) 802.11b. Wireless hotspots and local area networks using equipment working to this standard are now ubiquitous. Regrettably the 802.11b standard has no mechanisms for providing QoS across wireless channels. Users of 802.11b networks cannot rely on the same support for QoS that would be available in a fixed network.

This thesis proposes the redesign of 802.11b gateways using fuzzy logic to include mechanisms that deliver Quality of Service. A fuzzy controller has been developed that implements QoS with CAC, UPC and MPC. This controller was optimised for 802.11b WLANs. Fuzzy logic has been used as a control mechanism for each QoS component. It converts imprecise human observations to crisp outputs for computer processing. With fuzzy logic it is possible to enhance performance at various points in the packet transmission process. Fuzzy feedback control regulates admissions to the network (CAC)

preventing a link from becoming saturated. Once an admission is made, a fuzzy controller smoothes individual flows (UPC). Traffic flows are classified and prioritised by class and then sent to the designated queue for that given class (MPC). A fuzzy packet scheduler regulates packet transfer through each wireless gateway. In this research, experiments have been carried out in real-time with CAC, UPC and MPC using fuzzy controllers for multimedia transmission over 802.11b. The results have been successful, with faster response times and throughput despite having lower processing requirements.

Chapter 1

Introduction

This project deals with the management of data transmission over the Internet. In the near future the bulk of all data passing across backbone networks will be delay sensitive video or audio traffic flows. For the user experience to be satisfactory, a minimum level of quality must be guaranteed for these flows. Substantial time and effort has been invested in developing tools to guarantee end to end quality for Internet traffic. These mechanisms are suitable mainly for fixed transmission links whose characteristics can be determined in advance. There is now a widespread use of wireless equipment particularly with the adoption of the 802.11b standard for wireless networks. For this reason we need to develop products that are designed to support Quality of Service (QoS) in wireless networks. This thesis proposes a new method to provide QoS management in wireless packet switched networks using fuzzy logic. Chapter 1 defines the context for the research and puts forward the concept of a hierarchy of four levels for wireless applications. The existence of a substantial market within each of these levels confirms the impact that wireless technology is having on our daily lives. The chapter then discusses the factors affecting wireless transmission, and identifies how fuzzy logic is used in network management. A brief explanation of the way in which video frames are transmitted is provided as background to the research. Finally the chapter concludes with the plan of research.

1.1 Research context

The Internet is expanding daily. From nine million users in 1996 it has grown to nearly six hundred million simultaneous connections (Source http://www.nua.com). By the year 2005 it is estimated that the Internet will support over one billion clients. There has also been a significant growth in mobile wireless appliances. If the claim made by Negroponte in 'Being Digital' of a wireless society creating the 'Negroponte Switch' comes true the wireless world will become the core of our Internet experience. We can identify changes such as the replacement of circuit switching with packet switched technology and a move from wired to wireless systems at the edge of packet switching networks. Other changes include increased competition for frequencies in the wireless spectrum along with a greater density of wireless traffic at each frequency. This expansion has far reaching implications, especially in the management of wireless devices. Most importantly we will see a growing need for products to perform the function of core routers, within solely wireless networks. Currently wireless gateways are limited to simple products acting as gateways either to home networks or campus type communities. These provide minimum routing requirements for a few users, but do not include QoS features. Within a packet switched network QoS is used to describe a minimum guaranteed level of service for different classes of traffic. These include defining constraints such as maximum latencies for voice or video traffic. At present this is dependent upon provisioning within each network provider. Because of the diversity of network provision it is not possible to provide end to end QoS across the Internet. In fixed systems QoS depends on the service level agreements with network providers. More and more high cost access servers are being replaced at the client end with broadband wireless routers. Client systems operating on the 802.11b standard have no QoS capability. If consumers are to be encouraged to make use of the

Internet new products need to be developed that will guarantee minimum standards of quality of service. These devices should support routing protocols and have congestion avoidance mechanisms similar to today's packet switched routers. They will also require the error handling mechanisms necessary to manage a harsh wireless environment. To achieve this, changes will be needed in the way tasks are processed at packet scheduling and processor scheduling level. At present consumer wireless equipment is limited to simple gateway devices and Ethernet style bridges supporting the 802.11b standard. Manufacturers will need to adapt existing the technology to cope with ever increasing demand.

1.2 Levels of opportunity in wireless networking

Currently sales of 802.11b devices translate for vendors into four levels of opportunity.

1.2.1 Level One

Level One is the deployment of core routing equipment to provide network services. This will replace 'last mile' switching equipment to cater for subscribers to the telecommunications services. The conversion to wireless will allow new entrants to the market to leapfrog established providers in the lucrative area of broadband services. Level One corresponds to the 'local loop' in a telecommunications company exchange.

1.2.2 Level Two

Level Two is the provision of infrastructure to support Local Area and campus based networks in addition to wireless 'hotspots' for commercial usage. Take up of these services will need a high level of technical support along with security and encryption guarantees. The market is in its infancy and as yet few suitable products are available. Hotspots are now being installed in international airports, metropolitan railway networks and even hotels. One example is the Paris 'Metro' wireless network. It is claimed that when this is complete, the whole of Paris will be accessible to 802.11b devices. Equipment for use within Level Two corresponds to the type of access server sold by CISCO such as the 1700 and 2500 series.

1.2.3 Level Three

Level Three is the provision of client subscriber circuits in Personal Area Networks (PAN's). These are limited local networks usually confined to one or two households and currently a maximum of 10 clients per network. The existing connection to the network provider is through a fixed broadband circuit with wireless connections to units inside the PAN. This represents the largest volume growth sector and will be fuelled by the convergence of domestic appliance or 'white goods' and home computer markets. Technologies such as 802.11b, Bluetooth, Universal Mobile Telecommunications System (UMTS) and Digital Enhanced Cordless Technologies (DECT) will dominate this sector. The future PAN will deliver video, audio and other data, whilst providing a portal to external databases for uses such as maintenance of domestic goods. An example would be a service engineer using the bluetooth device built into a refrigerator to query the performance of a cooling fan, by comparing it with manufacturer's data stored elsewhere. In the future a typical household is likely to contain many embedded wireless devices.

1.2.4 Level Four

Level Four is the use of wireless in embedded devices where the environment may be harsh or even hostile. This might include wireless network adaptors as well as equipment such as mobile registers, stock control analysers, and radio wands for bar coding. In addition there are other products such as surveillance cameras and similar equipment. An expanding growth area is in the field of military operations, both for administrative and defence purposes. As an example the US Defense Commisary Agency (DeCa) has deployed 802.11b devices as part of stock control management since 1996. Here in the UK many commercial ports have been using 802.11b radios to transfer details of container movements to aid logistical support for some years.

1.3 Factors affecting performance of wireless equipment

There are several ways in which the performance of wireless equipment may be affected.

1.3.1 Interference from other wireless devices

A common factor in poor performance is interference from other devices operating on the same frequency. The most widely applied standards operate across the 2.4 GHz range popularly known as the Industrial Scientific and Medical frequency (ISM). This is an internationally designated channel with no licensing requirements. Microwave ovens, 802.11b, DECT and Bluetooth devices all use this frequency. This increases the opportunity for interference to a transmitting channel from more powerful signal sources. Recent research [1] indicates that the interference caused from the accumulated output of industrial microwave ovens in the USA is increasing. One consequence of this may be that in the future low power transmissions from Bluetooth and 802.11b transceivers will become subject to disruption as a result of interference.

1.3.2 Effect of atmospheric conditions

Sources of disruption for wireless equipment include rain, wind and electro-magnetic radiation from the sun. Radio equipment is liable to interference in the same way that drivers are affected by luminous interference from fog. Signal loss can occur in driving rain as well as conditions of varying humidity. Data relating to environmental interference is presented later in the thesis. Radiation from the sun has a drastic effect on wireless transmissions as does changes in humidity caused by varying wind patterns. These factors may lower the received signal strength or increase the measured error.

1.3.3 Signal attenuation and multipath fading

Signal attenuation in free space results in a reduced signal at the receiver. This can be calculated from the formula

$$\text{Path loss in free space}(Pl) = 32.4 + 20 * \log(F_{Mhz}) + 20 * \log(R_{Km})$$

Reception weakens as the distance from the transmitter increases. This path loss may have a significant effect in microwave transmission. International regulations govern the output of transmission equipment using the ISM frequency. It is not permissible to raise the power at the source to compensate for attenuation. Therefore a clear transmission path must exist or messages cannot be carried. Since the horizon is the boundary of direct line of sight, the maximum distance is about twenty kilometres. The fresnel zone around the transmission path must also be clear for satisfactory operation since any obstruction will absorb power and inhibit the signal. Multipath propagation or 'fading' occurs when signals transmitted within urban areas reflect off solid structures such as buildings, causing them to arrive out of phase. One effect is to create duplicate or ghost signals. These are interpreted as errors in the receiving device. Fading can cause signal dropouts, resulting in brief periods of noise or in extreme cases complete signal loss. There are health issues associated with the presence in the atmosphere of electromagnetic radiation. As awareness of the dangers presented by wireless technology grows, governments are more reluctant to permit erection of transmission masts, and the public has become resistant to their continued further deployment. This has necessitated the development of techniques to increase the density of transceivers per mast. In addition concern has been raised about the hazards of using cellular radio equipment.

1.4 Possible uses for fuzzy logic in networking systems

A summary of the main factors affecting the widespread deployment of radio equipment was provided in the last section. New technology being developed must overcome these barriers before entering the marketplace. New methods that extract improved performance from existing equipment are also being explored. The race is on to make machines work smarter to provide more for less.

1.4.1 Use of fuzzy logic

One promising line of inquiry is the application of fuzzy logic [2] to replace existing flow control techniques both in transmitting video across low bit rate networks [3]. Wherever a heuristic based process occurs fuzzy logic can be applied. This has the advantage of improved performance along with reduced processing cost [4]. Fuzzy logic has been used successfully to simulate the human decision making process. Uses for fuzzy logic include automatic camera focus, road traffic management in town centres, and even analysis of stock market trends.

1.4.2 Fuzzy logic in Network management

To develop and promote standards the Internet Engineering Task Force (IETF) has set up the Differentiated Services DIFFSERV[6] and INTSERV[7] groups for Quality of Service provision across the Internet. Currently fuzzy logic has been applied to connection admission control in ATM networks [5] and to processor control in task scheduling [4]. Other research areas include management of buffer occupancy to support transmission of video across network links.

1.5 Transmission of video

This section covers the compression and transmission of video across packet switched networks.

1.5.1 Video standards and composition

To see how fuzzy logic can be of importance in this area it is necessary to understand the process of packet transmission of video services. Currently the main standard for video transmission is the Motion Picture Standards Group (MPEG) version 2.0 for transmission of video across packet switched networks. MPEG II requires that video is transmitted as a Group of Pictures (GOP) of 3 frame types.

1.5.2 Frame types and transmission sequence

Intra or I Frames are the highest priority and are self contained. Each GOP must start with an I frame. Of less importance to quality but vital to compression are predictive or P frames that use previous I or P frames as a reference. Bi-directional or B Frames have the lowest priority and are not used for encoding. A GOP will be a maximum of 15 or 18 frames in length depending on whether it is in PAL or NTSC format. The order of frames in a GOP follows the sequence:-

I B P B P B P ….

1.5.3 Characterisation of video and its problems

The peak rate for video traffic is usually not known in advance. To establish constant quality it is necessary to vary the quantisation parameters during the encoding process. One outcome of this may be an increase in the number of back to back packets during scene changes. This 'burstiness' occurs on scene changes or when there is greater movement in any scene. Usually as the action changes the data sent increases. Generally within a scene the largest frame is transmitted at the beginning (I frame) with predictive (B frames) and interpolative frames transferred consecutively until the next scene change. I frames may be significantly larger than P or B frames. A new I frame is sent as a new scene occurs. This could be significantly larger than previous frames so generating a large number of back to back cells. Unfortunately it may not be possible to know in advance that an I frame is being transmitted. If a number of I frames from the same video source are sent to different clients it will generate a peak burst that could exceed the available bandwidth and packets are discarded. To maintain constant quality a variable bit rate link is needed. The link gateway can become saturated as the MPEG decoder works to maintain a constant quality transmission. When this happens the gateway passing the traffic may become unresponsive as its buffers are exhausted. Most routers rely on simple buffer management policies, such as Weighted Random Early Detection (WRED) and Random Early Detection (RED) to cope with unresponsive or misbehaving traffic flows. By preference any management policies should work to delay rather than discard packets. Ideally we should work to design such mechanisms for wireless routers since they lack even these rudimentary management systems

1.6 Thesis objective

This thesis proposes the use of fuzzy logic to improve Quality of Service over 802.11b wireless networks. The test is to see whether or not the performance of a radio packet switched network can be enhanced with a fuzzy logic controller. The results show that a fuzzy based system has faster response times and uses less processing power when compared with a system using conventional flow control.

Chapter 1 introduces the problem domain and sets the context for the research. This chapter provides the framework for the thesis and how wireless technology is significant in today's Internet. Chapter 2 looks at congestion management in packet switched networks, and discusses radio error. Readings taken during the period of research are analysed to see how transmission can be affected by radio error. Chapter 3 is an overview of fuzzy logic as a tool in process control. Chapter 3 also discusses the arguments of those researchers in favour of fuzzy logic as well as those who do not see it a rigorous scientific method. Chapter 4 focuses on Quality of Service mechanisms. At this point, the literature of QoS research is reviewed. A novel QoS mechanism is suggested to implement admission control. Chapter 4 explains how process management works in packet scheduling. A method of processor scheduling for wireless devices is proposed that will form the basis for the packet scheduling design used in this project. Chapter 5 discusses the methodology of research and the design for a fuzzy logic controller to manage the mechanisms for Quality of Service. The experimental results are presented and discussed in chapter 6. Chapter 7 discusses the project puts forward a conclusion and makes recommendations for future directions for research.

Chapter 2

Reliability and error in packet switched wireless networks

2.1 Introduction

This chapter focuses on the concept of packet switching and the advantages of replacing circuit switched with packet networks. Robust protocols for sequencing and routing are needed to make packet switching work successfully. This is the justification for using the transport protocols described below. The chapter discusses possible causes of error in wireless systems and how the Simple Network Management Protocol (SNMP) can be used to monitor transmission errors in a wireless network. The distinction between congestion and random errors in a wireless channel is explained. Conventional congestion control techniques are discussed and the literature in this area is reviewed with special emphasis on wireless networks. Current congestion management policies are geared to using errors as a congestion indicator. This chapter proposes that congestion management should take into account the different architecture of wireless networks.

2.2 Current network technologies

Most networks, even those using microwave radio links are based on some form of packet or cell switching technology. Whether the topology is ethernet, asynchronous transmission mode or an arbitrated ring the basic unit of data is a packet. The fundamentals of packet switching stem from research undertaken in the 1960's[8], though there have been numerous refinements since.

2.2.1 Definition of packet switching

We can describe a packet switched network as the type of network in which relatively small units of data called packets are routed to a destination address contained within each packet. In a packet switched network nodes can be in simultaneous communication with more than one adjoining node. This allows multiple connections through a single route, and also provides economies of scale by supporting a larger number of users on a link. The packet switched node has a faster response as a connection need not be established before a request is made. This permits further connections to be made even if one is in progress. . Packet switching has no call setup or tear down requirements so helping to keep costs to a minimum. Packet networks are therefore able to service a greater number of connections at a much lower cost. The Internet engineering Task Force has adopted Transport Control Protocol/Internet Protocol (TCP/IP) as the *de facto* transport mechanism for Internet traffic. The main protocols that contribute to TCP/IP traffic are User Datagram Protocol (UDP) and Transport Control Protocol (TCP).

2.2.2 User Datagram Protocol

UDP is a lightweight messaging service designed for transmission of short messages. It has no capability for ordering or sequencing of byte streams and is not reliable. This protocol is useful for message transmission where no requirement exists for reliable two-way dialogue. Examples of UDP usage are FTP and DNS traffic. Because UDP need not be reliable there is no overhead for storing connection state or maintaining copies of data in the event of loss. This makes UDP attractive to application designers who are prepared to forgo reliability in place of low end-to-end latency. UDP is now being used for real time transfer of video and other time sensitive applications. However as this protocol is aggressive in transmission it is more likely to be penalised in network gateways, especially by routers operating class based queuing techniques [9,10].

2.2.3 Transport Control Protocol

The main disadvantage of packet switched networks is their ‘unreliable’ nature. A packet switched link does not require completion for messages to be transmitted, so data may be lost periodically. To allow packet switching to compete with circuit switched networks it is necessary to build in mechanisms to make them reliable. TCP forms the reliable element of TCP/IP and the bulk of all packets within the Internet. This permits data to be sent from one link to another across any supported medium without concern for its integrity. The assurance is that by using TCP messages will be transferred reliably. In practice this reliability imposes an overhead on any data transfer. So long as the only Internet traffic remained limited to file transfers, emails and other documents this posed no problem. It was accepted that reliability came with additional bandwidth demands and that file transfers would be necessarily slower. In addition to this there was no procedure to control contention for the links between nodes upon which data was transmitted. The gateways used to transmit packets contained no mechanisms to expressly control packet rates or even to determine incipient congestion or prevent new users coming online. To satisfy changing user demands, the growth in multimedia traffic requires the development of new systems.

2.3 Requirement for Quality of Service

A wireless circuit is by definition impossible, so it follows that wireless networks are packet driven by default. Due to the inherent error in packet wireless methods must be provided to support reliability. Minimum levels of quality are required irrespective of the protocol in use. The data sent has to arrive within a given period of time. This section focuses on the need to provide minimum guarantees for Internet traffic.

2.3.1 Internet Engineering Taskforce working groups for QoS

In recent years there has been a shift to an integrated services approach within the Internet. By this we mean that voice, video and data services are now being pushed through the packet switched channels. The transmission of a file provided the destination exists and a link is available presents no major problems. Once a byte stream is sent it is not important how long it takes to arrive provided that it is intact and correctly sequenced at the other end. This is not however the case for voice and video data. If the components of a voice message cannot arrive within a determined period of time, the message will be incomprehensible. This phenomenon is known as latency or jitter. The convergence of all these services, voice, data and video upon the Internet and the gradual shift from separate circuit and packet data networks to an integrated network has meant systematic and widespread changes to the infrastructure provided for packet transmission. Modern packet switched networks must be fast, adapt to changing volumes of traffic and capable of supporting a range of services. In addition they have to be reliable and guarantee minimum quality standards to their users. To accomplish this the IETF have set up two working groups:-

- INTSERV responsible for managing integrated services and specifying standards for packet transmission of voice, video and data
- DIFFSERV, to manage quality levels for the different types of service.

The primary objective of both groups is to define minimum quality levels for each application type. This quality is both empirical (capable of measurement) and subjective based upon the user experience. For QoS to exist there must be procedures to reserve and request a particular service, and mechanisms to monitor service level agreements. Network gateways need to ensure reliable data transmission and maintain an agreed level of quality for each traffic class. For example video should have minimum frame rates and maximum latency for each packet sent at the agreed service level. For voice and video traffic the multimedia conferencing standards to be met are defined by International Telecommunications Union (ITU) H323, now extended to all packet switched networks.

2.3.2 Network provisioning

The responsibility for traffic on Local Area Networks (LAN's) lies with the host company. It is straightforward to guarantee support for QoS across a LAN if it is reasonably well provisioned. Once the requirement extends to the wide area the situation is more complex. A network provider may lease bandwidth to an organisation but the costs to ensure QoS may be onerous. In any event most telecommunications providers allow multiple users to cross their networks at the same time. This multiplexing creates contention for scarce resources at network gateways and may result in loss of traffic or failure of connection. If a provider has insufficient resource to offer the agreed level of service as specified in the traffic contract delays or congestion will occur. If on the other hand the network is provisioned to ensure that sufficient bandwidth is available at all times, the network could be under utilised at high cost to the provider. Most telecommunication companies proceed on the basis that the network should support the average bandwidth of all their customers but not their peak bandwidth. If all users exploit their maximum possible bandwidth at the same time severe congestion and degradation occur. Designing a network therefore requires knowledge of network performance coupled with understanding of the customer's needs. By developing tools to predict and even modify network usage the network manager's task is simplified. At present we are very far from this position and must rely on simulations for prediction and projection of network trends. Figure 2.1 is an example of usage for a network link supporting 10 to 15 users using a broadband wireless connection over the 12 months August 2002 to 2003

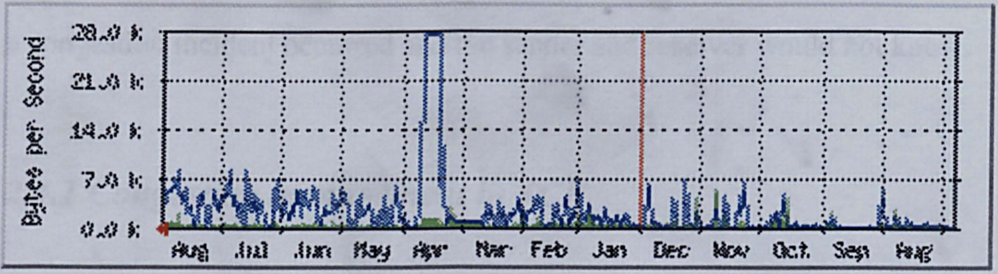


Fig 2.1 MRTG graph of the network load on a wireless link

Except for one point in April 2003 the peak rate never exceeded 7 Kbytes per second. On this basis the link provisioning could have been met with an ISDN 2 connection, instead of a 500 Kbs wireless connection. This is not a criticism of the installation but it serves to highlight the reasons behind network provisioning. It is possible to make considerable savings by allocating resources as and when needed. This is preferable to over provisioning or inadequate resource provision. In summary packet switched networks transmit data at given rates depending on the availability of network resources. At the local area network level where only a single link layer is in operation it is relatively simple to adequately provision a network to provide whatever quality required by the user. Wide Area Networks (WAN's) present more challenging situations since they may be composed of different network topologies with users having varying requirements, despite sharing a common infrastructure at certain points.

2.4 Congestion control in TCP

Packet switched networks are inefficient and require means to prevent them becoming saturated with user request that cannot be met. As the load increases, they are more subject to failure at critical points, particularly at network boundaries. Deploying faster switching technology may not be an option because of the costs involved. The first TCP implementations had no way of discovering if data was not being sent. Data could be lost if a congestion incident occurred and the sender and receiver would not know.

2.4.1 Congestion management in TCP

In the seminal work by Jacobson [11] a congestion control method was proposed for TCP. With modifications this congestion control mechanism remains in place today. It is based on an additive increase multiplicative decrease algorithm implemented with a sliding window for packets sent. Transmission involves a slow start phase, then an exponential increase in the sliding window size until a maximum is reached. Once the threshold limit for duplicate acknowledgments are received, the algorithm is initiated and the sending window size reduces to its minimum, causing slow start to begin again. While TCP congestion avoidance is of great value the process is not well adapted to wireless networks. In addition there are still very few suitable methods by which feedback relating to traffic on a link can be returned to transmitting or receiving nodes.

2.4.2 Congestion management and wireless error

When data is sent simultaneously from multiple users across a shared channel collisions frequently occur. In ethernet networks this is handled within the link layer by access protocols. Fixed link ethernet networks use Carrier Sense Multiple Access with Collision Detection (CSMA/CD). Two stations sense when a collision occurs and cease transmission for differing periods of time. Once this 'backoff' period has expired the stations resend and hopefully no further collisions occur. Wireless networks require more complex sensing mechanisms, as there is no way of detecting collisions without expensive full duplex radios. The 802.11b standard for wireless networks implements Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. A sending station upon receipt of a CTS (clear to send) signal from a receiver with its own identity stamp sends a packet data frame on the understanding that all stations in the area have also received the CTS and will therefore not transmit. There is a transmission overhead incurred with CSMA/CA as it is a broadcast protocol. Response times with CSMA/CA radios are slower because only one station may transmit to the receiver at any one time. Also if a station doesn't receive the CTS yet transmits anyway collisions can still occur.

When ethernet traffic increases the chance of collisions also increases. Collisions are manifested as errors resulting in retransmissions of the affected data if the protocol is a reliable one such as TCP. As errors increase so do the retransmissions. This creates a cycle of transmission and failure. Packet data networks therefore need mechanisms to detect incipient congestion and control it. Various congestion management algorithms are in use, though the most commonly implemented one is TCP SACK [12]. The central issue here is that the only method used to detect congestion is to monitor the error rate then either discard packets or queue them whilst reducing the sending rate along each affected network path. Unfortunately with wireless networks an increase in the error rate is not only a congestion indicator [13]. There may be other reasons for an increased error rate including environmental factors, general background error or a poorly chosen maximum transmission unit. Activating congestion control may not be appropriate in a wireless network with an expected error rate above the congestion threshold. The congestion mechanism may be initiated even though the link remains largely under utilised. It is therefore necessary to develop mechanisms that distinguish between errors as a result of congestion, or from other causes.

2.5 Alternative congestion management protocols for Wireless LANs

To manage the special case of wireless networks some researchers are recommending the use of new TCP congestion mechanisms designed for WLAN's [13]. These do not rely on errors for detecting congestion, but take averages of bandwidth product delay over a period of time and factor in link utilisation. Understanding the behaviour of the network is necessary to maintaining QoS across a WLAN. If the error rate is sufficiently high that the network remains permanently in slow start mode as opposed to fast transmit the utility of the network is permanently low. This makes it impractical to use only error rates as a congestion indicator for wireless networks.

2.5.1 Examples of wireless error

To better understand how congestion is detected in WLAN's it is useful to consider the causes of error. As mentioned previously the most common causes are increased traffic, signal noise caused by interference, poor line of sight, multipath fading and atmospheric conditions. Figures 2.2 and 2.3 show the effects of error rates on traffic load over a WLAN on December 30th 2002. From the two graphs we see that the error rate is not simply a function of network load since it is remains high whilst the load decreases. The increased error rate may be related to the humidity. The plot in Figure 2.4 records humidity for December 30th 2002.

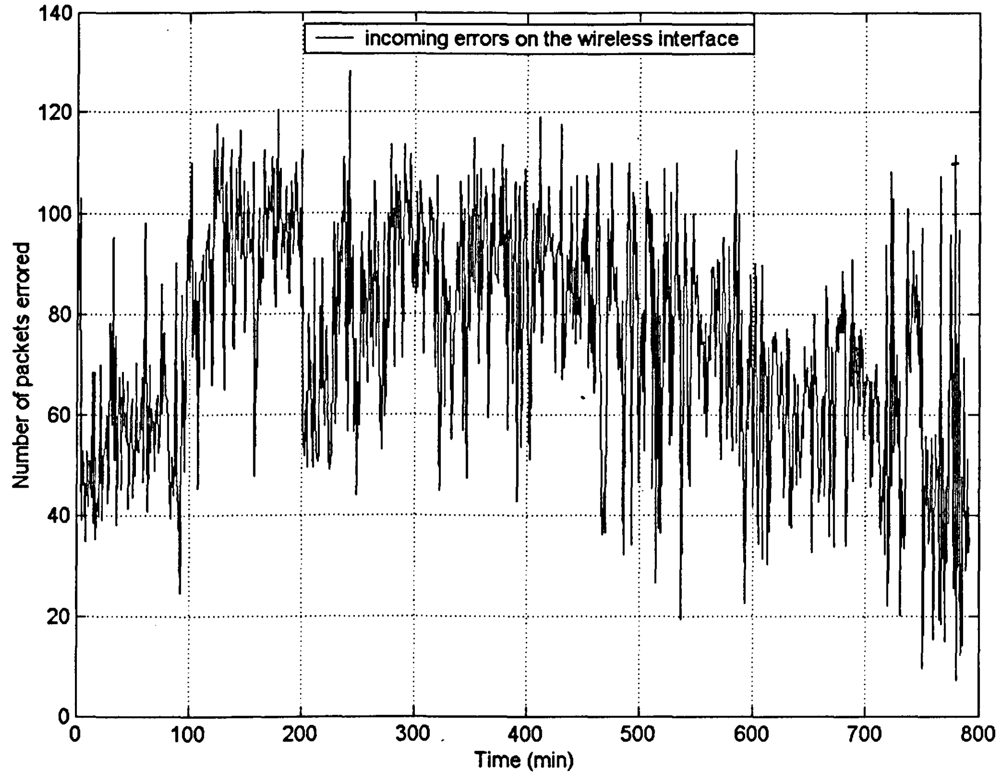


Figure 2.2 MatLab plot of error rates for a wireless device

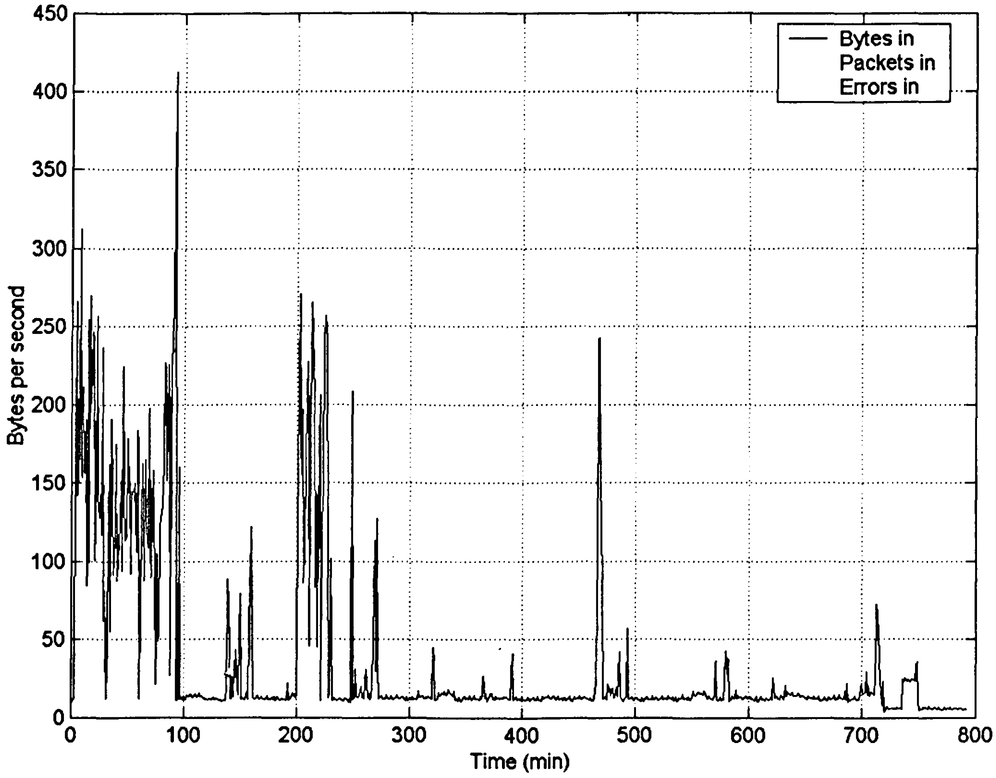


Figure 2.3 MatLaB plot showing the load on wireless device

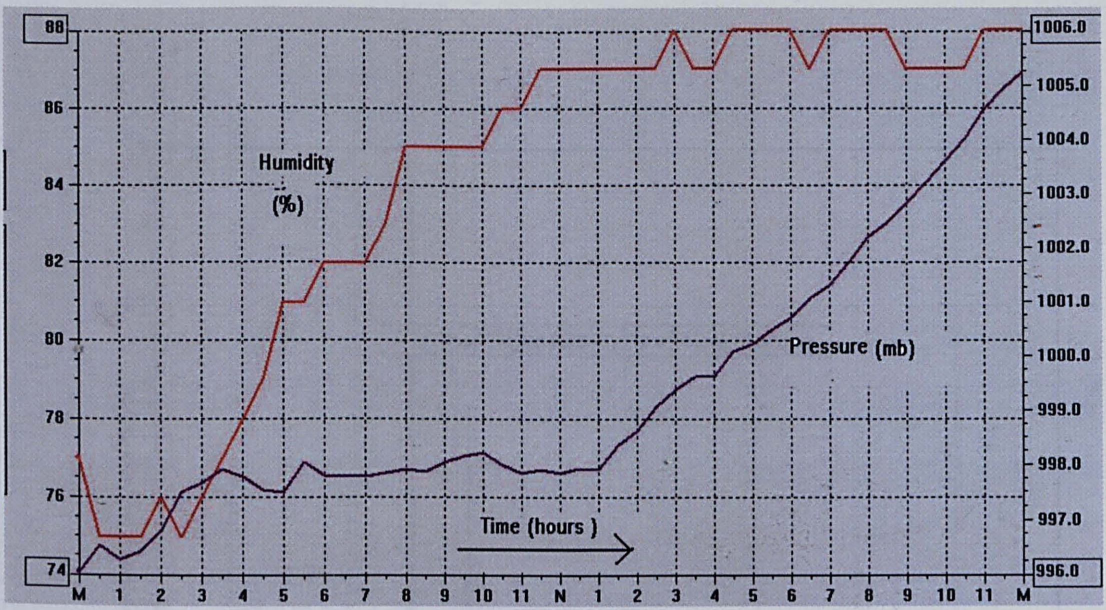


Figure 2.4 Davis Weather station plot of humidity and atmospheric pressure

Although it is well documented that changes in atmospheric conditions influence the overall performance of wireless systems, Figures 2.5 and 2.6 illustrate that there is not a simple relationship [66].

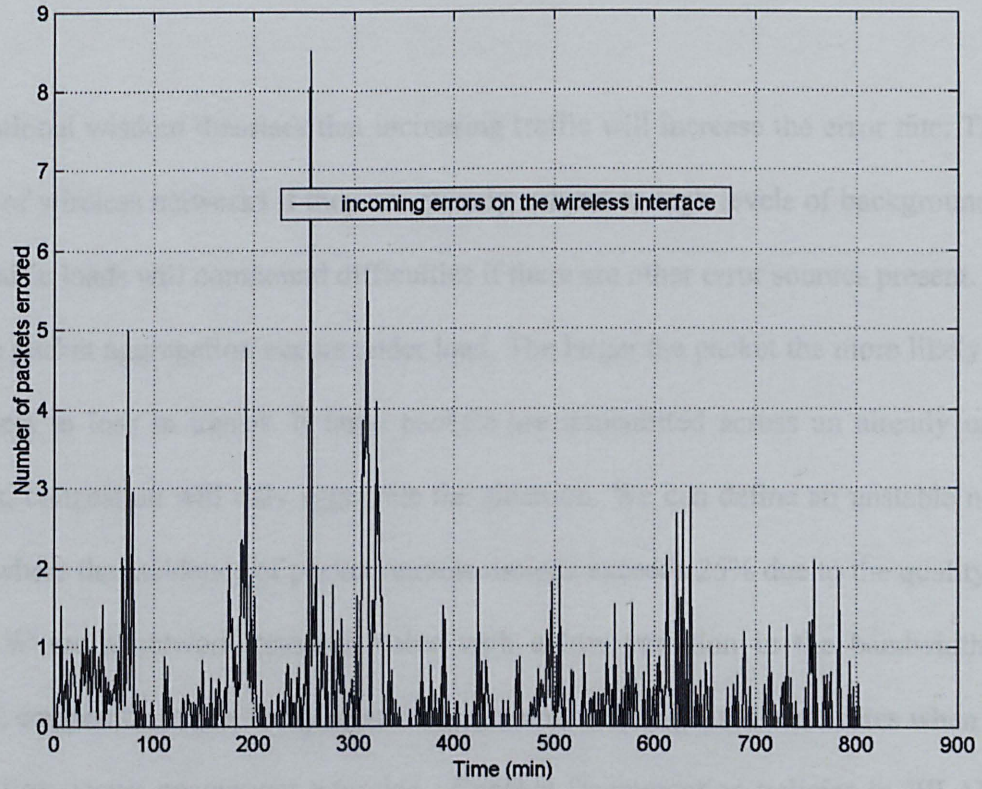


Figure 2.5 MatLab plot of measured errors on a wireless device January 31st 2004

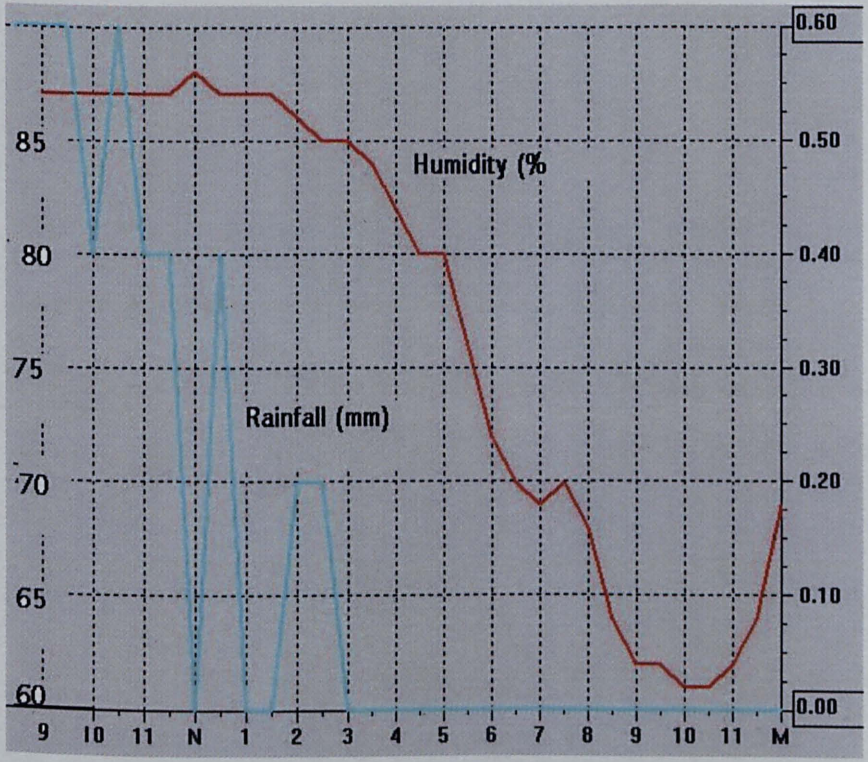


Figure 2.6 Davis weather station plot of humidity against time for January 31st 2004

2.5.2 Relationship between network load, packet size and error

Conventional wisdom theorises that increasing traffic will increase the error rate. This can be true of wireless networks if they are already subject to high levels of background error. High traffic loads will compound difficulties if there are other error sources present. This is because packet aggregation occurs under load. The larger the packet the more likely it is to be subject to loss in transit. If large packets are transmitted across an already unstable network, congestion will only aggravate the situation. We can define an unstable network as one where the incidence of packet retransmissions exceeds 25% due to the quality of the signal. Where a network remains stable with a low variation in the bandwidth delay product, congestion is less likely to create problems. The increased error rates when packet aggregation occurs encourages adoption of packet fragmentation policies in WLANs and makes them candidates for rate smoothing techniques as well.

Two kinds of error are apparent from observation of wireless networks. The first is caused by network congestion. When congestion occurs TCP congestion control mechanisms are initiated to manage data transmission. The graph in Figure 2.7 demonstrates how the error rate varies with increasing load. As the load increases, packet aggregation results in larger packet sizes that are more prone to errors.

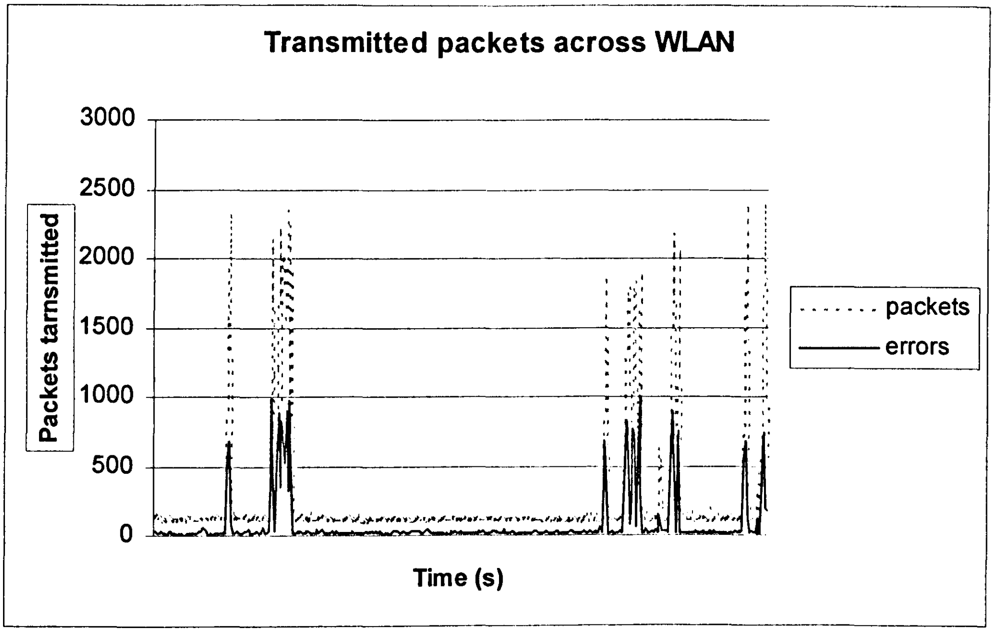


Figure 2.7 MatLab plot of variation of error with load for a wireless channel.

The second form of error is background error dependent on physical conditions in the wireless network. Slow start occurs when the congestion window increases in small increments after a congestion incident In a wired network once the congestion is removed, the slow start very quickly gives way to an additive increase phase. Background error however may cause TCP to remain in a permanent slow start phase during transmission. This background or random error manifests itself by initiating congestion avoidance even when the channel is under utilised. In this way throughput remains at the original sending window size rather than a multiple of this value.

2.5.3 Background error

Background error can be attributed to several causes that have already been described. It should be noted however that it is unlikely to be eliminated from any transmission across a wireless link. Throughput can be improved through modification of the transport or link layers. To modify the transport layer it is necessary to develop new transport protocols for wireless links that can take account of background error before initiating congestion avoidance. One useful technique is to avoid the slow start phase as much as possible by using mechanisms such as TCP SACK. Here fast retransmit mode is initiated on discovery of three duplicate acknowledgements. Fast retransmit means that only the data from the last correctly acknowledged packet is resent. TCP SACK has several drawbacks including the issue of handling data arriving out of sequence. TCP Westwood [14] uses packet inter arrival times to determine a congestion event. This may be of some use in distinguishing between errors and congestion events. TCP Veno [15] has been proposed for wireless devices as a method of varying the sending window based on an analysis of the actual error. Other methods seek to modify the link layer to improve throughput as for example TCP SNOOP. This mechanism uses a split connection protocol that analyses packets at the wireless interface to explicitly distinguish non-congestion loss, for example by marking a flag in the IP Header. SNOOP has been modified to provide for Explicit Loss Notification (ELN) in wireless networks ELN [16]. The wireless gateway and wireless client may be modified, but there is no need to modify intermediate wired gateways. The main advantage is that SNOOP Operates in reverse from mobile host to wired or wireless client. However there is no mechanism for determining the cause of loss and no way of handling loss of the ELN packet.

It is possible to use link layer protocols to hide evidence of retransmissions due to background error from the transport layer [17,18]. Any errors detected by TCP would then be attributed to congestion. The problem with such link layer retransmission is the insertion of further delays that can severely affect time sensitive traffic [19] such as video. Some researchers maintain that 802.11b does not retransmit frequently at the link layer therefore 'random' or background error is not an issue. This research relates to experiments carried out within a controlled internal environment [20,21] and not externally over a long range where path loss and signal attenuation are common. The findings of this project show that signal attenuation over long links results in excessive background error. Pau [20] does conclude that wireless packet transmission exhibits widely variable round trip times, but fails to make the obvious conclusion that this is caused by background error.

The challenge of 'competing error recovery' [22] arises when there is no co-ordination between link – layer recovery protocols such as Automatic Repeat Request(ARQ) and higher layer congestion protocols such as TCP Tahoe. This can result in copies of data being resent by both the wireless device and the application in progress. One way around this is to define a link layer persistency. This is a holding time for each packet before it is forwarded to the next link. If this is set at the right level, recovery mechanisms can be synchronised to avoid unnecessary retransmissions. Active queue management [23] is another approach where time sensitive packets are dropped from the wireless buffer after an expiration period. If the sending device requires the packets to be resent it can do so at application level. A large initial sending window size can ensure that throughput is not reduced significantly. This is however not a practical option where there is a high background error since sending a large number of packet can provoke an immediate congestion response. Any modification to a protocol stack whether link or transport needs consultancy and widespread agreement. These are long term solutions incurring high cost since they need to be built into the firmware of network devices. Ideally we are looking for a rapidly deployable solution to enhance existing technology.

2.5.4 Tradeoff between throughput and delay on a wireless network

Analysis of packet wireless networks establishes two facts:-

1. The relatively low quality of the transmission signal leads to congestion and degradation of the channel under load. With current transport protocols this initiates congestion avoidance and reduces the sending window. Reducing the sending window when there is no congestion prevents full utilisation of the channel.

2. Background error is random noise that may be attributable to path loss, congestion or interference from other sources. This error produces widely variable round trip times for packet transmission but is not caused by channel utilisation.

The main implications of this are:-

- Low channel availability for video applications, this makes constant quality an issue where there is a required quality of service particularly in the transmission of variable bit rate video.

- Variable latency during transmission of audio and video

One option is to keep the sending buffer well below the sending window size since this can minimise error but it will also minimise throughput. At what point do you establish a tradeoff between low throughput and low delay and high throughput and high delay?

2.6 Conclusion

The chapter introduces the concept of packet switching and gives reasons for its adoption by telecommunications providers for Internet traffic. The need for reliable networks is vital to the commercial success of the Internet. Mechanisms have been developed to implement and maintain reliability in packet networks. These mechanisms whilst being successful are open to misuse when network congestion increases. This has led to the development of congestion avoidance algorithms for instance TCP Reno and TCP Tahoe. QoS is necessary to guarantee minimum standards for data transmission. Offering this facility encourages the use of packet data networks for video and audio applications. Implementing QoS is complex and needs mechanisms to detect traffic congestion in the early stages. These mechanisms are not so effective with wireless equipment since errors can be wrongly interpreted as congestion indicators. It is therefore imperative that new transport protocols be developed specifically for wireless devices. Examples of such protocols, for instance TCP SNOOP are under development.

Chapter 3

Overview and justification for using fuzzy logic

3.1 Introduction

This chapter explains fuzzy logic, what it is and seeks to achieve and how it compares with conventional binary logic. Examples are provided of real life situations where using conventional systems introduces error by discarding useful information. Fuzzy logic includes both precise and imprecise data thus expanding the options at the core of the inference engine performing process control. Mathematical conversions then ensure that crisp outputs are obtained from all data provided. A fuzzy logic engine consists of a rule base and inference engine. Input variables are sets described by membership functions that are processed to obtain resultant outputs also described by membership functions. The paradigm is then mapped to a mathematical model that can be converted to a computer algorithm. The chapter moves on to discuss the application of fuzzy logic in real world systems as part of a feedback control mechanism. Instances are provided demonstrating where fuzzy logic has been successfully applied to a problem domain. The discussion considers inappropriate use of fuzzy logic or situations where the rule base may too large to be manipulated. An argument from researchers who debate the value of fuzzy logic and criticise its usefulness is included. A counter claim that fuzzy logic reduces system development time and that fuzzy systems work faster is discussed.

3.2 What is fuzzy logic?

"Everything is vague to a degree you do not realize till you have tried to make it precise."

[Bertrand Russell]

3.2.1 A definition

This chapter begins with a discussion of the fundamentals of fuzzy logic and an example of a problem domain. Factors affecting the choice of heuristics are considered and the chapter concludes with a commentary on research applications.

Fuzzy logic [2] is a means to derive an outcome from imprecise data. This is in direct contrast to the performance of conventional flow control that can only consider precise data for action. Conventional logic uses routines that are 'accurate but not correct' [24].

Fuzzy logic is particularly appropriate for non-linear models of the form:-

$x = f(x) = g(x)u$

For a detailed analysis of fuzzy set theory the interested reader is referred to [25].

3.2.2 Example problem domain

Consider the classification of a group of 25 students as tall, short or medium.

A count provides the data in table 3.1

Table 3.1 Heights of students in a class

Height of Students (in)	Number
58 - 60	2
60 - 62	7
62 - 64	3
64 - 66	2
66 - 68	6
68 - 70	5

We could define three sets as follows :-

'All people taller than 68" are tall'.

'All people shorter than 60" are short'.

'All people in between are medium'

We have now reduced the groups to three based on rather vague terms such as tall or short. From the results a computer would conclude that 2 students were short and 5 students were tall. A summary provided by the computer would actually exclude significant information about the distribution of height within this class! In summary a person considering this domain might otherwise suggest that nearly half of the students are 'fairly' short whilst almost the remaining half are 'fairly' tall. The challenge is that our systems do not understand imprecise phrases such as 'fairly', 'nearly' and 'almost'. Therefore the results obtained from the computing system are 'accurate but not correct'.

The babysitter example illustrates the flexibility of fuzzy logic. A babysitter provides a service to two families. Both request that the children be put to bed not too late but how do you define that? In one household the children are normally put to bed at around 8.30 pm whilst they go at 9.00 pm approximately in the other house. Both families consider these as definitions of 'not too late' but how is the babysitter to avoid putting the children to bed at the wrong time?

The basic rule set can be modelled in either a conventional or a fuzzy system

1 If it's early let the children stay up
2 If it's late put the child too bed

What makes the fuzzy system cope with the differences in relative time is the inclusion of rule 3 into the inference table. This states that 'if it's not early put the child to bed'.

We now have the rule table below:-

1 If it's early let the children stay up
2 If it's late put the child too bed
3 If it's <u>not</u> early put the child to bed

This additional rule works when evaluated jointly with the other rules. The rule set says it is early or late a further rule is then applied which says effectively even if it's not late put the child to bed if it isn't early.

The simplicity of this extra rule would be nearly impossible to match in a conventional flow control program and yet when tested it provides a swing of up to 1.5 hours that caters for the difference in personal attitudes in two sets of families.

3.2.3 A more complex definition of fuzzy logic

Fuzzy logic supports control systems by not discarding significant information on which to base decisions. Through approximating the human decision process outcomes can be obtained that more closely reflect the choices made by an expert. In the example discussed in 3.2.2 a conventional system would note only five people as members of the set tall. Fuzzy logic however might classify eleven students as *fairly* tall. If the outcome were to provide clothes for fairly tall people more orders would be fulfilled using fuzzy system.

By introducing the concept of imprecision, fuzzy logic manages data by converting it into a form that can be considered mathematically. The results are then converted or defuzzified into real values for processing purposes. Fuzzy logic should not be confused with uncertainty. We do not define membership of a fuzzy set from the probability of a value appearing in it. The degree of membership of a value (its truth) within a set is determined mathematically but all values within the domain are known or measurable. In summary fuzzy sets classify imprecise data, evaluating the degree of membership for each data point. The results are then passed to an inference engine and output as a resultant set. The resultant is then converted to crisp form.

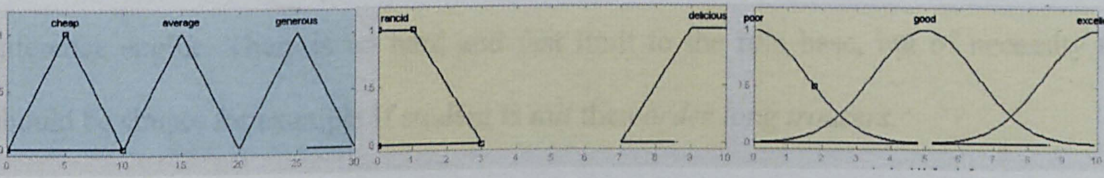
3.3 Components of fuzzy systems

3.3.1 Membership functions

These are the sets of the universe of discourse. Since there is a continuum between each set there needs to be some method of estimating the boundaries and the extent to which an input becomes a member of a particular set. In fuzzy logic an input is not strictly wholly of one set but can have a degree of membership. What separates fuzzy logic from conventional methods is the fluidity of these Membership Functions (MF's). The range of MF's need not be zero to one, it can be any set that is at least partially ordered.

A fuzzy set A in X is defined as a set of ordered pairs. $A = \{x, \mu A(x) \mid x X\}$

Membership functions may assume different shapes according to the population of the sets. Because of its simplicity the triangular MF is the most popular though others exist (Gaussian, trapezoidal etc). The Gaussian function is popular for implementing fuzzy representations of single numbers. The function has a relatively wide main body that drops to zero as the distance from the centre increases.



Triangle Trapezoidal Gaussian

Figure 3.1 Example shapes of fuzzy membership functions

The support of a fuzzy set is the domain over which it's MF is not zero. Knowledge of this can speed up computation by avoiding operations in null areas. The height is the maximum value attained by the MF. A fuzzy set is normalised if it's height = 1. The traditional approach is to use overlapping trapezoids. Kosko [26] uses 7 fuzzy sets to represent the practical range of a variable. The use of at least 5 membership functions within fuzzy logic to represent a variable has now become commonplace. This is useful for detailed analysis but probably not vital for prototyping. Kosko suggests a minimum overlap of 25% at boundaries of adjacent trapezoids, but comments the trapezoid does not perform well [27]. Another very common function providing good input - output mapping is the triangular function, also used in this work. The use of a *Hedg*e (linguistic qualification of a set to provide a modified set eg: sweet wine and 'very sweet wine') is also acceptable.

The Hedge 'very' may be obtained by squaring a function

The Hedge 'somewhat' is obtained from the square root

3.3.2 Inference engine

This is the method by which rules are applied to the inputs within each membership function. Having ascertained the degree to which a variable is part of each membership function. Rules are extracted from a rule base then applied to the values contained in the membership function variables. The rule base is the collection of rules used to drive the inference engine. There is no hard and fast limit to the rule base, but of necessity they should be simple for example If student is *tall* then *order long trousers.*

Table 3.2 Inference engine operations

Operation	**Meaning**	**Action**
Negation	NOT (1- x)	TRUE if X is FALSE
Conjunction	AND (min x)	X + Y (TRUE) if both X and Y are
Disjunction	OR (max x)	X OR Y TRUE if X or Y is TRUE

The three operations in Table 3.2 above are used in applying the rule base or Modus Ponens

1) RULE: If an animal is a dog, then it has 4 legs
2) PREMISE: This animal is a dog
3) CONCLUSION: This animal has 4 legs

The standard method of computing this is known as the Correlation product inference

As defined in equation 1 below:

(1) $$\mu_{B,A}(x) = \mu_A \cdot \mu_B(x)$$

Where two rules result in the same conclusion from a different premise then the results are obtained by OR'ing the 2 rules together. After combining all implications, all rules are ANDed together. This is necessary because we base our results on the results of the truth of all rules. At this point we have a rule base:- This produces a membership function for a fuzzy set obtained by applying the rules onto measured data. The domain of this fuzzy set's membership function is the required result and will be dependent on the inputs from the antecedent fuzzy sets. How is the output calculated?

3.3.3 Output engine

This is the defuzzification process. Several methods exist to find the state of each output but the most common means is via the centroid method as defined in equation 2 below.

$$(2)\quad \overline{x} = \frac{\int_D x\,\mu(x)\,dx}{\int_D \mu(x)\,dx}$$

Before defuzzification it is important to validate the results obtained. A useful indicator is the height of the resultant fuzzy set. This is sometimes known as the compatibility index and should be reasonably large. If the resultant is uniformly small there may be too many or too few rules.

Points to consider in the defuzzification process:-

- A low height indicates some redesign may be needed.
- Very large heights (over 0.9) may highlight problems within the rules.
- The MF should be expected to vary considerably over the domain.

The sequence for determining the crisp outputs must depend on observations of the rule base. Standard practice is to produce a resultant fuzzy set for each rule. The result of these fuzzy sets are then OR'd if they are part of different membership functions or ANDED if they are part of the same resultant.

Table 3.3 Summary of resultant (Matlab)

Antecedent	**Consequent**
If Service is Poor or Food is rancid	Tip is cheap
If Service is Good	Tip is average
If Food is Good	Tip is average
If Service is Excellent or Food is Delicious	Tip is generous

Since rules 2 and 3 are implications into the same fuzzy set there results are first ANDED. All results are then OR'ed as they are implications into a different fuzzy set

3.3.5 Operation of a fuzzy system

The crucial part of fuzzy logic is to ensure that *all rules are fired where possible and the results combined.* Since there is no requirement to sum results to 1 the combination can then produce crisp output. In effect information is not lost. For instance Rule 4 may fire because service is excellent, on the other hand the food may taste awful and we would want to include this factor (rule 1). Fuzzy logic allows us to combine all possible rules and therefore record all information. Whilst this is a simplistic example, it could be vital in the management of an automatic temperature gauge in a power station. In practice building a simple model may generate results within defuzzification for further analysis. By varying the size of the resultant trapezium it's possible to change the centroid area. This will in turn vary the desired output considerably. When the final design is ready the success of the fuzzy engine will depend upon fine-tuning based on the results generated.

The sequence of events in a fuzzy logic program runs thus

1. Define membership functions for input and output variables
2. Evaluate Truth of each input
3. Devise and apply rules
4. Combine all results either using negation, conjunction or disjunction
5. Obtain Centroid of resultant
6. Convert centroid value to crisp output
7. Display and process output

3.4 Purpose and application of a fuzzy system

The previous sections discussed the structure and development of a typical fuzzy system used to evaluate imprecise data. This section considers the inappropriate and appropriate use of fuzzy logic.

3.4.1 Inappropriate use of fuzzy logic

It is redundant to use fuzzy logic where an ordinary feedback system can suffice. Such an instance might the execution of processor instructions in a task such as printing a page of text. The use of fuzzy logic techniques can greatly simplify the design of non-linear control systems or systems, incorporating expert knowledge. Development and maintenance time can be reduced and a high level of robustness against variations in system parameters is provided

3.4.2 Possible uses

Fuzzy logic can be applied where decisions are based on imprecise information. This kind of event requires a human intelligent approach to decision making. This should consider past actions and be capable of flexibility and change. The skill lies in choosing the correct application area and devising a suitable rule base. This makes the steps one and three vital. If fuzzy variables cannot adequately represent a system it will not be practical to implement. In addition unsuitable rules will produce unsatisfactory results. As discussed earlier the evaluation of output data is straightforward if the algorithms are constructed properly and the rule base is correct. However this only indicates the correct operation of the rules and MF's but does not confirm their accuracy. To do this it is necessary to model the problem domain and consider the results obtained from the simulation [28].

3.4.3 Problems with the application of fuzzy logic

Fuzzy controllers are very efficient with a small rulebase. Unfortunately fuzzy systems scale poorly. However management becomes more difficult as the number of rules in the rulebase increases. It has been suggested that the use of fuzzy logic to manage large systems may not be appropriate [29]. As the popularity of fuzzy logic grows the concept will inevitably be applied to systems requiring a larger number of rules. Coping with this increased rule base may result in an unwieldy system or the overhead forces it to a halt.

3.5 Arguments for and against the use of fuzzy logic

3.5.1 Resistance to fuzzy logic

There is residual scepticism associated with the use of fuzzy logic despite its successful application in many areas. This has been put down to the lack of a solid mathematical reasoning on which to base fuzzy principles. This absence of rigour appears to challenge western minds. However in the Far East fuzzy logic has been enthusiastically received and developed for at least 20 years, and the Japanese are now far advanced in understanding its advantages.

3.5.2 Other commentaries on fuzzy logic

Even proponents of fuzzy logic question its validity. Elkan[29] asserts that the premise within fuzzy logic is merely binary and that rules are ignored by fuzzy controllers operating on a 2 state system. In effect he maintains that fuzzy logic collapses to binary and cannot be multi valued. This is however disputed by Nguyen [30]. A hypothesis is put forward for a 'commonsense equivalence' mathematically different from the two valued equivalence claimed by Elkan. Another criticism is that fuzzy logic has demonstrated success mainly when used in embedded controllers but theoretical work deals largely with reasoning and knowledge representation

Stability has been one of the central issues since Mamdani's pioneering work [31]. "Most of the critical comments to fuzzy control are due to the lack of a general method for its stability analysis. We are still seeking an appropriate tool for the stability analysis of fuzzy control systems, though this situation is now improved." [32]. Not surprisingly even this statement has aroused intense debate! Zadeh contends that stability is not an issue in process control, as long as there are sufficient rules to account for all events. Mamdani states that stability analysis cannot take place without an accurate mathematical model of the problem domain. Complex plants, such as cement kilns, cannot be accurately modelled mathematically.

"The fuzzy controller design methodology primarily involves distilling human expert knowledge about how to control a system into a set of rules. While a significant amount of attention has been given to the advantages of the heuristic fuzzy control design methodology... relatively little attention has been given to its potential disadvantages. For example, the following questions are cause for concern

- Will the behaviours observed by a human expert include all possible unforeseen situations that can occur due to disturbances, noise, or plant parameter variations?
- Can the human expert realistically and reliably foresee problems that could arise from closed-loop system instabilities or limit cycles
- Will the expert really know how to incorporate stability criteria and performance objectives into a rule-base to ensure that reliable operation can be obtained? "

Source D.F. Jenkins and K.M. Pasino, "An Introduction to Nonlinear Analysis of Fuzzy Control Systems," J. Intelligent and Fuzzy Systems, Vol. 7, 1999.

It has also been argued that the main reason for the popularity of fuzzy logic amongst programmers and scientists is the reduced learning costs associated with its application. This ignores the undoubted evidence presented by numerous researchers in all aspects of control theory. These have provided research showing fuzzy systems to outperform conventional systems by:-

- Reducing the development cycle
- Consuming less resources
- Responding more quickly within the control cycle
- Being adaptive to changes
- Providing a more robust response in the event of failure or unknown events

Table 3.4 Timescale for fuzzy development

LEARNING FUZZY CONTROL	*Timescale*
• Working pragmatic knowledge of fuzzy sets and membership functions	1 week
• Working pragmatic knowledge of Mamdani method	1 week
LEARNING CRISP CONTROL	
• Differential equations	8 weeks
• Linear algebra	10 weeks
• SISO servos	14 weeks
• State space methods/stability theory	14 weeks
• Optimal control	8 weeks
• Multivariable robust control	14 weeks

(Source Michael Athans – MIT 1999)

3.6 Conclusion

This chapter defines fuzzy logic and describes the individual components that make up the fuzzy logic engine. Examples of problem domains are given to explain the concept of imprecision. Scepticism of fuzzy logic exists within the scientific community and arguments for and against it have been debated. One notable is Elkan, who maintains it is merely an extension of binary logic and cannot claim to be a new mathematical system. If Elkan is taken at his word fuzzy logic has failed in proving it is a multi-valued system. Despite this, rules for multi-valued systems hold true for fuzzy calculus. For this reason fuzzy is an incomplete system. Since fuzzy can not disprove that it is only a binary valued system it is also inconsistent. Goedel's theorem suggests that this does not matter since a system can be complete yet not be consistent.

Critics of fuzzy logic also point out that other forms of multi-valued logic are more comprehensive and therefore more effective. Neural networks have roots in Lukasiewicz logic a process that is complementary to fuzzy logic. In general Lukasiewicsz logic is used mainly in micro-electronic circuits rather than computer processors. This is not the case though for fuzzy systems. In fact computer scientists have used fuzzy logic to very effectively develop mission critical systems for a wide variety of applications. Perhaps the best conclusion for the artificial intelligence community is 'horses for courses'. Fuzzy logic may not be rigorously based in the same way as binary logic. It does however work and proven results for it have been recorded.

Chapter 4

Quality of Service mechanisms and process management

4.1 Introduction

This research has concentrated on the need to develop QoS mechanisms for wireless networks. Chapter four looks at QoS in detail concentrating specifically on mechanisms for regulation. The primary standard for QoS in the Internet is Resource reServation Protocol (RSVP) which operates by dividing traffic into different classes. Key QoS components are Connection Admission Control (CAC), Usage Parameter Control (UPC) and Multipriority Control (MPC). This chapter reviews the literature and covers the research into different implementations of these QoS components. We discuss fuzzy implementations in the literature (where they exist) of CAC, UPC and MPC. A novel approach to providing QoS using fuzzy logic is proposed. This forms the main experimental work in the thesis. When data passes through a network gateway the packet scheduler is crucial to ensuring successful transmission. The gateway has to allocate priorities for each process and prevent transmitted packets from being discarded or lost. The chapter concludes by describing a fuzzy scheduler designed to improve queue management in a wireless gateway.

4.2 Quality of Service in packet switched networks

4.2.1 What is Quality of Service?

We start with a definition of quality and the mechanisms and regulations associated with it. Quality of service is the generic term applied by the IETF to define the levels of service applicable to the different traffic classes transmitted across packet networks. In the past when the Internet was used largely for the transfer of static data files these distinctions were either inappropriate or unimportant. However with the move to integrate classes of traffic such as voice over IP (VOIP) and video over IP, a new model is required for packet switching. In order to understand packet switched traffic it is useful to define flows according to their behaviour. Flows fall largely into two categories. The first category is high priority requests to be completed within a short space of time. These have an intrinsic rate that must be preserved by the network. Examples include real-time video and audio sources, and voice/video over IP phone calls. Secondly there are requests with no time limits for completion. These correspond to the transfer of digital documents. Here the rate adapts to the available capacity of the channel. These types may alternatively be characterized as, either Type A (stream) or Type B (elastic) flows, the former depending upon duration and variation in rate [33]. In general video and voice traffic is delay sensitive and responds badly to network 'squeezing'. File Transfer Protocol (FTP) traffic and other one way file transfer application such as e-mail are more tolerant to bandwidth variations. Inevitably the conclusion is that video applications should receive a higher priority than simple byte stream transfers such as FTP.

4.2.2 Resource Reservation protocol and priority

At present it is not possible to make end to end guarantees for QoS within the Internet. Where network providers offer QoS to customers it is through priority classes. Traffic is divided into classes with different levels of priority, with each class having an agreed minimum bandwidth. This guarantees a pre-determined service level to each class. The IETF requires that these QoS levels be implemented using Resource reSerVation Protocol (RSVP [34]).

RSVP defines three classes of service:

- Best-effort Service Differentiated Services (DiffServ [6]):
- Guaranteed service [35]: bandwidth, bounded delay and no-loss guarantee
- Controlled load [36]: approximates best-effort service in a lightly loaded network

DIFFServ is a coarse grained procedure, all flows from the sending gateway are treated according to the particular service level agreement with that destination. DiffServ maps services with different levels of "sensitivities" to delay and loss. That is, without being associated with explicit values or guarantees. It does not attempt to guarantee a level of service. Packets are classified and marked to receive a particular per-hop forwarding behaviour (PHB) on nodes along their path. The IETF has recently specified two PHBs namely, Expedited Forwarding [37] and Assured Forwarding [38]. Integrated Service Framework [7] for the Internet (INTServ) also exists but it has proved difficult to scale since it is a fine-grained process that involves management at individual flow level.

When a flow is transmitted from network to network, the procedure for implementing QoS is approximately as follows. Flows are checked to ascertain the service class. Packets are then sent to different input queues within the gateway depending on the service class. They will then be processed and transmitted to the next gateway. Processing will depend on the priority allocated to each class. Individual packets may be delayed as part of scheduling or discarded due to a congestion response. RSVP is not yet widely accepted and has no method for implementation in wireless networks. Without universal adoption RSVP cannot provide end to end guarantees. In addition it imposes a penalty on RSVP aware applications and is subject to delay and latency. At present there is no built in support for

RSVP in the 802.11b standard. These are some of the reasons why RSVP is not a first choice for implementing QoS in wireless networks.

4.2.3 Implementing QoS

There are three key components used to implement QoS in packet switched networks. These are Call Admission Control (CAC), Usage Parameter Control (UPC) and Multi-Priority Control. To provision a network effectively the provider needs to ensure that traffic is not allowed to saturate available channels. CAC works by preventing over utilisation of network links. CAC supports QoS by restricting admission calls if they are have no chance of successfully completing. At first CAC was confined in the main to ATM networks. In the Internet CAC implementations must conform to the standards defined by RFC's 2205,2211,2212. The second component UPC prevents an overuse of the network by any one flow. Each user is limited to the amount specified in the traffic contract or that requested at the admission point. The restrictions imposed by UPC ensure that all users have reasonable access to the network. This prevents any one flow from consuming all available resources. Flows in excess of the agreed traffic contract are delayed (smoothed) to control the sending rate. Rate smoothing is a provider facility at the user - network interface whilst UPC is part of end to end rate control at the public – network interface. Smoothing usually occurs at the sender whilst UPC is a function of a network buffer. The primary focus of smoothing is to delay rather than discard packets since there may be no competing flows existing within the sender buffer. A network buffer initiating usage parameter control may delay or discard packets depending on the circumstances. Packet scheduling is the means by which both UPC and rate smoothing is achieved. Packets are transmitted from link to link at a guaranteed rate. They are directed to queues at gateways and then transmitted according to the packet scheduler for that queue. Interrupting packet flows at specified intervals controls the committed rate for that queue. These are generic mechanisms for all packet switched networks. To provide packet scheduling it is necessary to design a robust buffer manager, with very accurate timing mechanisms.

Traffic needs to be organised according to traffic class by creating different priority queues for traffic classes. Multi-priority Control (MPC) was discussed in Chapter two and is a widely used technology. Usually it is implemented as Class Based Queuing (CBQ) in core routers. MPC has also been implemented successfully in packet radio networks. Mobile wireless transmissions are currently managed by segregating wireless traffic into access types to reduce the potential for different service classes to disrupt other user communications. CBQ plays a part in congestion management, and also minimises latency in delay sensitive traffic. Fuzzy logic can be applied to CAC, UPC and MPC to enhance their efficiency. There are also routing and diagnostic imperatives in addition to this that can benefit from using fuzzy logic. Routing decisions are required by network gateways of all types to provide connections for network flows. These decisions include link setup and tear down as well as re-routing traffic after a link failure. Information about network conditions must be transmitted to the provider along with network users. Means by which failure or impending failure can be detected are vital. Fuzzy logic controllers are ideal for monitoring to discover possible signs of network degradation or collapse.

4.3 Review of literature relating to QoS and fuzzy applications

Early proposals for QoS centred upon the use of CAC within ATM networks. This was rapidly extended to include UPC and by 1996 CBQ within integrated packet switched networks that were not ATM based. In due course researchers have looked at how fuzzy logic could enhance these mechanisms still further, as described in Section 4.3.1.

4.3.1 Overview of Research on Connection Admission Control (CAC)

Most of the approaches consider admission control related to ATM networks and involve inserting some form of fuzzy controller into the CAC platform. These approaches generally modify the conventional measurement based approach. This assesses the overall number of flows, to judge the impact of additional streams if accepted. Chen [39] proposes that the admission controller determine if the worst case delays of the requesting and existing connections can be satisfied given the available network resources. If so, the CAC allocates appropriate network resources to the requesting connection. The system uses fuzzy logic to capture the knowledge for adapting its strategy to dynamic systems. This policy is termed adaptive admission. The main concern with this strategy is it appears difficult to implement and focuses on ATM networks. Fontaine [40] looks at the AAL layer of an ATM buffer. The CAC procedure is able to determine online the Cell Loss Probability (CLP) that a connection will exhibit when accepted into the ATM network. Unfortunately the paper's details are vague about the effectiveness of this approach.

Piyaratna [41] considers using genetic algorithms to tune a fuzzy logic controller. The controller makes decisions on whether or not to admit a request by monitoring the network for sign of congestion. The model under development had only been tested as a simulation with OPNET and relates to ATM only as at 1998. Measurement based admission policies [42,43,44] sample network traffic at intervals to determine peak and average loads then decide whether new admissions will increase the aggregate load. This is preferable to the standard method of connection acceptance that takes either an optimistic or pessimistic view of load but no measurements. This can result in network under utilisation or severe congestion if the network is not correctly provisioned. The approach taken within this thesis has some points of comparison to that pursued by Elek [45]. It consists of sampling traffic over a series of intervals to establish usage and error levels. Based on these results a decision is made on whether or not to accept a connection. The advantage of this approach is simplicity, immediate response and low overhead imposed by the monitoring equipment. The results from previous work [46] confirm the value of a CAC policy in negotiating successful transmission.

4.3.2 Overview of Research on Usage Parameter Control (UPC)

Connection admission is only the first step in providing quality of service within an integrated packet network. Once a call is accepted the gateway manager needs to regulate and separate potentially destructive transmission flows. When UPC forms part of a connection control policy, it seeks to prevent networks from becoming over burdened by competing requests that cannot be met. If a network request is unlikely to succeed it is rejected. The net result is that only successful requests are accepted, and all accepted requests should obtain a reasonable response. The process of ensuring that bursty traffic is isolated from other flows is termed traffic policing. This includes rate smoothing or traffic shaping and Usage Parameter Control (UPC). It could be argued that rate smoothing is a special case of UPC not requiring the involvement of a network provider. Rate smoothing usually involves the provision of a buffer at the sending station acting to delay traffic should it exceed a set packet rate. UPC is implemented at a network-network interface and may result in the discarding or dropping of packets that violate the traffic contract. The packet scheduling process is similar, irrespective of whether or not UPC or rate smoothing/shaping occurs. It is the management and positioning of the mechanisms that vary. In any event the fuzzy approaches to implementing these features are similar.

Tsang [47] proposes a method of shaping traffic in order to force conformance to the traffic contract. Real-time variable bit rate traffic is compressed within buffers, to ensure a uniform cell rate without major variations. This results in traffic entering the network at 'an almost constant bit rate'. Hu [48] considers Usage Parameter Control (UPC) using a self tuning fuzzy controller to apply feedback signals to normalise buffers for Available Bit Rate (ABR) traffic. The above work relates to ATM networks, however some work has also been done using fuzzy logic within rate control of packet switched networks. Loukas [49] suggests a Fuzzy RED mechanism for dropping cells if they don't conform to the token bucket specification. This approach would seem to result in a loss of cells and has not yet been implemented in a production network. The approach considered in this thesis moves away from the conventional method of rate policing though it incorporates accepted procedures such as maximising statistical multiplexing gain.

Traditional methods of implementing UPC involve applying the GCRA. Cells arriving at the ingress point are issued with tokens at a set rate. Any cell without a token is determined to have violated the bounds for its cell rate and is then discarded or has its priority changed. The rate is set within the traffic contract at the admission control point and is based upon the peak cell rate, average cell rate and maximum burst tolerance.

The leaky bucket generates one token for every cell at a constant rate. Therefore it is simple to calculate the incoming rate and to implement a cell shaping policy, though some work must be done in providing optimal parameters for the token policy. Applying the GCRA to wireless networks may not be so effective as the bandwidth delay product varies according to the channel state. This is due to the error prone nature of wireless traffic. Flows are naturally bursty [49], they will inevitably be penalised, as the link state changes. The peak rate needs to be set at a level to maximise traffic flows whilst allowing a suitable burst tolerance. The outcome of this is that the leaky bucket algorithm poorly characterises the traffic pattern. Also reducing the rate may be straightforward but increasing it in the event of a heavily loaded wireless link is more problematic.

When computers use store-and-forward packet switching, they use a given link only when they send a packet. As a result, the same links can be used efficiently by a large number of intermittent transmissions. This method of sharing a link among transmissions is called statistical multiplexing. The capacity of the outgoing link may be smaller than the sum of the incoming channel capacities. The ratio of the total incoming capacity to the outgoing capacity is called the multiplexing gain. By making use of statistical multiplexing it is possible to set a higher average cell rate than the theoretical link capacity. This supports link provisioning and avoids the need to impose an overcautious rate on incoming flows. Statistical multiplexing gain can be used as a performance indicator. By measuring the gain when UPC is applied, it is possible to describe the effectiveness of the shaping policy.

Wireless 802.11b devices can benefit from statistical multiplexing, and rate control. The fuzzy logic controller described in this work periodically measures the rate of transfer from the sending device. It will then adjust the transmission buffer size, and enforce a delay. The output rate when measured is very close to the desired rate required to ensure cells conform (average cell rate). Through these actions, the controller *actively* maintains the rate as closely as possible to the conformance target. In the face of competing flows the controller co-operates to reduce the flow and avoid congestion. Since UPC is imposed at the transmission device, there is no need to maintain per flow state in the gateway, so reducing memory requirements.

4.3.3 Overview of Research on Multipriority Control (MPC)

The third mechanism for providing QoS is MultiPriority Control either in the form of Unequal Error Protection (UEP) or Class Based Queueing (CBQ). An example of UEP is the transmission of codes in WCDMA. Here the compressed signal is split into different channels, and each channel has different priorities assigned. One side effect is that partitioning the signal may increase bit rate. Any error detection scheme will involve changes to the MAC layer of the transmitter. Unequal error coding imposes hardware and software overhead in the form of some kind of decoding device, ultimately this is expensive and involves production issues as well as problems with legacy equipment.

The other alternative of CBQ is a router management algorithm that divides user traffic into a hierarchy of classes based on any combination of IP addresses, protocols and application types. In a sense it is a corollary to UEP but implemented at the network rather than the MAC layer. Class based queuing [9] has been applied to link sharing mechanisms to support different traffic types, and to ensure that priority is given to delay sensitive traffic.

The IETF defines seven classes of traffic.

A. Network Control; High requirement to maintain and support the network
B. Voice; less than 10 millisecond delay
C. Video; less then 100 millisecond delay
D. Controlled Load; some important application
E. Excellent Effort; Best Effort for important users
F. Best Effort; ordinary LAN priority
G. Background; bulk transfers, games etc.

The ITU-T (ITU-T G1010) recommendations for latency of packet transfers:-

Conversational voice/video	100 ms
Voice/video messaging, web transactions	1,000 ms
Streaming audio/video, File Transfer Protocol	10,000 ms
Fax and background transfers	1000,000 ms

A software approach based on CBQ can fit comfortably within current IETF transmission standards for QoS and co-operate with existing 802.11b devices. Because it works at the network layer, CBQ provides the same benefits across any Layer 2 technology and is equally effective with any IP protocol, such as TCP and UDP. It also operates with any client or server TCP/IP stack variation, taking advantage of standard TCP/IP flow control mechanisms to control end-to-end traffic. CBQ has several benefits notably that it restricts competition from low priority traffic. CBQ also prevents head of line blocking allowing other receivers to 'jump the queue' if the primary link is blocked [50] and is relatively simple to deploy. By improving link efficiency CBQ also reduces bandwidth costs.

There are some examples of fuzzy logic based research in the literature relating to CBQ. Fuzzy approaches have largely been used in ATM networks [5,39,40,47]. Ascia [5] focuses on Cell Priority Control (CPC) ensuring during times of congestion that high priority traffic remains unaffected, by low priority cells already admitted by the call admissions policy. TCP-LP [51] focuses on providing non-intrusive transmission for low-priority flows. This protocol has been tested within simulations and requires application sensitive software to operate. It performs similarly to unspecified bit rate service in ATM networks by making use of redundant link availability for elastic file transfers as background transmissions. TCP-LP uses algorithms to determine advance congestion indicators and is probably too complex for use in low value wireless access points. There are no fuzzy TCP-LP examples.

Random early detection (RED) is one mechanism by which CBQ implements drop or delay packets at the queue level. Packets are divided into traffic classes, and the queue manager makes the decision to drop any packets. Decisions in RED are based on queue length. Fuzzy RED [49] is a refinement of ordinary RED techniques using fuzzy logic. The general view now is that as a queue management method RED is limited and can increase congestion through unnecessary retransmissions. Etemazedine [52] presents a design for a Proportional Integral Derivative (PID) controller tuned using a fuzzy system. This provides a differentiated queuing system for Internet traffic loosely based on DIFFSERV classes. As soon as congestion is detected the PID controller implements a CBQ drop and delay algorithm. The limitation here is that it is a simulation and not tested in practice. PID controllers also do not work well for non-linear systems or systems which have no precise mathematical models [52]. Zhang [53] proposes a limited drop and delay prioritisation based on differentiated traffic. Fuzzy heuristics are used and the types are differentiated as real and non-real time traffic. This is a coarse grained approach to packet scheduling within core routers across Internet links as opposed to edge gateway connections and the model is only at the simulation stage. The approach however has merit if only to confirm the design presented here.

Chapter Two discussed congestion control mechanisms used by wireless and wired networks. Errors in wireless transmission may trigger congestion control actions even when the system is not heavily utilised. Queue buffers may increase in wireless gateways experiencing large background transmission errors. The congestion controller may see this as evidence of congestion and arbitrarily drop packets. Servicing queues on wireless gateways requires more refined methods of detecting congestion events and there is no evidence that the examples discussed here would work across wireless networks. In this project the focus has been on implementing a limited form of CBQ for a wireless gateway that can distinguish between useful and not so important transmissions and prioritise them. In addition a distinction is made between different MPEG frames to maintain a reasonable signal to noise ratio (SNR). Periodic latency checks are made across the network and the link is then classified as good, satisfactory or unsatisfactory using a fuzzy pre-processor. The gateway access point is kept informed of the current network state. Queues at the access point may contain video, voice or data packets. If there is any problem with network latency time sensitive packets are prioritised whilst ordinary data packets may be retarded for a short period. If an I frame transmission is in progress the UPC controller marginally increases the buffer size. Applying a higher priority to I frames helps ensure that the quality of a video transmission is maintained even across a heavily loaded circuit

4.4 Processor management

4.4.1 Importance of processor management

This section considers the deployment of a time division multiplexing process scheduler using fuzzy logic to enhance performance for multimedia applications. In addition the environment and methods of mitigating its impact on RF transmissions are also studied. Details of the design of the process scheduler are provided in Chapter 5, the significance of these processes and their context within this thesis are debated below. At the root of all successful computing applications is the satisfactory management of their component processes, by the operating system. This applies whether the product is a multimedia application providing streaming video, or a simple print task from a word processor.

4.4.2 Effect of poor process management on performance

Despite significant advances in technology, general-purpose operating systems such as Windows 2000 or LINUX are still not efficient in real time at managing diverse applications. The result is processes contend for processor time on personal computers and in some cases do not receive a fair share of their allocation [54]. This contention prevents applications receiving maximum benefit during their run cycles. The situation is magnified when applications span multiple networks. Networked programs are subject to phenomena such as delay and jitter and sometimes data is completely lost and requires resending. Generally when threads are repeatedly executed by a function the execution times are similar for long periods and then increase dramatically. This is known as burstiness. Examples of burstiness have been observed whilst measuring cyclical processes during the construction of the fuzzy process scheduler. This will occur even on lightly loaded systems and seems independent of other processes currently in operation [4] though it could relate to buffer starvation. Burstiness may contribute to the failure of many applications - especially long running processes - to complete satisfactorily. When this effect is magnified across networks it produces unreliable results leading to poorly performing systems particularly in packet scheduling. Some examples of this might be the downloading of an excessively large file from an FTP site or the delivery of a real time video application across the Internet. Workstations have many uses. An individual may word process a document whilst listening to (or watching) a live Internet broadcast and simultaneously printing. During this time the machine is available for receiving email. All these tasks place burdens on the processor since they require the continual use of peripheral equipment for storage and input/output. The processor is constantly polling these devices for instructions to be executed. In turn the operating system must balance the priorities of all these tasks. This allocation has to be fair to provide user satisfaction.

4.4.3 Process priority

There is evidence to suggest that processor scheduling does not produce a fair result for all processes. In fact whilst certain processes are generally given a high priority in order to complete within predetermined bounds others lose process time constantly. Overall this leads to deterioration in performance of all processes within the system [55]. Observations indicate that tasks scheduled at the same time (within the same process) - irrespective of the peripherals they use will complete within the same timescale. Therefore if the operating system deliberately assigns a higher priority to one device, the lower priority thread retards the performance of the higher priority one. This happens even if one input/output (i/o) device has a higher priority than another - typically network cards receive a higher priority than disk controllers [56]. The net results are that overall the user sees a degrading of performance, slow printing and file copying, poor reception of broadcasts etc. A carefully tuned machine however, can demonstrate increased performance even with older components. For instance a machine with Ultra Direct Memory Access (UDMA) enabled in software can improve hard disk i/o by up to 40%. Other performance improvements include making use of peripherals incorporating Direct Memory Access (DMA) within the firmware as for instance printers supporting enhanced capabilities port (ECP), or network interface cards with buffer memory.

4.4.4 Conditions for process scheduling

The problem is to adequately manage the resources provided by the operating system for the benefit of all running processes. As the intention is to improve existing performance two conditions set by third party schedulers can be discounted.

1 Real time systems need to be deterministic in accepting and running tasks. Here there is no need to derive bounds on performance guarantees as Fuzzyscheduler is not guaranteeing real time performance at present.

2 To obtain performance improvements, it is not necessary to change process priorities. In fact in a non-deterministic environment such as the Internet any attempt to modify priorities could severely impact performance of the machine in general. Observations have shown that arbitrarily changing process priorities can retard completion times substantially. In a real world context it would be impossible for running programs to manipulate their place within the process queue, and the scheduler takes this into account in determining improvements.

Manipulating processes with kernel mode device drivers can also have an impact on overall performance. For example a graphics device driver may deliberately steal cycles in order to improve its own performance, by exploiting its higher priority level in the process queue [55].

4.5 Proposal for a process scheduler

4.5.1 Overview of process scheduler

The proposal is to implement a resource management scheduler (Fuzzyscheduler) that will augment the existing operating system and ensure multiple processes can be satisfactorily run to completion. Its success is measured by the difference in time between running the applications in native mode and with the scheduler. The current implementation runs on Windows 98 and Windows 2000 based systems, which are examples of pre-emptive and non pre-emptive operating systems. The relevance to packet scheduling is in the ability of the scheduler to develop separate queues for improved management of flows at network gateways. For more detail on how Microsoft implements its thread scheduling algorithms the reader is directed to [57]. Some explanation for why the scheduler actually succeeds in providing a performance improvement needs to be given. Two possible reasons could be priority inversion and the removal of short term blocking interrupts. Windows 2000 automatically increments thread priorities as they are removed from the running queue. Low priority threads are incremented periodically to ensure that they are run at some point (priority inversion). By voluntarily releasing its timeslice, threads receive an inverted priority increment. This may ensure processes receive their full timeslice. The thread receives more processor time therefore than it would have achieved in a best efforts context. Operating systems run background processes that spawn short term threads. These threads may block whilst waiting on low level interrupts such as i/o calls. Suspending application processes may help to clear these blocking threads from the system since they operate over a minute time interval. As a result of this other processes may receive larger shares of processor time since they are not waiting on any blocking calls from low level interrupts. These low level interrupts may be responsible for thread burstiness (See Figure 5.1 below).

4.5.2 Scope of the project

The aims of this project component are :-

- Demonstrate how process management succeeds by aggressively suspending processes
- Evaluate whether or not prioritising traffic classes benefits delay sensitive traffic
- Compare this with traffic across a gateway where no process management was in place
- Confirm that using fuzzy logic for feedback control improves overall response

4.5.3 Implementation

The initial project brief was to develop and install a resource manager for process scheduling. The intention is to improve overall performance rather than individual user tasks. Three choices were available to determine the most appropriate inputs for the resource scheduling. These included, specific inputs encoded within the system, human intervention (hit a zoom button) or finally apply fuzzy logic. The option chosen was to use fuzzy logic to devise the optimum inputs then program these in to the system. Through the use of fuzzy logic performance improvements of up to 19% have been achieved. The main difference between the predicted outputs and the results arises from the conservative scaling factors applied within the MATLAB™ program. In each case the actual test data has followed the trends established by our fuzzy rule set. This packet scheduler was then adapted to work with the multipriority controller by aggressively suspending lower priority traffic queues. Whilst these queues were held immobile the time sensitive traffic was allowed to pass unhindered across the gateway to its destination.

4.5.4 Application of fuzzy logic

The first prototype used results from a fuzzy model as a method of determining the interrupt times of the packet scheduler. Further work is being undertaken to incorporate a dynamic fuzzy controller in the packets scheduling element. The advantage of this is the option to incorporate an adaptive element within the fuzzy control. Once a rule set had been developed it was tested. The rule base can then be refined through successive iterations to reach an optimum. The time saved in development terms in using the Fuzzy Logic Manager is substantial. Scaling the system increased its accuracy. This has implications for the efficiency of client-server based applications and their management. Fuzzy logic has allowed us to reduce the state space of our search environment dramatically. We can also apply the same heuristics in further development work related to multimedia applications. The outcome of this is to reduce the energy consumption of the processor whilst improving its performance substantially. The benefits for wireless based systems installed in laptops this and for any externally mounted systems are profound.

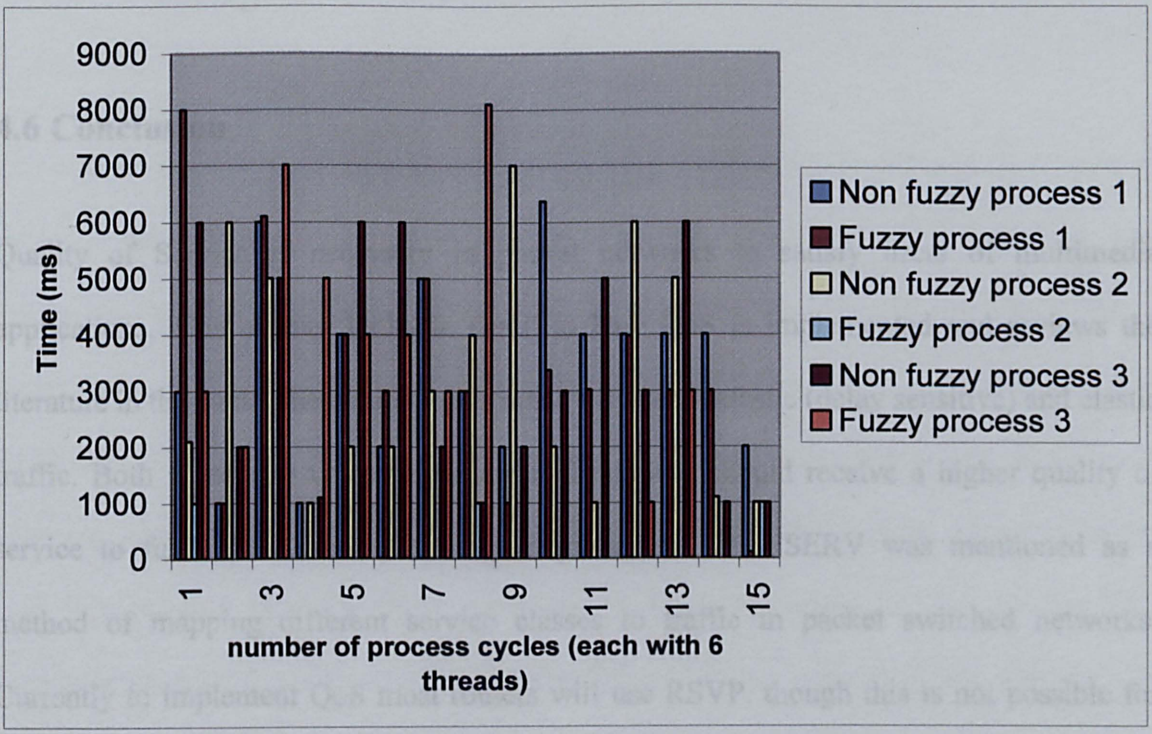


Figure 4.1 Time taken for each process in file copy

All three processes in the fuzzyscheduler were run repeatedly. Each process contained two threads one of which was interrupted by the fuzzy controller whilst the other ran without interruption. The results are shown in Figure 4.1 above. These results indicate how successful the fuzzy controller was in reducing the overall time for process completion.

4.6 Conclusion

Quality of Service is necessary in packet networks to satisfy users of multimedia applications. This chapter looks in detail at how QoS is implemented and reviews the literature in this area. The distinction is made between inelastic (delay sensitive) and elastic traffic. Both video and voice traffic are inelastic and should receive a higher quality of service to fulfil their minimum delay requirements. DIFFSERV was mentioned as a method of mapping different service classes to traffic in packet switched networks. Currently to implement QoS most routers will use RSVP, though this is not possible for bridges such as 802.11b access points. There are three key components to providing QoS in packet networks. Connection admission limits the level of traffic by refusing calls that may exceed available capacity; Usage Parameter Control ensures that individual flows are prevented from impacting traffic generated by other users; Multi-priority control (class Based Queuing) prioritises delay sensitive traffic over elastic file transfers. These components have not been implemented in contemporary 802.11b wireless devices. A brief explanation of techniques where fuzzy logic can be applied in packet switching has been supplied. At this point the focus is shifted to research into the key QoS components and the application of fuzzy logic to enhancing their operation.

The chapter went on to discuss the importance of processor scheduling and its relation to packet scheduling. The key issue here is one of priority. Most network transmissions may fail to complete due to process starvation if their flow priority is too low. This is particularly true for small flows in networks that may fail using queuing techniques such as RED since such flows have the lowest priority. A scheduler guarantees that all accepted processes receive sufficient time to complete irrespective of their queuing priority. Chapter four introduced a proposal for a new process scheduler based on fuzzy logic. This scheduler ensures that all processes receive a fair share of processor time and actively readjusts process scheduling to achieve this.

Chapter 5

Methodology and Design

5.1 Introduction

This chapter looks at the research methods employed to support this thesis. We give an overview of primary and secondary research methods and explain the choice of methodology. The chapter discusses the mechanisms used for collecting data and details how the conclusions are validated. Different means were used to collect the data upon which the research is based. A weather station was used to measure the environmental impact on RF transmissions. Statistics relating to network traffic were gathered using Simple Network Management Protocol (SNMP) polling of all equipment. MatLab™ has been used to develop fuzzy simulations and for graphical presentation, whilst the fuzzy controller was constructed from C++ routines developed specifically for that purpose. The section on design explains the research objectives and how the design must fit these aims. Details of the project design are provided. The components include a fuzzy Connection Admission Controller, a separate fuzzy Usage Parameter Controller, fuzzy Scheduler and fuzzy MultiPriority Controller. The design describes the fuzzy rules as well as the operation of each device.

5.2 Methodology

The previous chapters were primarily concerned with establishing the background and constructing a case for the thesis. The introduction proposes that QoS is necessary to successful wireless video transmission and that fuzzy logic can enhance QoS. A synopsis of existing use and future developments within the wireless community is provided to justify a new approach to wireless transmission. This need for justification arises because despite rapid advancements in technology the growth in deployment of wireless appliances cannot be supported by the existing transmission infrastructure. As packet switched networks are now the *de facto* method for communication within the Internet it helps to understand their limitations and advantages. Chapter One describes current technology whilst providing an overview specifically for wireless networks. Reasons for the choice of fuzzy logic for feedback control are given in chapter Two. To improve video transmission we need standards to regulate manufacturers products and ensure interoperability across networks. Chapter Four details current Internet regulation relating to Quality of Service. Research in quality management for packet switched networks is discussed, along with methods of implementing fuzzy Quality of Service. This section reviews my research methods.

5.2.1 Choice of methodology

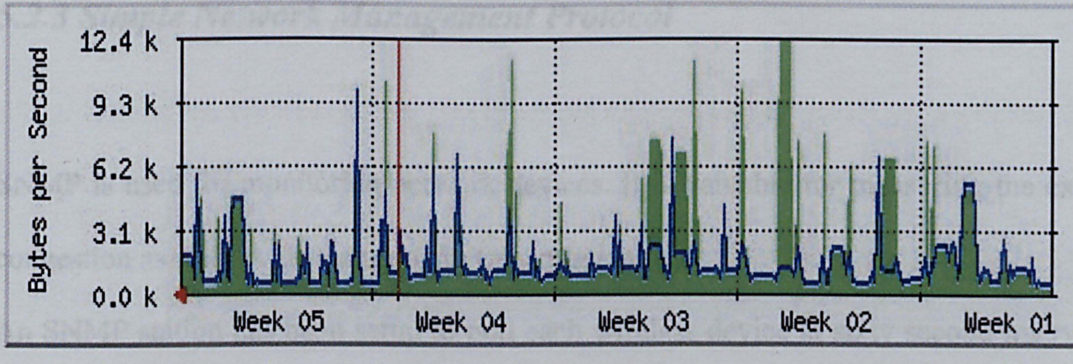
There are many reasons for selecting a particular research methodology. The computing world is one of facts and figures. Numbers are important to academic researchers. The existence of information lends credence to a particular set of ideas. In the development of 802.11b wireless networks there is very little published work around. Much of it relates to either lab simulations or measurements of internal networks operating over short distances.

The lack of research data on wireless networks has forced the adoption of a quantitative research style in order to provide material for the thesis and to create the data needed. The approach used involves generating research data from measurements taken during daily network operation. Both primary and secondary research techniques have been used. The primary data sources are detailed below. The secondary research is used to explain or corroborate the data gathered from primary methods. The methods used to collect network data over a significant time frame (not less than 12 months) have been detailed in the following sub sections. An essential part of the project is the need to quickly evaluate and present information for the purpose of drawing conclusions or identifying trends. In addition a rapid prototyping tool quickly builds fuzzy logic simulations. The various research tools for data collection are now discussed.

5.2.2 Multi Router Traffic Graph (MRTG)

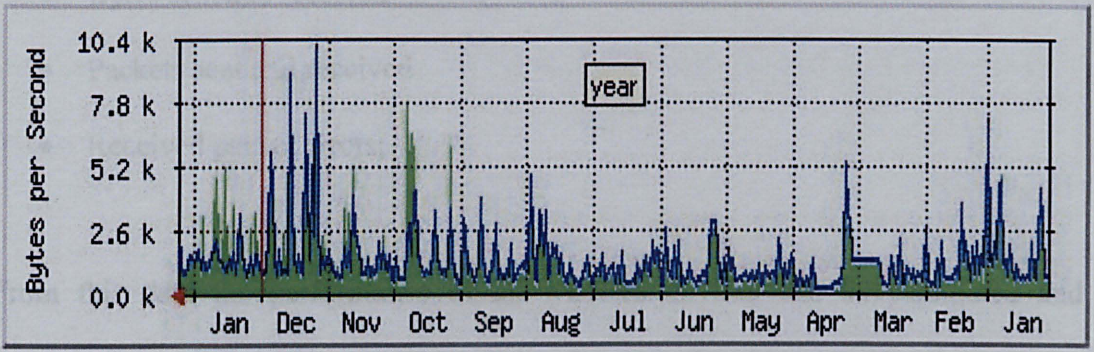
The need to monitor network usage required some form of continuous monitoring of LAN devices. Each wireless hop within the internal network and the Internet gateway are queried for information and the results are then graphed using MRTG [58]. A picture of traffic patterns has been built up since the program was initiated in 2001. The main advantage of this is cross-referencing results of experiments against the picture of network usage. Where our own tools indicated network congestion the precise level is confirmed by the MRTG output for that device at the time in question. MRTG takes the bytes across a network gateway in both directions then produces a graph based on this traffic updated at 5 minute intervals. This interval was selected because the granularity was coarse enough to depict trends over an extended period, but fine enough to show flow changes in the short term. Fig. 5.1 provides a sample of an MRTG Graph showing how the data collected from wireless access point on the network is summarised.

`Monthly' Graph (2 Hour Average)



Max In: 12.3 kB/s (3.3%) Average In:2003.0 B/s (0.5%) Current In:1633.0 B/s (0.4%)
Max Out:9800.0 B/s (2.6%) Average Out:1445.0 B/s (0.4%) Current Out:1882.0 B/s (0.5%)

`Yearly' Graph (1 Day Average)



Max In:9913.0 B/s (2.6%) Average In:1298.0 B/s (0.3%) Current In:2843.0 B/s (0.8%)
Max Out: 10.2 kB/s (2.7%) Average Out:1345.0 B/s (0.4%) Current Out:2641.0 B/s (0.7%)

Figure 5.1 Sample MRTG graphs for a wireless access point

5.2.3 Simple Network Management Protocol

SNMP is used for monitoring network devices. It is valuable for measuring the extent of congestion as well as the error rate in transmission.

An SNMP station has been setup to poll each wireless device at sixty second intervals for the following information:-

- Bytes sent and received
- Packets sent and received
- Received packet errors;

From this data the performance of all wireless devices can be calculated and then graphically displayed. Data is also available for analysis within MATLAB. SNMP data is collected from a LINUX server, processed then stored in a text file.

5.2.4 Measurement of atmospheric conditions with a weather station

Monitoring of the wireless equipment confirms that the signal quality varied during the day and also when the weather hanged. This variation manifested itself as a random error pattern and occurred even when network traffic was at a minimum. From this information it seemed possible that atmospheric conditions were influencing the error rate. In August 2002 a Davis Weather station was installed and set up to monitor atmospheric conditions that might affect the external wireless network. The station has been set up to record rainfall, atmospheric pressure, humidity and temperature. The readings taken by the weather station show a strong correlation between random error and atmospheric temperature and humidity

5.2.5 Use of MatLab™

MatLab™ is a mathematical presentation tool that incorporates a fuzzy logic toolbox. This simplifies the task of producing simulations for test purposes. Outputs from the MatLab programs were cross-referenced with independent fuzzy C++ programs to check their consistency. The outputs from MatLab were also copied to a text file then fed directly into the test design. The other use of MatLab is to present data graphically. This was necessary to support analysis of radio performance as the mathematical functions are more comprehensive than those provided by MS Excel.

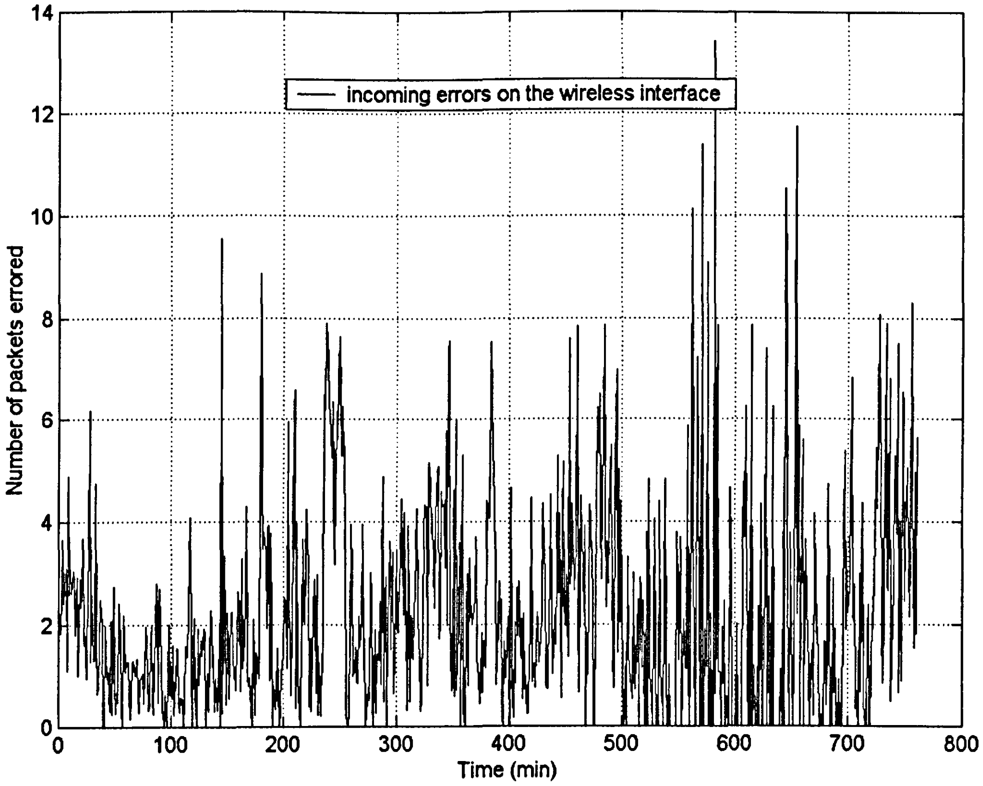


Fig. 5.2 Example of MatLab plot

5.2.6 Use of C++ fuzzy engine

Whilst MatLab was invaluable for obtaining fuzzy decisions it's operation is largely opaque to the user. Also adapting MatLab to third party programs is not a trivial task. For this reason a fuzzy engine based on C++ routines was developed. This had the advantage of providing real-time feedback to the program calling the routine. It was also useful in that the membership functions could be altered by hand coding to improve decision making accuracy. An important use for the fuzzy C++ engine was the evaluation of membership sets for investigating the truth of a population of statistics.

5.3 Network structure

Having discussed the methods of data collection it is useful to provide a description of the network as shown in Fig. 5.3 below

5.3.1 Network description

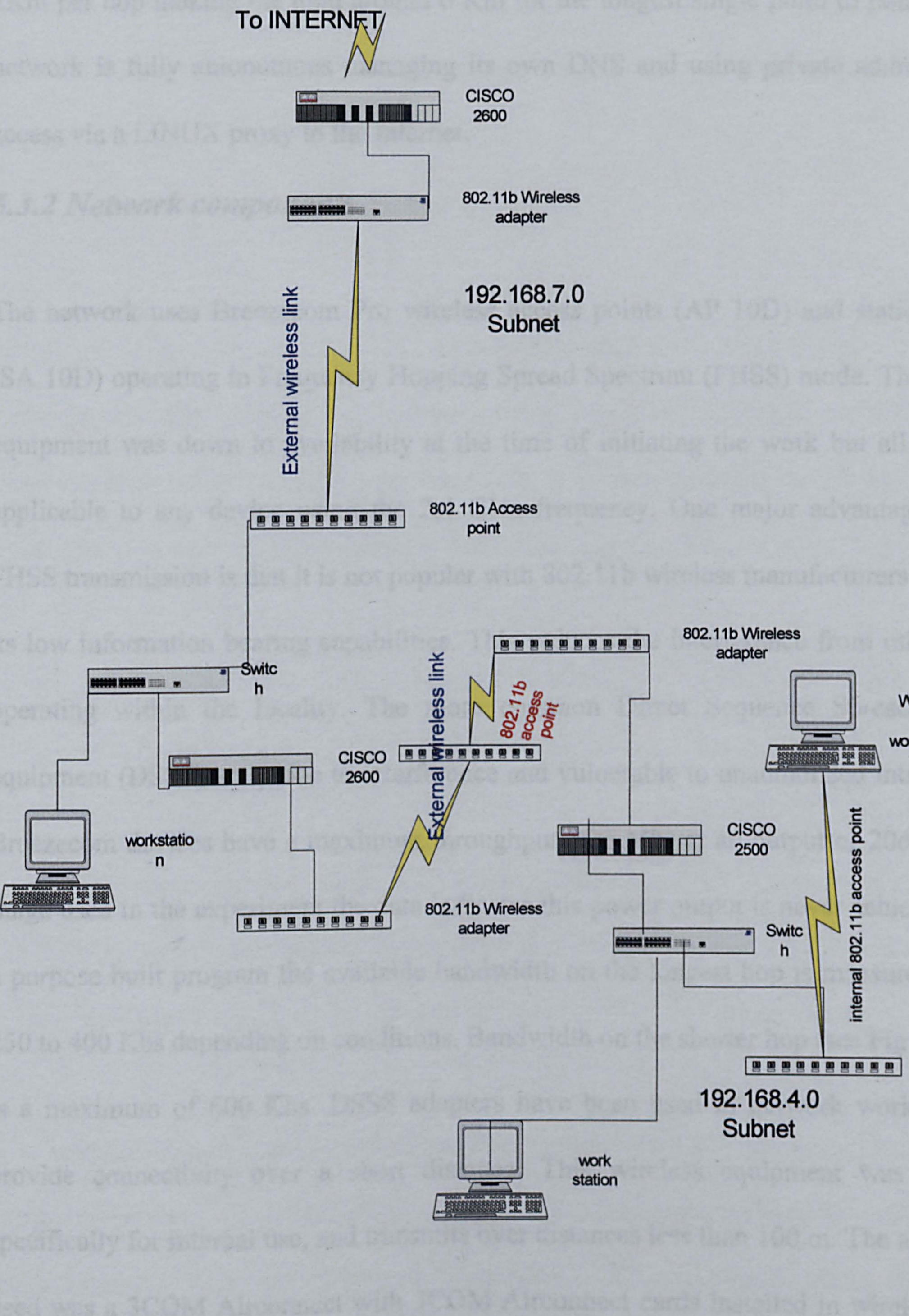


Fig. 5.3 Schematic of network used for the project

This is a local area network connected through a 1 Mbs leased line to the Internet. The last hop gateway is a managed CISCO 2610 router. The network contains two subnets linked by four wireless gateways. Each subnet supports at least 15 network devices including servers, printers and workstations and the distance between each gateway is approximately 2Km per hop making the total around 6 Km for the longest single point to point link. The network is fully autonomous managing its own DNS and using private addressing with access via a LINUX proxy to the Internet.

5.3.2 Network components

The network uses Breezecom Pro wireless access points (AP 10D) and station adapters (SA 10D) operating in Frequency Hopping Spread Spectrum (FHSS) mode. The choice of equipment was down to availability at the time of initiating the work but all results are applicable to any device using the 2.4 GHz frequency. One major advantage of using FHSS transmission is that it is not popular with 802.11b wireless manufacturers because of its low information bearing capabilities. This reduces the interference from other devices operating within the locality. The more common Direct Sequence Spread Spectrum equipment (DSSS) are prone to interference and vulnerable to unauthorised intrusion. The Breezecom devices have a maximum throughput of 3 Mbs at an output of 20dbm. At the range used in the experiment the data indicates this power output is never achieved. Using a purpose built program the available bandwidth on the longest hop is measured between 250 to 400 Kbs depending on conditions. Bandwidth on the shorter hop (see Fig 4.1 below) is a maximum of 600 Kbs. DSSS adapters have been used in network workstations to provide connectivity over a short distance. This wireless equipment was purchased specifically for internal use, and transmits over distances less than 100 m. The access point used was a 3COM Airconnect with 3COM Airconnect cards installed in wireless laptops and workstations. The 3COM equipment was capable of supporting a higher bandwidth than the Breezecom units but appeared generally less reliable.

5.4 Validation for methodology

These are the principal methods by which data has been collected during this research. The question is, are these methods reliable, capable of validation and do they possess general applicability?

5.4.1 Reliability and validation of data

SNMP as defined within RFC 1157 [59] is an accepted method for measuring network performance. Any SNMP compliant equipment should be capable of providing standard data samples for network management. Sample measurements taken by the SNMP collectors were verified in two ways to determine their accuracy.

- MRTG was used to measure network traffic between CISCO routers at each subnet then compared with readings taken from the wireless devices over the same time.

- File transfers were made with known file sizes across the network. For control purposes these transfers took place when the network was closed to other users. Readings taken from the wireless devices corroborated the transfers.

The weather station meets the MET Office requirements and providing it is calibrated correctly the data will be accurate. As a control measurements from the weather station were compared with those published by the MET Office at specific dates. An argument could be put forward that no work on microwave equipment would be complete without an analysis of the effects of interference from other equipment. As mentioned earlier the FHSS equipment is no longer widely sold within the UK and therefore is less likely to be affected by DSSS network transmissions. In view of this we have not provided spectrum analysis of wireless emissions in the locality where the equipment is situated. The evaluations made by the fuzzy logic engine and the conversions to crisp output are a matter of concern since they affect the quality of decision making by the inference engine. To ensure accuracy of fuzzy decisions MatLab simulations were generated for all C++ fuzzy routines and the results compared to see if there was any variance.

5.4.2 Use of data collection tools in wider context

Despite advances in network engineering, methods of evaluating quality of Service in packet switched networks are limited. The most common protocol TCP/IP has no procedure to announce congestion along any route. Without such detection mechanisms network transmissions will proceed even if they are likely to be unsuccessful. At present the only way routers can determine the state of a channel is to monitor duplicate acknowledgements (DUPACKS) from next hop gateways. New techniques such as explicit congestion notification [60] are now available, but these are limited to core backbone routing equipment and may not be supported across all links in end to end transmission paths. One fundamental reason for collecting network data is to develop a simple means of discovering incipient congestion and possible network collapse.

5.4.3 Application of SNMP

Most network devices are SNMP compliant and are fitted with the necessary capability to provide feedback on the state of the network. In addition the overhead imposed by SNMP collection is very small, limited to the minimal collection of data packets and the allocation of a buffer at each device. Providing there is some means to collect this information and suitable interpretation from the collector the use of SNMP can be an extremely powerful tool in network management as demonstrated in [46]. At a simplistic level one method of determining congestion in a network is to measure the bytes across an interface.

Table 5.1 Example traffic across a network interface

Time (Seconds)	Traffic (Bytes)
60	100,000
120	200,000
180	300,000
Rate	1,667 per sec

If the maximum bandwidth is 100,000 bps the link is has a roughly two percent utilisation at present and congestion is unlikely. This illustrates how SNMP supports network management.

Table 5.2 Errors across a network interface

Time (s)	Total Packets	Errors
60	1000	200
120	2000	400
180	3000	600
Error rate	20%	

The second example illustrated in table 5.2 shows the error rate for a wireless link. The substantial error rate is not due to congestion since only a few packets are being transmitted. As the link is only lightly loaded there are other factors involved. These may be atmospheric conditions or interference from other equipment. To isolate the cause of these errors it's necessary to consider other forms of data being collected for instance that supplied by the weather station.

5.4.4 Application of research methods in wider context

The findings gathered during this research show that the data being collected is important to correctly determining the operation of a wireless gateway. This in turn is essential to confirm the original hypothesis and quantify the results obtained. There is a wider context to the research. Can these methods be used to measure performance for all wireless equipment even mobile telephones? In addition is fuzzy logic a useful tool for regulating feedback of network devices and does the choice of membership function for each variable affect performance? Finally the continued monitoring of the wireless network has highlighted the part atmospheric conditions play in wireless performance. At present we can only speculate how important this discovery is for feedback control.

5.4.5 Where are the methods to be used

SNMP monitoring can discover congestion or poor performance of a system quickly and without the need to query intermediate gateways for information or wait for duplicate acknowledgements from next hop routers. Because of its low overhead SNMP is an ideal method of determining whether a link is under utilised or under performing.

5.4.6 Are there any alternative forms of data or data collection?

Explicit congestion notification is available as a means of determining incipient congestion in gateways. It however has the drawback of requiring specific implementation at each gateway and is largely unsupported at the local network level. ECN also is limited to notification of congestion and isn't suitable for wireless networks which may under perform even when there is no network loading. No standard for network management is so widely implemented as SNMP. It is cheap, ubiquitous, imposes low overhead and there are a wide variety of tools for deployment. There are security issues with SNMP but careful design can minimise the risks. This standard makes it relatively easy to take advantage of modifications without major modifications of wireless equipment, and equipment can be monitored using any web browser. DIFFSERV embraces SNMP and widens its scope but relies heavily on implementation at vendor level. This makes the use of DIFFSERV unsuitable for legacy equipment and costly to implement without a firmware upgrade. The ITU-T are currently developing Telecommunications Management Network (TMN) but this relates to the management of broadband communications and not integrated packet networks. It is not clear that TMN is likely to be deployed within Ethernet networks.

5.5 Design of project

To confirm the success of a project focus on the design aims then see if these have been realised within the design.

5.5.1 Aims for the design

This project is about improving Quality of Service for wireless devices. Designing simple implementations of CAC, UPC and MPC have been the basis for the QoS mechanisms used in our wireless fuzzy controllers. These methods of network management have been shown to improve performance. It is possible to modify existing network management for wired devices for use in wireless equipment. The monitoring data collected has shown that the behaviour of wireless equipment requires changes in the TCP/IP protocol stack to benefit from QoS techniques. As previously discussed in Chapter three these include variable packet sizes, aggressive monitoring of errors and effective packet scheduling. These considerations need to be allowed for in our design. The capability to characterise video transmissions helps network provision and ensures that priority queues can be maintained for a link near saturation. The design aim is to develop all of these services and to enhance them through the use of fuzzy logic as a method of feedback control

5.5.2 Design for negotiating call admission

The design of a Call Admission Controller for wireless networks should take account of the measured link error rate (E_R) and channel capacity (A_B).

To manage the call admissions a Mamdani fuzzy logic controller [31] has been implemented. The scope of the fuzzy connection admission controller is limited for the present to considering admissions related to Type A (inelastic) file requests. The aim is to determine whether or not transmission time remains constant for all accepted admissions. Each accepted transmission request should take approximately the same time to complete. Similar requests are made to a server that arbitrates requests based on set levels for A_B and E_R.

Outline of membership functions

For the sake of convenience the clients are programmed to make a request using the same value for the traffic descriptor (Peak Cell Rate). A fuzzy rule-base is interrogated when the client connects to the server system and makes a request for a file transfer, download etc. The metrics A_B and E_R are represented as two input variables. Triangular membership functions are used, defined as low medium and high (See Figs. 5.3 and 5.4 below). All membership functions have been normalised to 1.

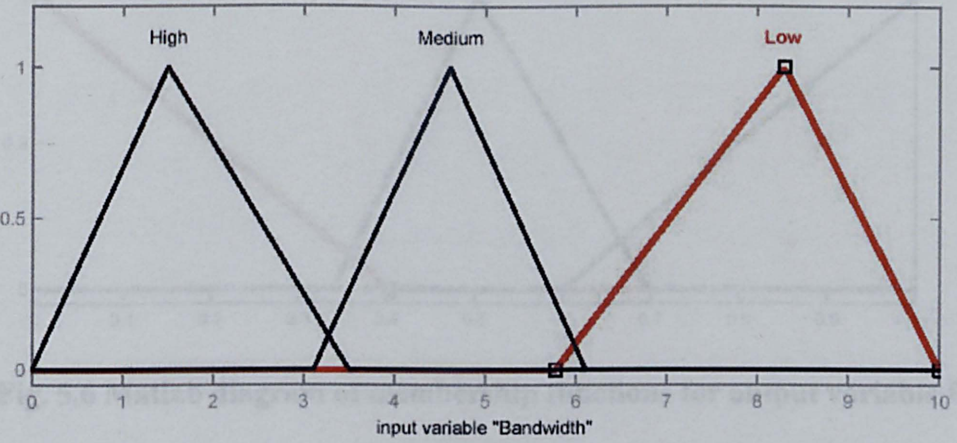


Fig. 5.4 MatLab diagram of membership functions for input variable Bandwidth

'Bandwidth' corresponds to link capacity and is a measure of the current channel availability. High indicates there is plenty of spare capacity in the channel, whilst a Low value for Bandwidth will result in a refusal due to insufficient channel capacity.

The 'Error Rate' (Fig. 5.4 below) has been set to remove bias created by the background error.

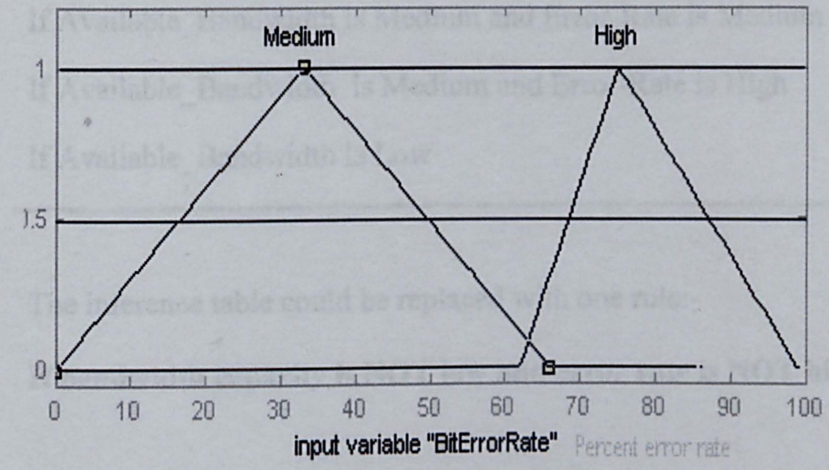


Fig. 5.5 Matlab diagram of membership functions for input variable Error Rate

The output also takes a triangular membership function, representing three choices namely, Refuse, Reserve or Admit.

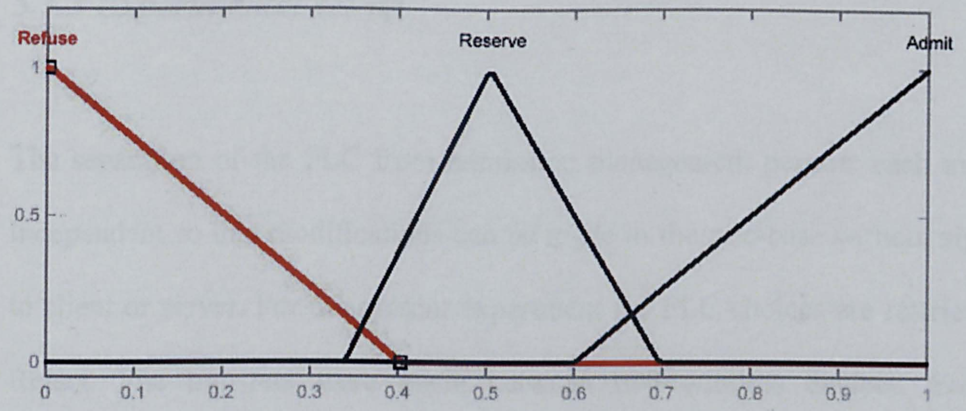


Fig. 5.6 Matlab diagram of membership functions for output variable Policy

Design of inference table

An inference table is constructed to determine the result.

Table 5.3 Inference Table for CAC fuzzy controller

Rules	Decision
If Available_Bandwidth is High	Accept
If Available_Bandwidth is Medium and Error-Rate is Medium	Accept
If Available_Bandwidth is Medium and Error-Rate is High	Defer
If Available_Bandwidth is Low	Reject

The inference table could be replaced with one rule:-

If bandwidth capacity is NOT low and error rate is NOT high then ACCEPT.

This would be limiting, since it would reject any situation where both bandwidth capacity and error rate are high. Finally crisp outputs are produced from the fuzzy resultant 'Policy'. This process, known as "defuzzification" of the results is obtained by applying the centre of average method to the resultant membership function.

5.5.3 Experimental set-up

The separation of the FLC from admission management permits each module to remain independent so that modifications can be made to the rule-base without significant change to client or server. For the present experiment the FLC choices are restricted to Accept or Reject. File transfers were made between two wireless devices. Each transmission consisted of a data stream socket to socket TCP transfer with a buffer size of 2KB. Both transfer and collection times were recorded for each 2 KB cycle. The total file size was approx 500,000 bytes and the transfer rate varied between 4 and 17 KB/s according to network load.

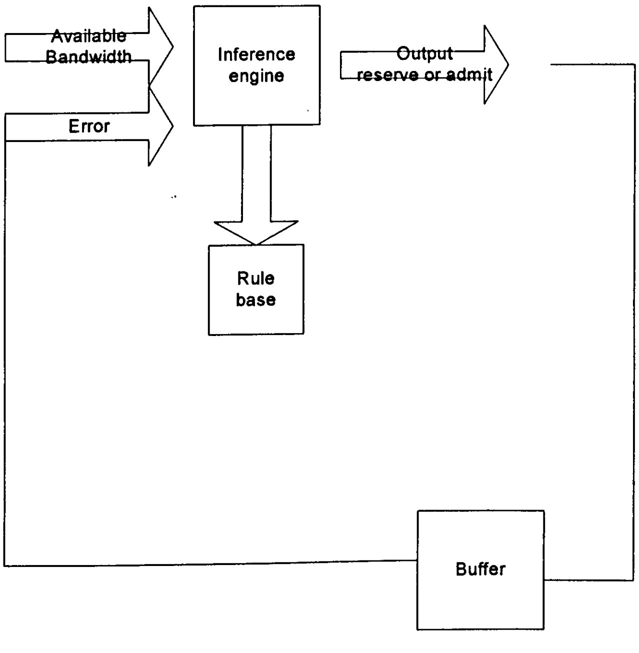


Fig. 5.7 Block diagram of Fuzzy Logic Controller

The FLC is programmed for either of two outcomes:-

A successful outcome is one where the request is accepted. This would provide bounded delays for completion times that remain within acceptable limits, satisfying QoS guarantees. An unsuccessful outcome is where the admission request is rejected. The QoS guarantee would not be honoured as the delay remains outside the bounds for that request. This outcome would occur within a heavily loaded network. The request is always rejected if the FLC considers that the request could not be fulfilled within the bounded delay time. The decision is taken by the FLC based on a consideration of the channel capacity and current error rate. Acceptance of a connection will be made only where capacity is available and the error rate is medium or less.

5.6 Rate control or smoothing

For Usage Parameter Control or 'rate smoothing' to work effectively certain parameters need to be known in advance. These parameters are the type of traffic, peak cell rate and maximum burst size

5.6.1 Design of controller

The aim here is to demonstrate that applying UPC improves performance as compared to a best efforts transmission, and to show that fuzzy logic can enhance UPC. For the sake of convenience the clients are programmed to make a request using the same value for the traffic descriptor Peak Cell Rate. A fuzzy rule base is interrogated when the server is contacted by the client and initiates a file transfer.

Membership functions

The input variable used by the fuzzy controller is Transmission rate. This has three triangular membership functions defined as slow, steady, and excessive.

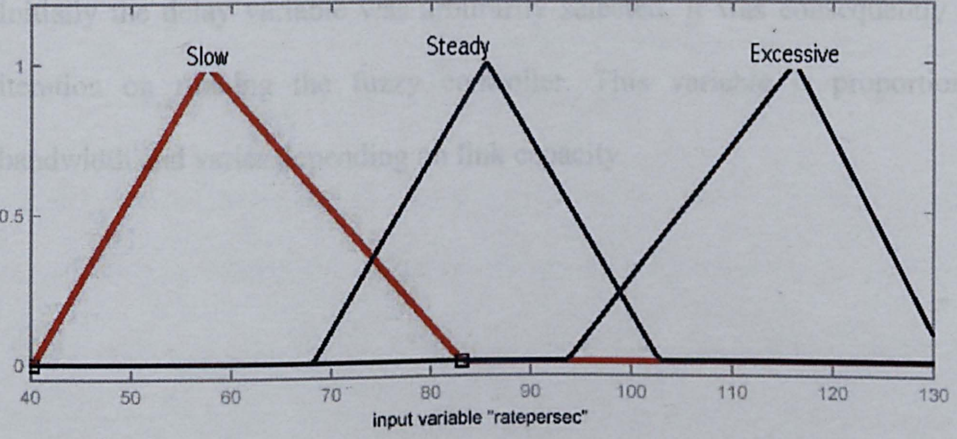


Fig. 5.8 MatLab diagram of membership functions for Transmission rate

The sending machine determines the current transmission rate and based on this the fuzzy controller selects output values for the buffer size and delay. It is this combination that ensures the transmission rate conforms to the agreed traffic contract. Experiments have shown the average buffer size for an 802.11b packet is in the region of 500 bytes. Large packets are prone to error. Smaller packets are more reliable. As in any ethernet device, packet aggregation occurs under load [46].

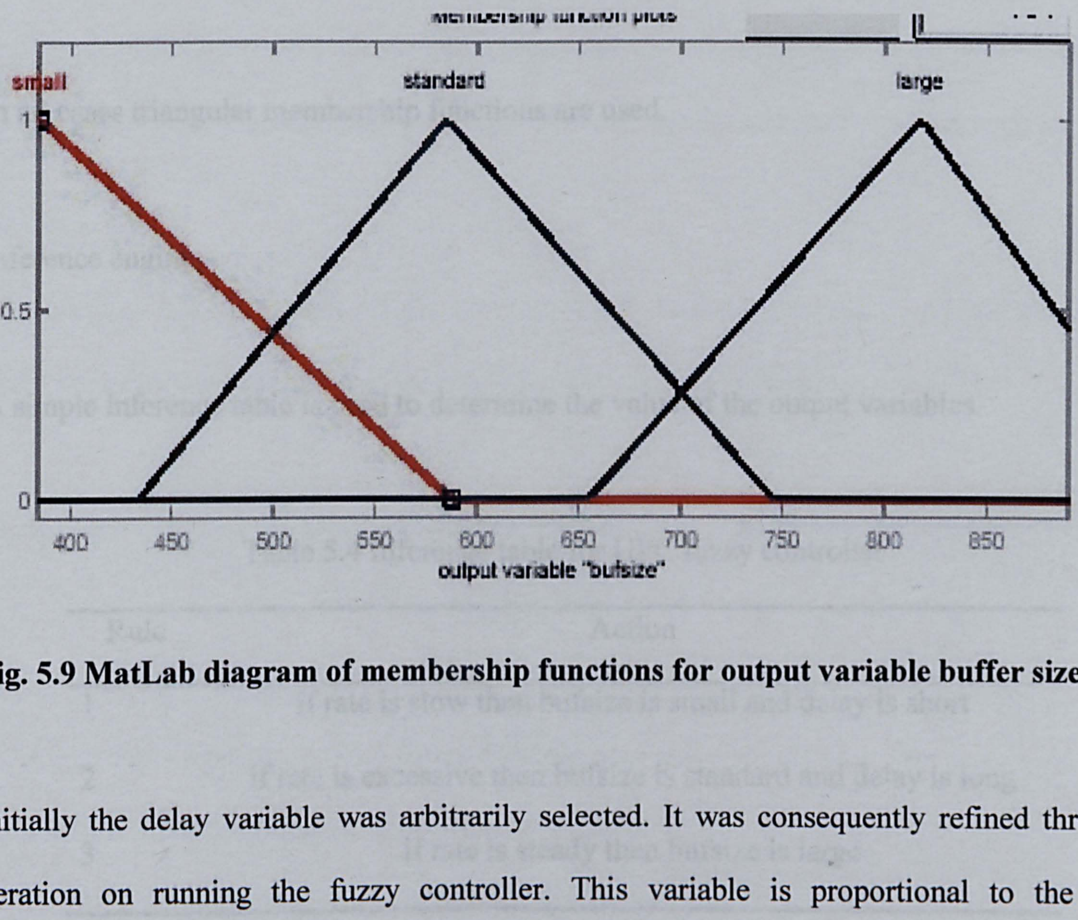


Fig. 5.9 MatLab diagram of membership functions for output variable buffer size

Initially the delay variable was arbitrarily selected. It was consequently refined through iteration on running the fuzzy controller. This variable is proportional to the link bandwidth and varies depending on link capacity.

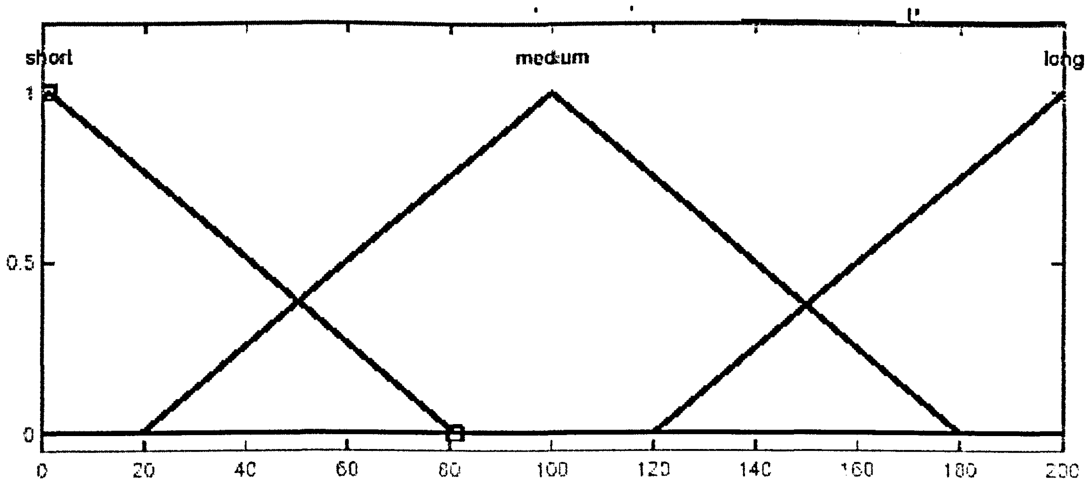


Fig. 5.10 MatLab diagram of membership functions for output variable delay

In all cases triangular membership functions are used.

Inference engine

A simple inference table is used to determine the value of the output variables.

Table 5.4 Inference table for UPC fuzzy controller

Rule	Action
1	if rate is slow then bufsize is small and delay is short
2	if rate is excessive then bufsize is standard and delay is long
3	if rate is steady then bufsize is large

Finally defuzzification is obtained by applying the centre of average method to the output membership functions. By delaying transmission and varying the buffer size the sending device imposes a controlled rate for each flow. This rate is actively managed at the sender. If for example a rate of 1200 Kb/s is selected as the maximum acceptable transmission speed, then this is the allowed sending rate. Where the system detects contention the buffer size is varied to provide competing flows an equal opportunity for transmission. This maintains an optimum rate for all flows, and maximises the statistical multiplexing gain. An alternative would have been to examine buffer occupancy and vary transmission accordingly. This would require the maintenance of a large buffer and impose latency within the system.

5.6.2 Experimental set-up for UPC controller

The separation of the FLC from usage parameter control permits each module to remain independent so that modifications can be made to the rule base without significant change to client or server. The sending device will actively manage the buffer during transfer.

Network

The network was a subnet of an Ethernet LAN bridged internally and externally by 802.11b devices operating on a frequency hopping spread spectrum.

Equipment

For the purposes of this test the wireless devices in use are:-

- Breezecom Access point (max. 3 Mbs)
- Win 2000 Workstation with wireless adapter
- Win 2000 Workstation with 100 Mb/s adapter

Dual simultaneous file transfers were made between the workstations. Each transmission consisted of a TCP transfer with an initial buffer size of 512 bytes. The total file size transferred was 5,202,824 bytes and the transfer rate varied between 60 and 140 KB/s according to network load. Two TCP streams are sent simultaneously to separate ports ensuring the link is fully utilised. The time for individual file transfers was recorded. This was to observe the effect of competing streams. Further socket transfers were made in synchrony with network file copying using Windows Explorer to see the effect of aggressive flows on UPC. It was noted that network speeds varied at different times of the day. One explanation could be that there was a change in atmospheric conditions, since this was the only factor to vary during the transmission period. This lends further proof to the assertion that the environment plays an important part in wireless transmission[1].

---

[1] A Davis Weather station was used to record atmospheric conditions during the research.

5.7 Priority control in video transmission

5.7.1 Components

The components of the priority controller consist of:-

- Latency monitor to measure the bandwidth delay product shared link
- Fuzzy pre-processor used to convert the bandwidth delay into fuzzy values
- Packet scheduler for rate smoothing and packet prioritisation

5.7.2 Latency monitor

As packets are transmitted across the network the latency is assessed to determine if it lies within acceptable bounds for delay-sensitive traffic. If the latency is unacceptable all delay-insensitive packets are briefly checked at the output port whilst video or voice is left alone. A probe measures the bandwidth delay product periodically, and then the results are passed to the sending device for evaluation by the fuzzy pre-processors.

The algorithm for the latency monitor

```
Loop
        Create sending socket
        Set timer
                loop
                        On timer
                        Ping destination 10 times
                        Get latency value then average result
                if socket connection made
                End loop
        Close socket
        Pass average latency value to connecting socket
if user input or exit
End loop
Create listening socket
        If connection made
                Get latency value
                Pass to fuzzy pre-processor
        End if
Close socket
```

5.7.3 Fuzzy pre-processor

Overview of fuzzy design

The fuzzy pre-processor computes the delay from outputs generated by the latency monitor. The time allocated to delaying packet transmission is based directly on the current latency. For example if the latency is 80 ms the delay for elastic file transmissions is set to 40 ms, not enough to delay transfers significantly but sufficient to ensure that time sensitive applications remain protected

Membership functions

The fuzzy pre-processor used for the priority controller consists of an input variable – latency and an output variable delay.

Membership functions are triangular in both cases for simplicity

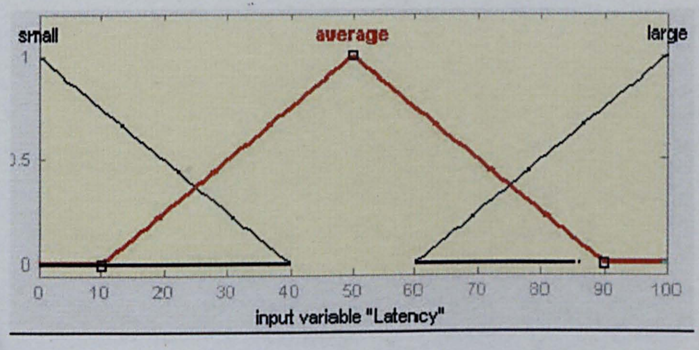


Fig. 5.11 MatLab diagram of membership functions for input variable latency

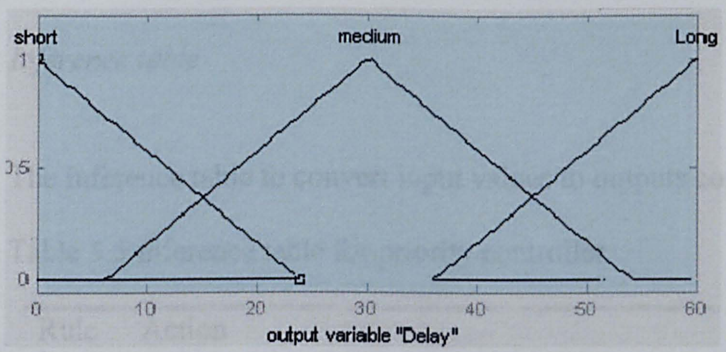


Fig 5.12 MatLab diagram of membership functions for output variable delay

Inference table

The inference table to convert input values to outputs contains 3 rules

Table 5.5 Inference table for priority controller

Rule	Action
1	If Latency is small then delay is short
2	If Latency is average then delay is medium
3	If Latency is large then delay is long

The ranges for the latency membership functions are based on ITU-T recommendations (see page 66), though classification of the outputs is a matter of trial and error.

Packet scheduler

The packet scheduler incorporates UPC to provide a rate smoothing function. It is an elaboration of the fuzzy UPC design. As the transmission buffer is fed to the receiving device it is examined in order to establish the nature of the data contained. If an MPEG video is in the buffer each GOP is measured and its size echoed to a graph onscreen. Currently this is just an information gathering exercise to graphically characterise the frame structure. In the future this information will be used as a predictor to scene changes. As soon as an I Frame is detected the buffer automatically increases its size by 15 bytes on each cycle until it reaches its maximum permitted size. The end result prioritises I frames over P and B frames by transmitting them at a greater rate. The remaining code is devoted to the usual UPC functions of rate limiting to prevent users from exceeding their maximum bandwidth.

Pseudocode for MPEG detection and frame characterisation

```
If
    Get GOP Sequence Header
        Get GOP Byte counter value
        Size of GOP = GOP Byte counter value
        Set GOP byte Counter to 0
        IF Iframe Header
            Set IFRAME True
        Else
            Set IFRAME false
        End if
        Write size of GOP to screen – Draw point on Graph
End if
```

Implementing multipriority control

Algorithm for priority control within the wireless access point

```
Get value of latency
If
    latency is small do nothing
    Else
    if
        latency is average or large
        Suspend voice queue packet by x milliseconds
    Endif
Endif
```

5.7.4 Experimental set-up for UPC controller

The separation of the FLC from usage parameter control permits each module to remain independent so that modifications can be made to the rule base without significant change to client or server. The sending device will actively manage the buffer during transfer.

Network

The network consists of two subnets of an Ethernet LAN connected by an access point. Each subnet links to the access point from a wireless bridge. The distance between subnets is approximately 5 Km. The network schematic can be reviewed in Fig 5.3.

Equipment

For the purposes of this test the wireless devices in use are:-

- Breezecom Access point (max. 3 Mbs)
- Breezecom wireless bridge (subnet one gateway)
- Breezecom wireless bridge (subnet two gateway)
- Pentium III 500 MHz workstation with 256 MB RAM in Subnet 1
- Dual Pentium IV 1 GHz Server with 1 GB RAM in subnet 2.

Dual simultaneous file transfers were made between the workstations. Each transmission consisted of an MPEG file of varying size (500 KB to 5 MB). The transfer rate varied between 25 and 40 KB/s according to network load. Two TCP streams are sent simultaneously to separate ports ensuring the link is fully utilised. The time for individual file transfers was recorded. This was to observe the effect of competing streams.

5.8 Conclusion

The methodology of a research project is central to the thesis. To establish the credibility of a proposal it must be demonstrated that verifiable and reproducible steps have been taken to collect and present data properly. Accurate data is required, and any conclusions drawn must stand up to scrutiny. In this chapter the methods used to collect information are discussed as well as the tools for presentation. Both primary and secondary procedures are detailed. The primary tools used are automatic processes such as SNMP probes and a weather station and vitally the modules that implement the design of the fuzzy systems. The secondary tools are mainly MatLab™ to present data, spreadsheets for further analysis and published academic papers as support for the work undertaken. The design element focuses on the enhancing of a wireless gateway using QoS mechanisms and fuzzy logic. Diagrams are provided as an aid to understanding the fuzzy components and to acquaint the reader with the network context. Each component providing QoS is detailed starting with fuzzy CAC, then fuzzy UPC and finally fuzzy MPC. A description of the design of a fuzzy process scheduler is also included since this is necessary for the packet scheduling used in MultiPriority Control. The success of a project depends upon whether its aims have been met. In this chapter the design aims were to develop mechanisms to support QoS in 802.11b networks. This covers the implementation of CAC, UPC and MPC as well as the characterisation of video to permit adequate provisioning.

Chapter 6

Experimental results

7.1 Introduction

This chapter discusses the experimental results obtained from testing each component of the project. The project has been designed using separate standalone modules. Performance testing has focused on obtaining results for the individual elements as opposed to a complete system test. The modules developed were a fuzzy Connection Admission Controller, fuzzy Usage Parameter Controller, fuzzy Scheduler and a fuzzy MultiPriority Controller. The benefits of applying fuzzy logic are also considered. The contribution of UPC to QoS is also debated. The concept of statistical multiplexing gain is introduced. Evidence is offered that fuzzy logic can maximise the multiplexing gain when compared to the use of non fuzzy UPC. The results include a discussion of the general considerations for wireless performance including buffer size and the effect of the environmental on network transmission. The design for a fuzzy process scheduler was also tested and the results demonstrate the improvement obtained using a fuzzy based scheduler. There is an analysis of how fuzzy logic enhances thread performance even when the system is heavily loaded. Underlying trends are discussed such as inherent cycle time variation (burstiness). The final results obtained relate to the fuzzy MultiPriority Controller and the advantages conferred by its use of class based queuing. Does allocating different priorities to each class of traffic work? In the conclusion we provide a summary of the results obtained.

6.2 Fuzzy Connection Admission Controller

6.2.1 Methodology

The FLC was written in C++ with a visual interface. To test the performance of the design, file transfers were made with and without the FLC. Simple Network Management Protocol (SNMP) requests were used to monitor system load and error rate. The average results were tabulated for 5 seconds period. The test network comprised two Ethernet subnets connected by 802.11b wireless bridges. The link connection operated at a maximum bandwidth of 1 Mb/s with a separation of 3 Km. Two procedures were used to determine the maximum capacity of the wireless links:-

- SNMP collectors measured the power output of the wireless nodes .
- Internet Control Message Protocol (ICMP) was used to calculate link capacity from the following bandwidth equation

$$BW = 16*(P_l - P_s) / [(T_{2l} - T_{2s}) - (T_{1l} - T_{1s})] \tag{1}$$

Where P_l represents large packet size, P_s represents small packet size, T_{2l} is time for large packet size to second hop, T_{2s} is time for small packet size to second hop, T_{1l} is time for large packet size to first hop, T_{1s} is time for small packet size to first hop. The calculations in equation (1) is based on Round-Trip-Time (RTT) for two sets of packets with various sizes, P_l = 1100 bytes and P_s = 100 bytes. T_{2l} and T_{2s} are the average RTT to the second hop in milliseconds, and T_{1l} and T_{1s} are the average RTT to the first hop in milliseconds.

Multi Router Traffic Grapher (MRTG) is a tool to monitor the traffic load on network links. MRTG was used to record traffic and link utilisation during tests across the wireless link. The data was collected using SNMP monitors, then transferred to the MRTG server for analysis and display.

6.2.2 Scope of experimental Results

The results were studied from several perspectives:-

- Did the FLC correctly interpret the metrics passed from the network?
- Is there any value in having an admission control policy?
- Why does the error rate increase with the link utilisation?
- Benefits of using fuzzy logic over conventional flow control methods

6.2.3 Correct operation of the FLC

To determine the correct operation of the FLC tests were conducted under differing network load conditions. The results obtained from the controller were compared with projections from a MatLab model

Table 6.1 Comparison of FLC under differing loads

Measured AB %	Error Rate %	Rule	MatLab Decision	FLC Decision
8.90	26.90	1	Accept	Accept
68.80	31.00	2 & 3	Reject	Accept
69.00	38.00	3	Reject	Reject
96.00	18.20	3	Reject	Reject
98.00	43.00	3	Reject	Reject

From Table 6.1 above it can be seen that performance matched the simulation in all but one result. The MatLab model rejected the admission when applying rule 3. The real time controller chose to apply rule 2 and accept the admission. This was because it read the value for the error rate as being within the medium rather than the high error range. This exception highlights the need for fine-tuning of the membership functions. All requests were flagged as 'Reject' when the available bandwidth was low.

Fig. 6.1 displays channel utilisation during file transfers using the FLC. The first set of readings from 14.00 – 18.00 hours were recorded when the network was lightly loaded and therefore all requests were accepted. Subsequent readings were taken as the network load was increased.

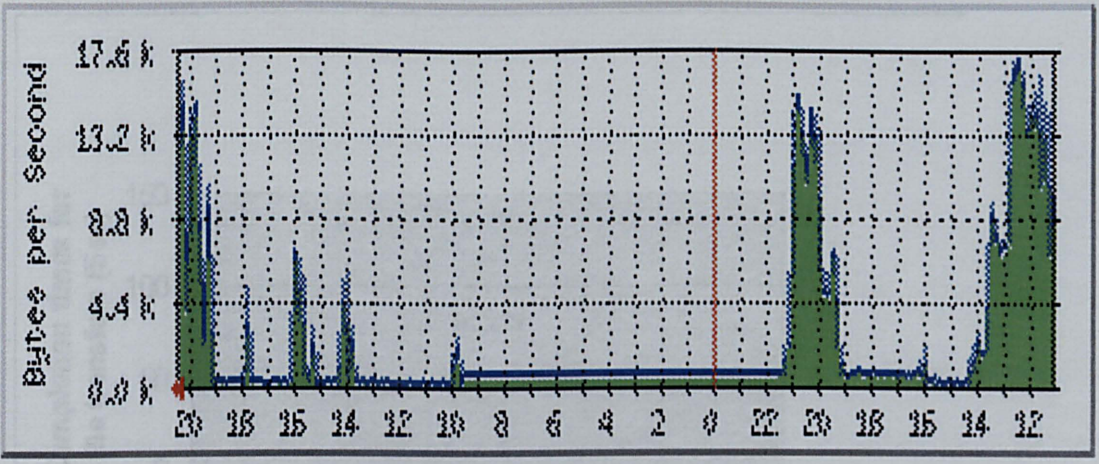


Fig. 6.1 MRTG graph showing the network load during file transfers

6.2.4 Advantages of employing a CAC policy

CAC is a necessary part of providing Quality of Service guarantees. Bounded-delays are essential to delivering Type A requests. When a real-time video request is not satisfied due to latency, it is valueless. Fig. 6.2 plots completion times for file transfers against the network load as a percentage. The dotted areas represent the transfers. The file transfers to the left of the vertical line are accepted and the file transfers to the right of the vertical line are rejected. Delay times for client requests increase with the network load (Fig. 6.2) If these were real-time video transfers, points within the area marked reject would lie outside acceptable delay bounds defined by the client traffic descriptors.

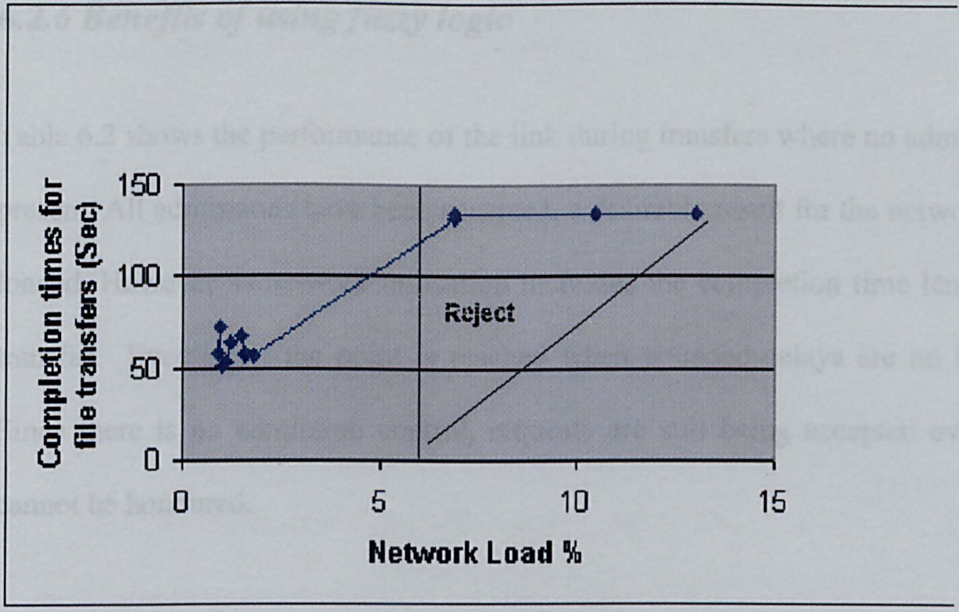


Fig. 6.2. Comparison of file transfer times against network load

Admission control limits the number of unsuccessful connection requests. Applying fuzzy logic reduces the computational resources upon the system and the delay in responding to any request. In addition information is not discarded since the FLC assesses the truth of all rules at once, unlike the a conventional controller which processes a decision only when measurements reach a given threshold.

6.2.5 Relationship between errors and link utilisation

From Table 6.2, it can be seen that the error rate increases with link utilisation. In a wired network, errors indicate congestion and force a reduction in the sending window size. Measurements taken from the wireless equipment indicated that interference was not a significant cause of error. The conclusion is that most errors are due to packet aggregation. High error rates during wireless transmission occur with larger packet sizes rather than congestion. Unfortunately increasing error rates initiate TCP congestion avoidance so reducing the sending window. This causes a variable throughput across the wireless link and prevents it from being fully utilised.

6.2.6 Benefits of using fuzzy logic

Table 6.2 shows the performance of the link during transfers where no admission control is present. All admissions have been accepted, a desirable result for the network when lightly loaded. However as network utilisation increases the completion time lengthens for each transfer. Eventually, the point is reached when bounded-delays are no longer possible. Since there is no admission control, requests are still being accepted even though they cannot be honoured.

Table 6.2 Client server transfers with no CAC

Measured AB (%)	Error rate (%)	Time (S)
15	30.7	37.8
13	36.0	44.7
90	0.1	86.0
84	3.4	90.0

Tests were also run with an admission controller using conventional flow control algorithms. Results on a congested network confirmed the controller worked as designed. It was not so efficient however, on the boundary between medium and low availability. Here context switches in memory doubled, as compared to the context switches used by the FLC in similar conditions. In addition the time taken to process a flow control statement increased by nearly 80%.

6.3 Fuzzy Usage Parameter Controller

6.3.1 Scope of results and objectives

Results obtained covered the following:-

- Transmissions on a best efforts basis, without UPC
- Transmissions using preset values for the UPC
- Transmissions using values suggested by the fuzzy controller.

The objectives are to establish:-

1. Does UPC improve quality of service?
2. Have the fuzzy logic inputs been correctly interpreted - is UPC working?
3. Can fuzzy logic enhance UPC to support QoS
4. Any other general considerations?

6.3.2 Does UPC improve Quality of Service

The objective is to maximise the Statistical Multiplexing Gain (SMG). This ensures that the gateway passes all traffic with the minimum possible delay.

The SMG has been calculated as follows:-

$$SMG = (IR_n + IR_{n+1}) / OR \qquad (2)$$

Where IR is incoming rate (Bytes/S) for each flow, n = first flow n+1 = next flow, OR = transmission rate (Bytes/S) when only a single flow is present

Fig. 6.3. Below is the gain achieved through active management without fuzzy logic.

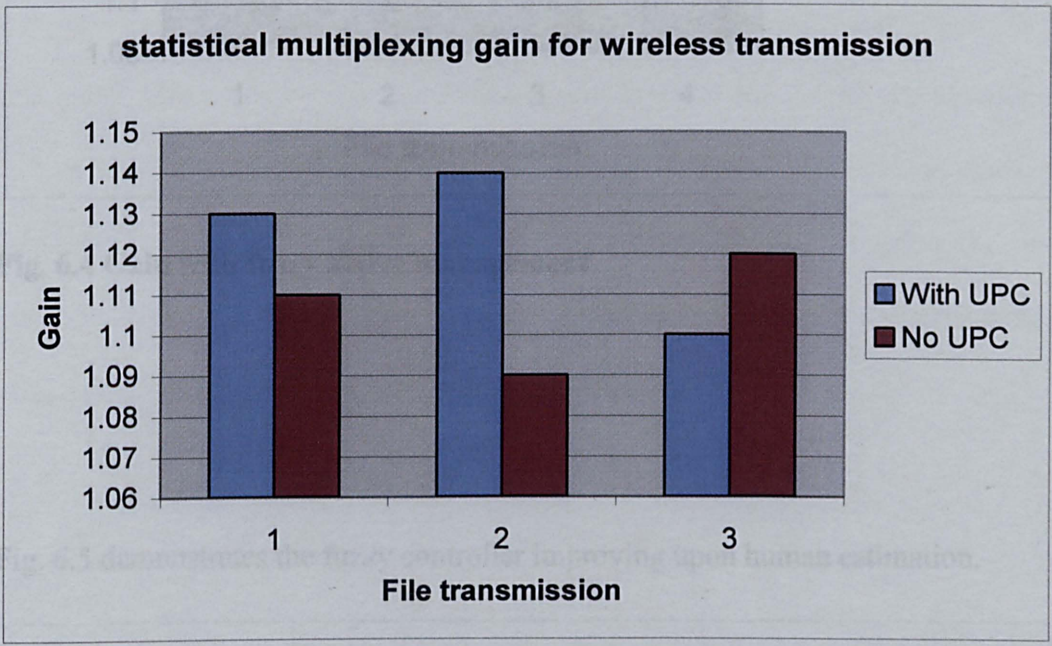


Fig. 6.3 Gain with active management

The results also demonstrate that, fuzzy logic with active management outperformed all other methods (Fig. 6.4 below). Parameters obtained from the fuzzy controller are used here to vary the sending buffer size as well as the delay.

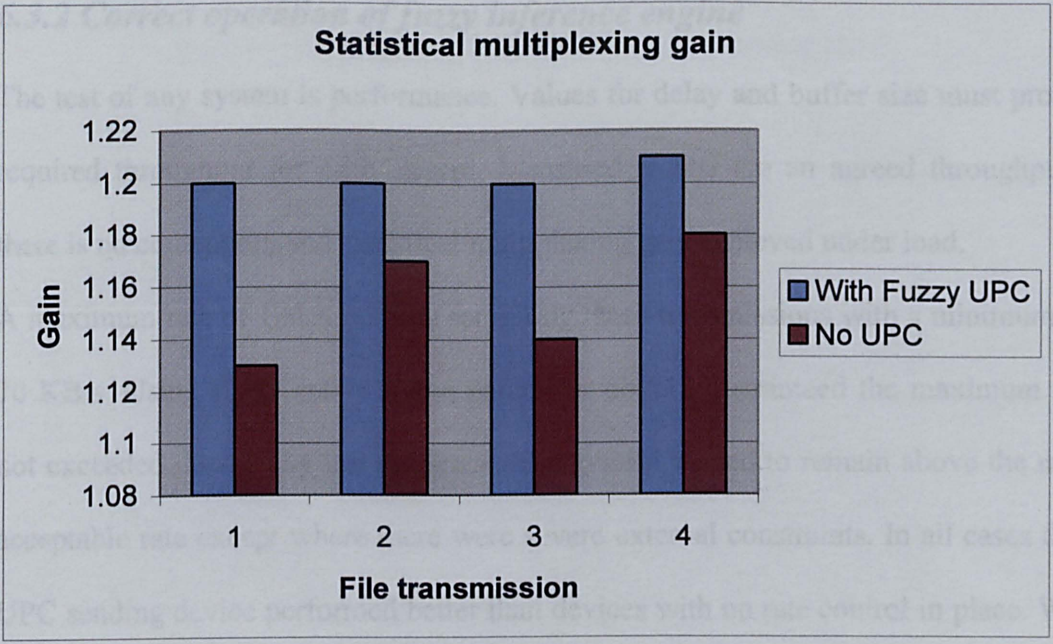


Fig. 6.4 Gain with fuzzy active management

Fig. 6.5 demonstrates the fuzzy controller improving upon human estimation.

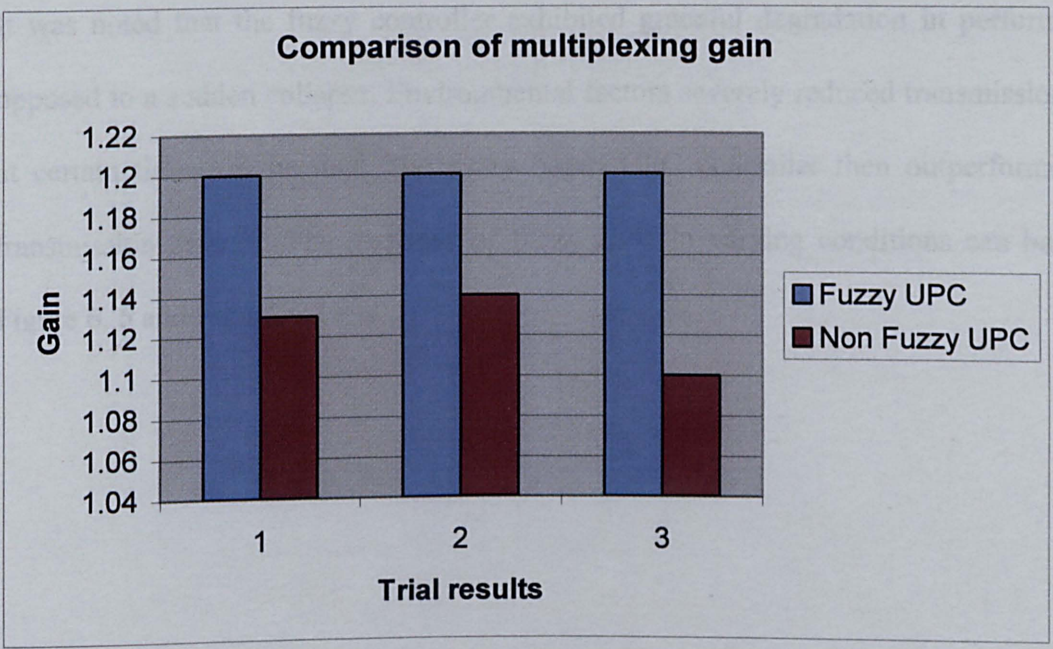


Fig. 6.5. Gain performance comparison

From these results it can be seen that usage parameter control enhances performance.

6.3.2 Correct operation of fuzzy inference engine

The test of any system is performance. Values for delay and buffer size must produce the required throughput for each stream. Measured results are an agreed throughput where there is no contention, and statistical multiplexing gain achieved under load.

A maximum rate of 120 KB/s was set during these transmissions with a minimum level of 70 KB/s. Using fuzzy active usage parameter control guaranteed the maximum rate was not exceeded during any test sequence. The system tended to remain above the minimum acceptable rate except where there were severe external constraints. In all cases the fuzzy UPC sending device performed better than devices with no rate control in place. When the fuzzy UPC was applied to a fixed link with a bandwidth of 100 Mb/s the rate control mechanism functioned satisfactorily. This is evidence to prove the traffic shaping policy is effective in limiting per flow use of available bandwidth.

6.3.3 Benefits of using fuzzy logic

It was noted that the fuzzy controller exhibited graceful degradation in performance as opposed to a sudden collapse. Environmental factors severely reduced transmission speeds at certain times of the day. The fuzzy based UPC controller then outperformed other transmission devices. The response of fuzzy UPC in varying conditions can be seen in Figure 6. 6 and Figure 6.7

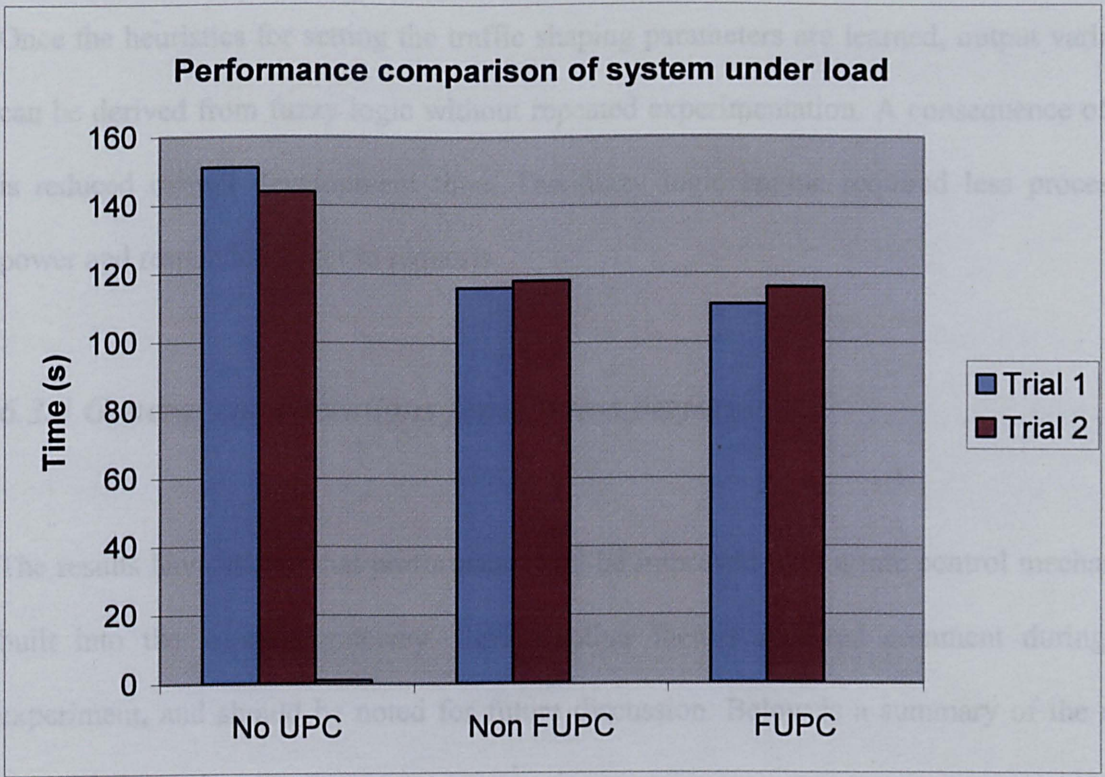


Fig. 6. 6 Performance of fuzzy UPC under load

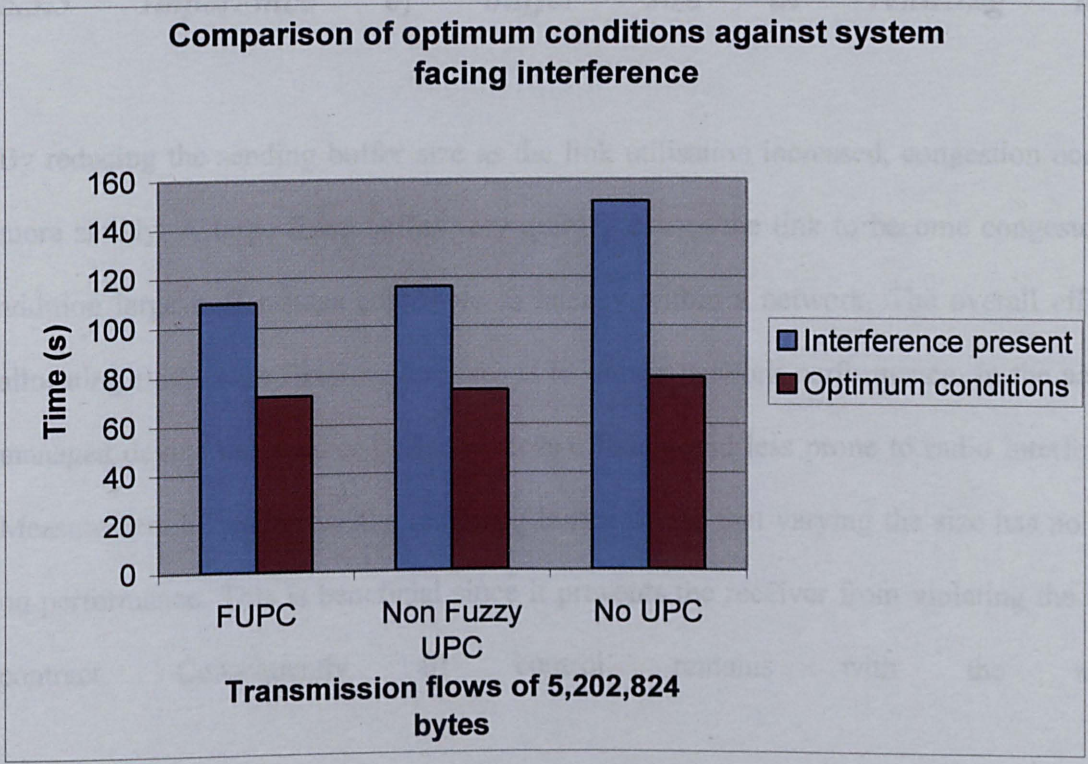


Fig. 6.7 Effect of interference on wireless systems

Once the heuristics for setting the traffic shaping parameters are learned, output variables can be derived from fuzzy logic without repeated experimentation. A consequence of this is reduced overall development time. The fuzzy logic engine required less processing power and responded faster to requests.

6.3.4 General considerations for wireless performance

The results have shown that performance can be improved with a rate control mechanism built into the wireless gateway. Several other factors received comment during the experiment, and should be noted for future discussion. Below is a summary of the main points for attention.

6.3.5 Importance of buffer size in reducing losses

By reducing the sending buffer size as the link utilisation increased, congestion occurred more slowly. A large fixed buffer very quickly causes the link to become congested.. In addition large buffer sizes contribute to latency within a network. The overall effect of allocating flows with fixed buffer sizes is to impair network performance. In the actively managed device the smaller buffer is more efficient and less prone to radio interference. Measurement of results for the receiving buffer shows that varying the size has no effect on performance. This is beneficial since it prevents the receiver from violating the traffic contract. Consequently all control remains with the sender.

6.3.6 Effect of environment on transmission response

System throughput varied considerably at different times of the day even with the same link utilisation. One explanation for this could be the effect of the environment. A temperature gradient is created which results in interference to RF transmissions. Interestingly this effect is more pronounced with internal transceivers. This is because the humidity level remains constant at around 60% whilst the external humidity varies dramatically. Fig. 6.8 below, charts the internal and external humidity during the experimental.

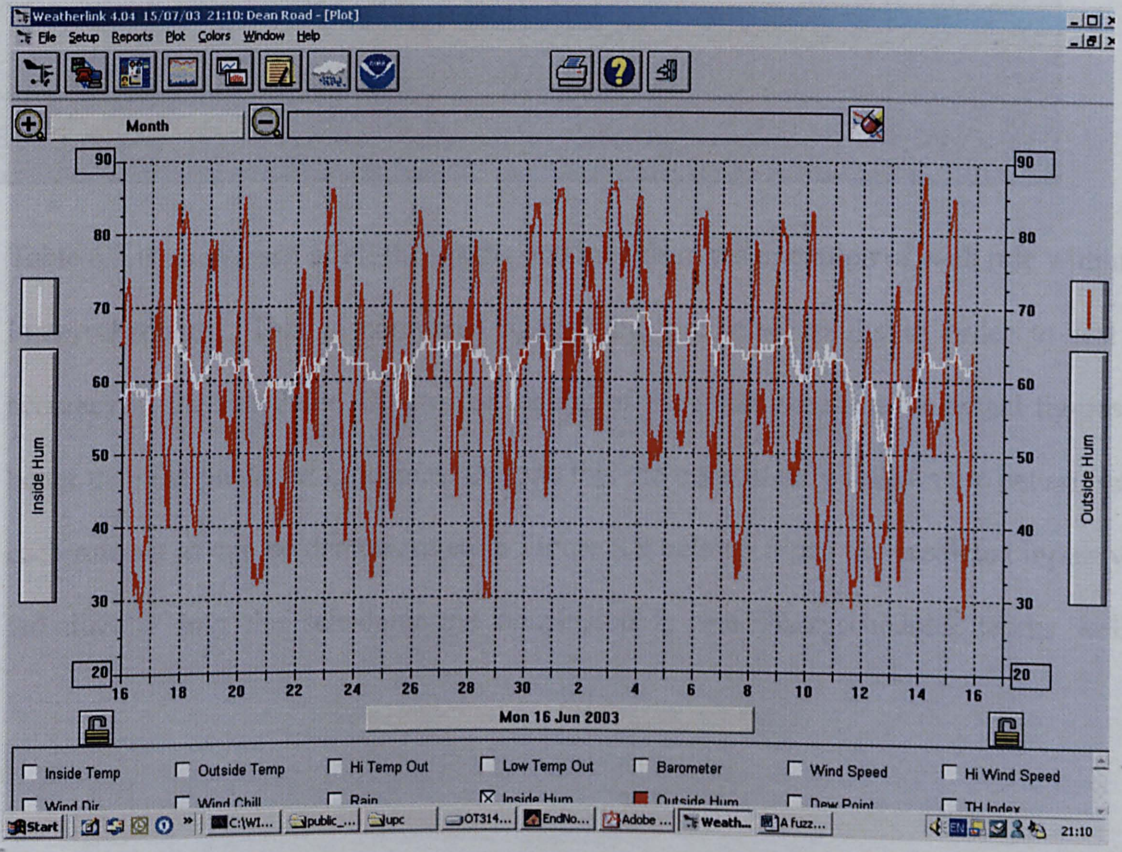


Fig. 6.8 Graph of external and internal humidity

6.4 Fuzzy Scheduler

6.4.1 Analysis of results from scheduling

Table 6.3 Average of outputs from each rule with 3 processes running

Rule	*Predicted improvement*	*Actual improvement*	*Variance*
1	5.1	2.1	-3
2	12	19	7
3	5.1	5.8	0.7
4	7	9.4	2.4
5	6.6	12.5	5.9

Table 6.3 is an average of all the results obtained from the operation of each rule within the Fuzzyscheduler. This is compared against the predicted results in order to test the accuracy of the scheduler. Due to the scaling of the input variables the actual figures are better than the predicted outcomes. Despite this the trend clearly follows the pattern set by each rule set as can be demonstrated in Figure 6.9 below. Since the predicted inputs were fed directly into the scheduler the conclusion is that Fuzzyscheduler works well in

scheduling processes, based on the existing rules in the rule base.

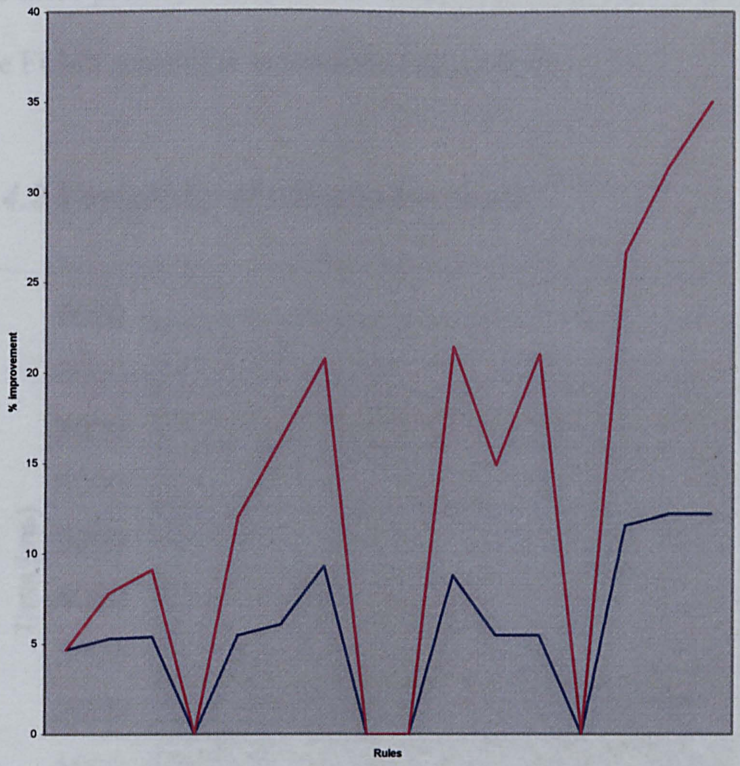


Figure 6.9 Actual performance against predicted

In Figure 6.9 we can observe the actual performance against that predicted by the FLM for each rule in the rule set. The trend bears out the predicted performance in each case despite the outcomes being significantly higher, due to the conservative scaling factors applied

Table 6.4 Predicted results against actual with 2 processes running

Rule	*Predicted improvement*	*Actual improvement*	*Variance*
1	5.1	1.9	-3.2
2	12	18.2	6.2
3	5.1	2.1	-3
4	7	6.3	-0.7
5	6.6	8.8	2.2

In Table 6.4 we see how the FLM loses accuracy as the number of processes are reduced. As more processes run, actual values tend to approach the predicted values. This confirms the FLM's scalability in resource management.

6.4.2 Variability of completion times

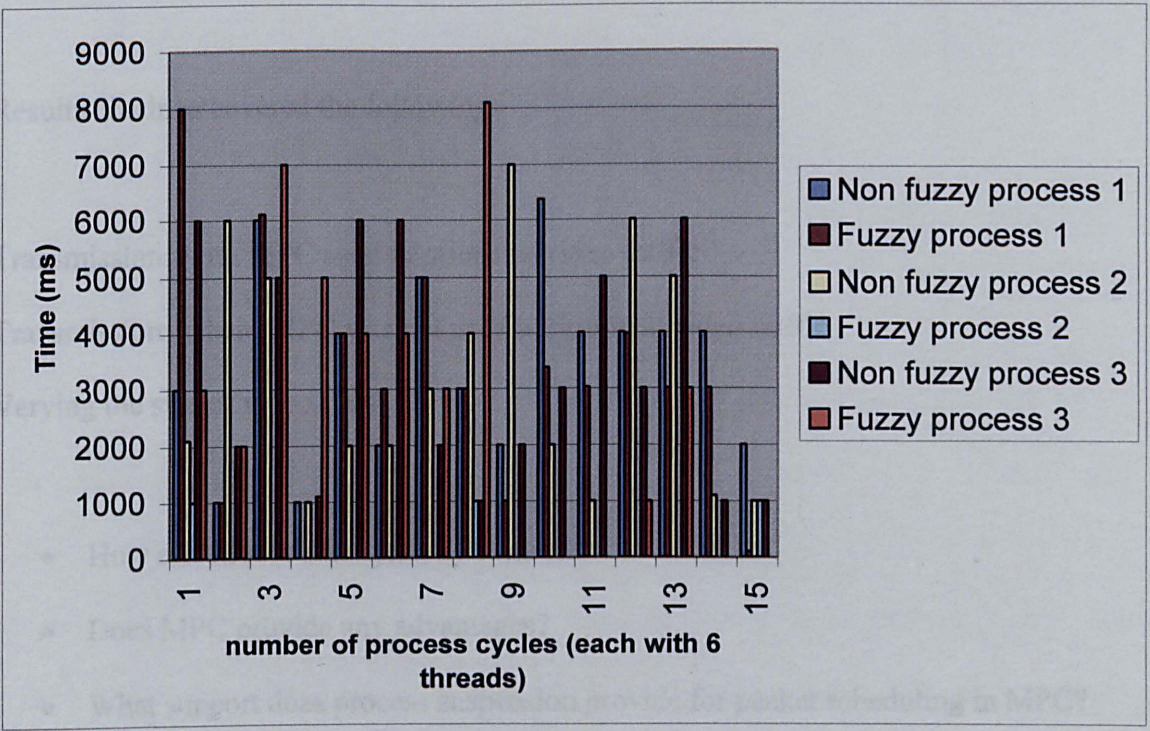


Figure 6.10 Time taken for each process cycle in file copy

Figure 6.10 shows time for each thread cycle. Every cycle starts from when a quantum of data is read from file and then written either to a network or local hard disc. A sample of 15 sessions containing 3 concurrent processes with two threads each was extracted to demonstrate the bursty nature of the processes scheduled.

6.5 Fuzzy Multi-priority Controller

6.5.1 Scope of results and objectives

Results obtained covered the following:-

Transmissions with MPC used to prioritise video traffic

Transmissions where MPC was not used to prioritise video traffic

Varying the size of video files

- How effective is multipriority control?
- Does MPC provide any advantages?
- What support does process suspension provide for packet scheduling in MPC?
- What benefits are provided by fuzzy logic?

6.5.2 How effective is MultiPriority control

In all results were gathered across a period of seven days. Simultaneous transmissions of three files took place and the times were recorded for each transfer. The gap between each transmission was approximately 2 minutes. MRTG recordings indicated that the link was under utilised at the time except for these transfers. The results in Fig. 6.11 below compare file transfers using MPC for video and non video. A simultaneous transfer of a video file that did not receive prioritisation is included. These are a sample from approximately 100 measurements taken during the test period. Two files were about 510 KB in size though the MPC video file is approximately 6% larger.

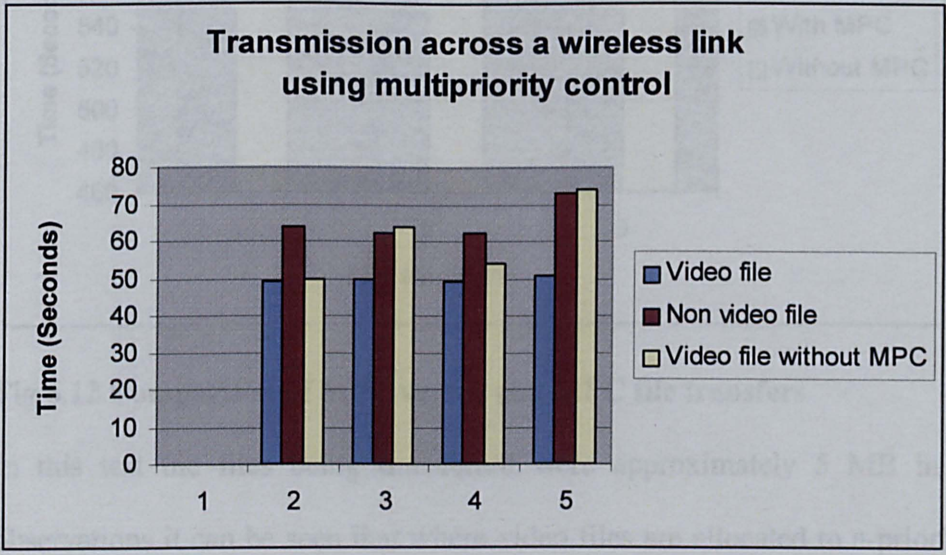


Fig 6.11 transmission across a wireless link with MPC in place

Observations show that in each case the video file placed in the highest priority queue completed transmission first. This ensured that the latency for the video transmission remained within the constraints for delay sensitive traffic. The delay varied from around 37 ms up to 168 ms depending on the state of the network. Despite this the latency for the most part remained below 126 ms, within the acceptable limits for time sensitive traffic. From these results we can infer that deliberately prioritising video traffic ensures its protection from aggressive flows.

6.5.3 Support provided by process suspension in MPC

We have demonstrated that MPC confers significant advantages for video traffic. Fig. 6.12 shows this advantage applies to flows of any size

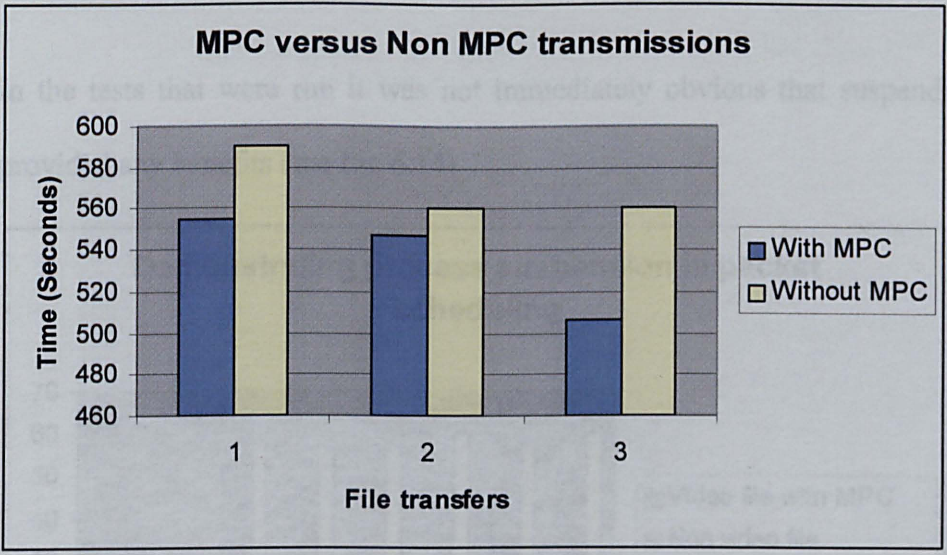


Fig 6.12 Comparison of MPC versus non MPC file transfers

In this test the files being transferred were approximately 5 MB in size. From the observations it can be seen that where video files are allocated to a priority queue overall transmission time is reduced.

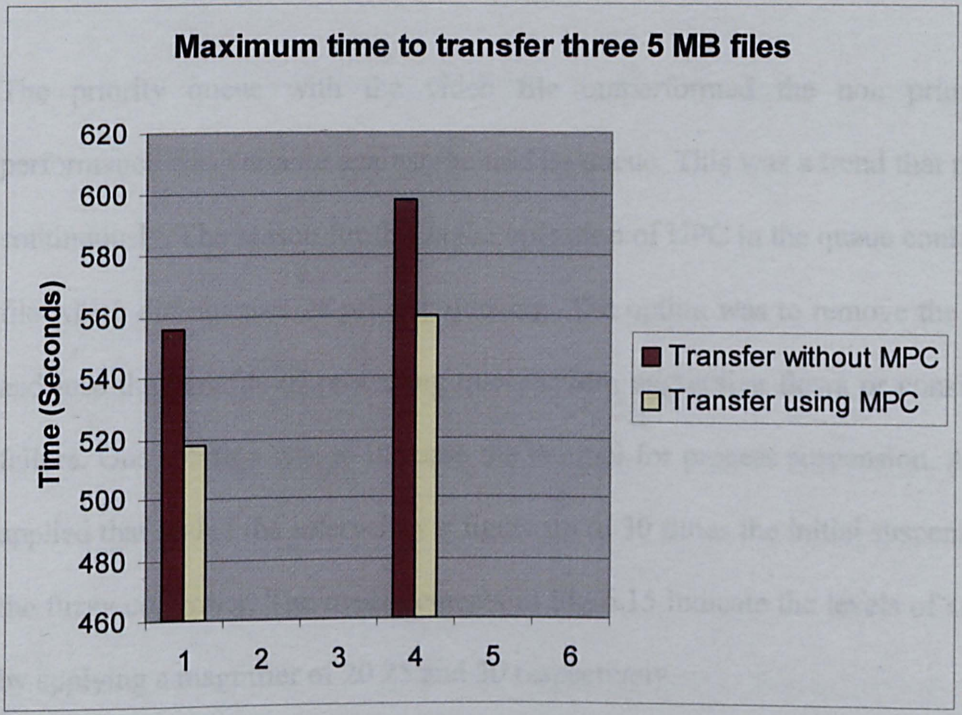


Fig 6.13 maximum time to transfer three 5 MB files

This test measured the overall time to transfer three 5 MB video using both MPC and without MPC. Note performance is improved in all queues.

In the tests that were run it was not immediately obvious that suspending each process provided any benefits (see Fig 6.14)

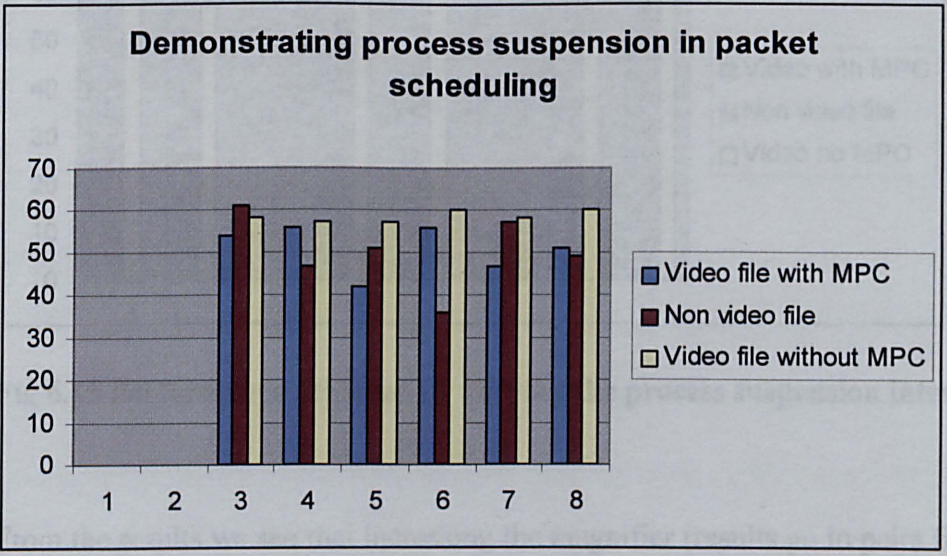


Fig 6.14 Suspending processes using MPC

The priority queue with the video file outperformed the non priority queue but performance was variable against the middle queue. This was a trend that manifested itself continuously. The reason for this is the operation of UPC in the queue containing the video file which did not receive priority queuing. The option was to remove the UPC controller and lose the benefits of protecting queues from aggressive flows or consider the MPC a failure. One solution was to increase the interval for process suspension. A magnifier was applied that scaled the interval by a figure up to 30 times the initial suspension time set by the fuzzy controller. The measurements in Fig 6.15 indicate the levels of success obtained by applying a magnifier of 20 25 and 30 respectively.

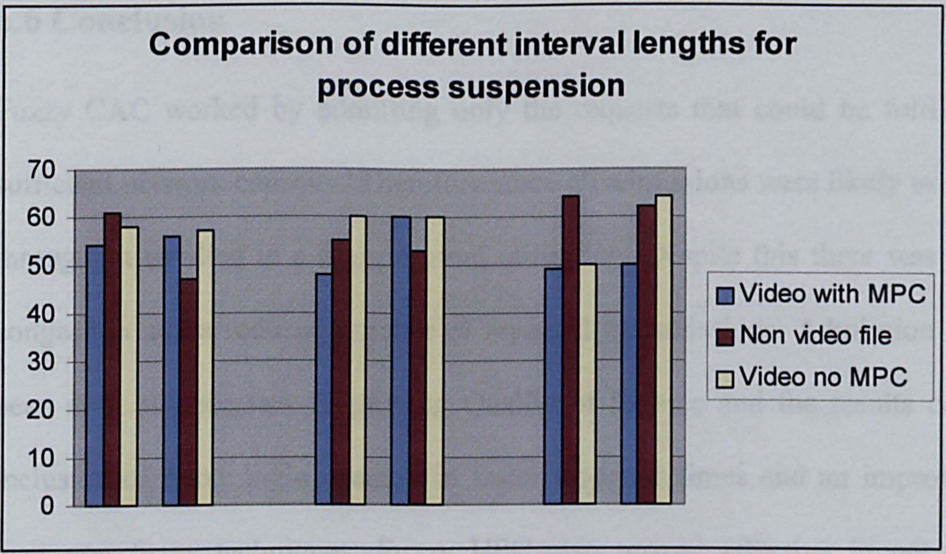


Fig 6.15 Performance achieved by varying the process suspension interval.

From the results we see that increasing the magnifier (results go in pairs from left to right) ensured that MPC proved more effective. The results shown in Fig 6.14 above used a magnifier of 30. These are one sample from the results collected. Varying the magnifier delivered much shorter completion times for all processes over and above the specific improvements to the file sin the priority queues.

6.5.4 Benefits provided by fuzzy logic in MPC

As in all cases the advantages of fuzzy logic are rapid prototyping and the scalability of our fuzzy model. A simulation was developed using MatLab to generate intervals for the packet scheduler. It proved straightforward adding the magnifier that improved the overall performance of the MultiPriority controller. This opens the route to develop a learning fuzzy controller that can significantly improve transmission times by creating queues for different classes of traffic. In hindsight it is fair to say that the importance of fuzzy logic in MPC will stem from our ability to test and modify the design based upon the actual results obtained from implementing the MPC controller. In my view even more impressive gains can be obtained by scheduling aggressively.

6.6 Conclusion

Fuzzy CAC worked by admitting only the requests that could be fulfilled if there was sufficient network capacity. Therefore since all admissions were likely to succeed the total throughput resulted in a high channel utilisation. Despite this there was a lower level of congestion and a reduced number of repeated transmissions. Admission control has long been seen as necessary to proving Quality of Service and the results confirm this. The inclusion of fuzzy logic resulted in faster response times and an improved performance over non fuzzy techniques. Fuzzy UPC also proved effective in not only preventing individual flows from disrupting other traffic but allowed most flows to complete within reasonable time. By using fuzzy logic to actively manage transmissions it was possible to react quickly to situations if the network utilisation increased. Flows were constrained from competing aggressively with each other. A common problem with modern computers is the need to manage resources so that all processes get a reasonable allocation of time and to avoid thread starvation. Fuzzy management of the scheduler permitted that processes with lower priority to complete. File transfer times were reduced by a significant factor.

MPC guarantees that delay-sensitive traffic will always receive priority in a congested channel. This is a further step to providing QoS by creating traffic classes which can be treated according to the agreed service class. The MultiPriority controller discovers the traffic class then selects the appropriate level of service. The scheduler within the controller then allocates process time on a priority basis and UPC is smoothes the flows out. In all cases priority is given to video traffic with a finer grained queuing applied to the individual video frames. For instance I frames receive a slightly higher priority and more bandwidth than P or B frames when the network becomes congested. Doing this provides protection to multimedia traffic travelling across this wireless network. The controller improves the transmission of delay sensitive traffic. In addition an overall increase in performance was achieved even for traffic in low priority queues.

Experimental results

The project objective is to implement Quality of Service to improve video transmission, with fuzzy logic as the primary mechanism used for flow control. We measured the project's success by recording the improvement in file transfer times through the wireless gateway. All of the design components described in this chapter achieved increases in performance during testing as compared to conventional methods of flow control.

Chapter 7

Discussion, conclusion and recommendations for further work

7.1 Discussion

The project objective is to improve the transmission of multimedia traffic in 802.11b wireless networks. The approach used delivers QoS through CAC, UPC and MPC enhanced with fuzzy logic. QoS is important in packet scheduling and transmission of data across fixed or wireless channels. This research shows how QoS reduces network congestion. The result is to increase user satisfaction and encourage consumer spending on mobile computer equipment. The inclusion of QoS in the HiperLan wireless specification underlines how important it is to wireless packet transmission. Also there is a draft specification of Quality of Service for 802.11b radios now known as 802.11e. This standard is a link layer implementation of QoS requiring new firmware and hardware. Simulations indicate that significant tuning of 802.11e parameters is required to make it work properly [61]. To reduce the need for complex radios, algorithms for priority based queuing should be inserted within the network layer. 802.11e is likely to have limited advantages since a large number of existing devices will not benefit from the technology. More and more radios are being manufactured that will support newer standards such as 802.11g and 802.11a. Equipment working to these new standards can cope with greater loads even if they are less efficient Ultimately it may be more cost effective to upgrade to 802.11g radios rather than remain with the 802.11b. It could be argued that with these options available there is no need to develop QoS mechanisms in wireless gateways. This would be a false economy in my opinion. The justification for this research is the need to make faster and more efficient systems. Wireless systems are subject to interference, and the number of wireless adapters is increasing. It is unlikely that improvements in compression will keep pace with demand for network capacity. It is vitally important that measures are taken to make wireless networks more efficient without raising the output gain. We need to discover means of extending the useful life of wireless equipment now being used in networks around the world.

There are arguments for and against the use of fuzzy logic. Some would contend that in purely mathematical terms it is no different from applying any multi-valued system to a problem domain. Fuzzy systems can be faster yet have lower memory requirements than conventional systems. The development time is usually much shorter and they are capable of modification whilst in operation. The proposal was to search for a method of enhancing video over wireless networks using fuzzy logic. One means of achieving this was to apply conventional techniques for QoS that had not previously been used in 802.11b systems. The use of fuzzy logic in the management of wireless systems is novel. Fuzzy systems consume less processing cycles than conventional methods and have faster response times. This supports the design aim of extending the battery life of portable appliances. Longer battery life encourages the purchase of laptop computers. In my view the reduced power requirements and fast response times justifies using fuzzy logic.

An examination of the data being collected revealed that there were wide variations in wireless performance during the day. Further research indicated this variation was dependent upon weather conditions. These results were not caused by accepted atmospheric behaviour such as absorption or scintillation. Other factors are operating that may impact upon wireless transmissions quite severely. These findings are significant and merit further research specifically related to this topic. The scope of the research would be to determine how the phenomenon is to be harnessed for our benefit. One outcome could be some form of power management to reduce energy and prevent automatic gain increases when there is a change in the weather. Automatic gain control adjusts transmitter power when there is a drop in the Received Signal Strength Indicator (RSSI). The RSSI may be affected by external factors such as the environment. A promising avenue of opportunity is to manage the gain control using atmospheric readings. Given the research data collected here the opportunity exists for power savings at the base station and wireless receivers.

Finally we should consider directions for future research. This project has involved almost continuous monitoring of one of the earliest 802.11b wireless networks in the UK. Despite the popularity of WLANS, there are special difficulties associated with video over microwave radio links. All microwave technologies share the same characteristics so the mechanisms developed during this project are applicable to other microwave technologies. In the future, fuzzy logic can be extended to enhance QoS in video transmission over networks including Bluetooth and cellular phone systems. The effect of solar irradiation is a topic that would benefit from further research. Fuzzy controllers can be developed that reduce power consumption when changes in solar irradiation are detected. It may be possible to detect these changes by monitoring errors in microwave transmission.

Contribution of work

This work has extended current understanding in QoS for 802.11b wireless networks. CAC, UPC and MPC are not built into WLAN gateways though they are necessary to providing QoS. This project has shown that these mechanisms can improve the performance of wireless systems without requiring major modification of hardware or firmware. The application of fuzzy logic is an important step in the use of knowledge based systems for process control. Overall this is a demonstration of how a fuzzy approach to QoS can enhance wireless performance and also reduce the power consumption of packet radio transmitters.

7.2 Conclusion

The opportunities created by the expansion of the Internet and the development of local and wide area radio networking equipment have generated massive interest in wireless technology. To satisfy consumer demand manufacturers now have to build systems offering the equivalent of fixed networking capability. The project objective was to demonstrate how Quality of Service implemented by flow control software improves multimedia delivery in 802.11b wireless networks. The novel element is the inclusion of fuzzy logic as a feedback control mechanism. The research highlighted the inadequacy of existing packet services technology when coping with transmissions across wireless networks. New software has been designed implementing the main QoS primitives, CAC, UPC and MPC with fuzzy logic for flow control. These are the key components to providing QoS in packet networks. Connection Admission Control limits the level of traffic by refusing calls that may exceed available capacity. Usage Parameter Control ensures that individual flows are prevented from impacting traffic generated by other users. Multi-priority Control (Class Based Queuing) prioritises delay sensitive traffic over elastic file transfers. These mechanisms have been proven to work very successfully in fixed link systems. Despite this 802.11b devices have no equivalent means to implement QoS. This project also proposes a new process scheduler based on fuzzy logic. The scheduler ensures that all processes receive a fair share of allocated time and actively manages scheduling to achieve this. Network transmissions may fail to complete if they are not sufficiently high enough in priority. This occurs more frequently with short network flows. The fuzzy process scheduler was designed to prevent situations where buffer exhaustion interrupted flow transmission.

The software was developed and then tested to ensure it met the design objectives. The results for each element of the software were recorded and then analysed. Three sets of observations were taken. The first set included measurements of transfers without any modification to the wireless devices. The second group of results were taken from measurements of flow transmissions using software designed to support CAC, UPC and MPC. The final set of results covered the performance of wireless devices where the QoS primitives were enhanced with fuzzy logic. The fastest network transmissions were achieved using fuzzy logic with QoS. These results confirm that wireless networks are better at handling multimedia traffic if they include QoS support. In addition the use of fuzzy logic improves the performance of QoS primitives whilst reducing the processing requirements of wireless equipment. This permits faster transmission of multimedia traffic coupled with a longer battery life for mobile appliances. By using fuzzy logic to actively manage transmissions it was possible to react quickly if congestion occurred. Fuzzy management of the scheduler permitted processes with lower priority to complete. This improved file transfer times by a significant factor. The use of fuzzy logic provides performance benefits in addition to energy savings. In conclusion the research has produced a tool to implement Quality of Service within a wireless network. By achieving both cost savings and performance improvements the project has met its design aims.

7.3 Recommendations for further work

During the period of research detailed measurements were obtained from all wireless gateway devices. On combining these readings with the atmospheric measurements recorded by the Davis weather station some interesting patterns emerged. The conclusion based on the results detailed in Appendix 1 was that the environment had a noticeable effect on signal quality. One possible cause could be global solar irradiation. This is composed of two elements, direct and diffuse irradiance. Measurements indicate that either of these effects (they do not operate together) may cause a signal loss of up to 4 Dbm. If forward error correction codes were developed using readings based on solar irradiance it may be possible to eliminate the noise from this effect.

The proposal is to link these codes with real-time correction provided by a fuzzy logic controller and adjusted through sensors monitoring the atmosphere. We do not propose any new management technology at this stage. The intention is to highlight discoveries made whilst monitoring network transmissions that cannot be explained using conventional theories. It is our contention that these discoveries can be exploited for potential gain. There is a role for fuzzy logic here as part of a toolset using atmospheric sensors to reduce power consumption in wireless equipment. These tools might produce savings in transmission costs yet still maintain a wireless data transmission of acceptable quality.

What is the importance of these findings and how may they contribute to research on microwave technologies? If confirmed it would have significant implications for climatology and wireless computing. Firstly it could provide us with a low cost and accurate measure of solar irradiation. Current methods involve the fabrication of costly pyranometers that lack sensitivity and accuracy. It suggests also that current methods of measuring solar irradiance could bear further scrutiny. Climatologists would be presented with a new set of tools for monitoring changes caused by solar radiation. In addition it would become easier to develop ways and means of tracking and managing solar collectors used for renewable energy sources. As far as the wireless community is concerned, it would permit the prediction of wireless quality in advance, this would lead to more accurate provisioning and reduced power consumption. The UK alone uses over 40 million mobile phones drawing up to 7 watts of power on a daily basis, excluding the 35000 base stations supplying signals transmitting an average 500 mW power (source *OFCOM*). If any savings can be generated they are likely to be significant. Once a thorough understanding of the relationship and proportionality were developed it would also be possible to produce robust transmission codes that could eliminate the error caused by solar irradiation. Such codes can be applied using fuzzy logic in order to reduce power increases initiated by signal inhibition from increasing solar irradiance.

Bibliography

1. Rantalal, A. and P. Eskelinen, *MICROWAVE OVEN INTERFERENCE IN ISM-BAND LINKS*. 2002, East Siberian Centre for the Earth's Ionosphere Research.
2. Zadeh, L., *Fuzzy Sets.* Informatics and Control Systems, 1965. **8**: p. 338 - 353.
3. Kazemian, H. and L. Meng. *A fuzzy approach to video transmission over Bluetooth ACL links*. in *CCNC 04*. 2004. Las Vegas, Nevada: IEEE.
4. Soud, D. and H. Kazemian. *Fuzzyscheduler a Generalised Process Manager using Fuzzy Logic for Multipurpose Operating Systems*. in *SCI2002*. 2002. Orlando, Florida.
5. Ascia, G., V. Catania, and D. Panno. *An efficient buffer management policy based on an integrated Fuzzy-GA approach*. in *INFOCOM: 2002*. 2002. New York, NY, USA: IEEE.
6. Grossman, D., *New Terminology and Clarifications for Diffserv*. 2002, IETF.
7. Braden, R., D. Clark, and S. Shenker, *Integrated Services in the Internet Architecture: an Overview*. 1994, IETF.

8 Baran, P. (1964*) On distributed Communications Networks* IEEE Trans. Commun. Syst., March 1 - 9.

9. Parris, M., K. Jeffay, and D. Smith, *Responsive vs. Unresponsive Traffic: Active Queue Management for a Better Than Best Effort Service.*
10. Floyd, S. and V. Jacobson, *Link-sharing and Resource Management Models for Packet Networks.* ACM Transactions on Networking, 1995. **3**(4): p. 365 - 386.

11. Jacobson, V. and M. Karels. *Congestion Avoidance and Control.* in *SIGCOMM 88.* 1988. Stanford, CA: ACM.

12. Mathis, M., et al., *TCP Selective Acknowledgments options.* 1996, IETF.

13. Thoppian, M. and A. Veduru, *TCP for Wireless Networks.*

14. Mascolo, S., et al., *TCP Westwood Bandwidth estimation for enhanced transport over wireless links*, in *Mobile Computing and Networking.* 2001. p. 287 - 297.

15. Chengpeng, F., *TCP VENO: END-TO-END CONGESTION CONTROL OVER HETEROGENEOUS NETWORKS.* 2001: Hong Kong.

16. Balakrishnan, H. and R. Katz. *Explicit Loss Notification and Wireless Web Performance.* in *GLOBECOM 98.* 1998. Sydney, Australia: IEEE.

17. Parsa, C. and J. GarciaLunaAceves, *Improving TCP Performance over Wireless Networks at the Link Layer.* ACM Mobile Networks & Applications, 1999. **5**(1): p. 57 - 71.

18. Montenegro, G., *TCP/IP for Wireless WANs.* 1999.

19. Kapoor, R., M. Cesana, and M. Gerla. *Link Layer Support for Streaming MPEG Video over Wireless Links.* in *ICCN 03.* 2003. Dallas, Texas: IEEE.

20. Mascolo, S., et al., *End-to-End Bandwidth Estimation in TCP to Improve Wireless Link Utilization.*

21. McKinley, P. and S. gaurav, *Experimental Evaluation of Forward Error Correction on Multicast Audio Streams in Wireless LANs*, in *(ACM) Multimedia.* 2000, ACM. p. 416 - 418.

22. Lefevre, F. and G. Vivier, *Optimizing UMTS Link Layer Parameters for a TCP Connection.*

23. Chen, J. and V. Leung. *Applying Active Queue Management to Link Layer Buffers for Real-time Traffic over Third Generation Wireless Networks.* in *WCNC 03.* 2003. New orleans, LA: IEEE.

24. Luedtke, K., *Absence of Malice*, S. Pollack, Editor. 1981.

25. Passino, Yurkovich., Fuzzy Control 1998: Addison-Wesley.

26. Kosko, B., *Neural networks and Fuzzy Systems.* 1992: Prentice Hall.

27. Mitaim, S. and B. Kosko, *What is the Best Shape for a Fuzzy Set in Function Approximation?*

28. Klement, P. and W. Slany, *Fuzzy Logic in Artificial Intelligence.* 1994, Christian Doppler Laboratory for Expert Systems.

29. Elkan, C. *The Paradoxical Success of Fuzzy Logic.* in *AAAI-93.* 1993. Washington, D.C.: M.I.T. Press.

30. Nguyen, H., O. Kosheleva, and V. Kreinovich, *Is the success of fuzzy logic really paradoxical?* Journal of Intelligent Systems, 1996. **11**(5): p. 295 - 326.

31. Mamdani, E., H. and S. Assilian, *An experiment in linguistic synthesis with a fuzzy logic controller.* International Journal of Man-Machine Studies, 1974. **7**(1): p. 1 - 3.

32. Sugeno, M., *On Stability of Fuzzy Systems Expressed by Fuzzy Rules with Singleton Consequences.* IEEE Transactions on Fuzzy Systems, 1999. **7**.

33. Roberts, J. and S. Oueslati-Boulahia. *Quality of service by Flow Aware Networking.* in *IMA Workshop on Scaling.* 1999.

34. Braden, R., et al., *Resource Reservation Protocol (RSVP)*, in *RFC 2205.* 1997, IETF Network Working Group.

35. Shenker, S., C. Partridge, and R. Guerin, *Specification of Guaranteed Quality of Service*, in *RFC 2212.* 1997, IETF Network Working Group.

36. Wroclawski, J., *Specification of the Controlled-Load Network Element Service*, in *RFC 2211.* 1997, IETF Network Working Group.

37. Jacobson, V., K. Nichols, and K. Poduri, *An Expedited Forwarding PHB.* 1999, IETF.

38. Heinanen, J., et al., *Assured Forwarding PHB Group.* 1999, IETF.

39. Chen, B., et al., *Fuzzy Adaptive Connection Admission Control for RealTime Applications in ATMBased Heterogeneous Networks.*

40. Fontaine, M. and D. Smith, *Fuzzy Logic for controlling call admission in ATM networks.*

41. Piyaratna, S., N. Shenoy, and S. Halgamuga. *A Genetic Algorithm Tuned Fuzzy Logic Based Call Admission Controller for ATM networks.* in *6th International Workshop on Intelligent Signal Processing and Communication Systems*. 1998. Melbourne, Australia: IEEE.

42. Jamin, S., et al., *A Measurement-based Admission Control Algorithm for Integrated Services Packet Networks.* ACM Transactions on Networking, 1997.

43. Floyd, S., *Comments on Measurement based Admissions Control for Controlled Load Services.* 1996.

44. Reisslein, M., *Measurement-Based Admission Control for Bufferless Multiplexers.* International Journal of Communication Systems, 2001. **14**(8): p. 735 - 761.

45. Elek, V., Karlsson, and R. Ronngren, *Admission Control Based on End to End Measurements.*

46. Soud, D. and H. Kazemian. *A Fuzzy approach to connection admission control in 802.11b wireless systems.* in *IECON 2003*. 2003. Roanoke, Virginia, USA: IEEE.

47. Tsang, D.H., B. Bensaou, and S. Lam, *Fuzzy-Based Rate Control for Real-Time MPEG Video.* IEEE Transactions on Fuzzy Systems, 1998. **6**(4): p. 504 - 516.

48. Hu, R., Q. and D. Petr, *Predictive self-tuning fuzzy logic feedback rate controller.* ACM Transactions on Networking, 2000. **8**(6): p. 697 - 709.

49. Loukas, R., S. Köhler, and A. Pitsillides, *Fuzzy RED: Congestion control for TCP/IP Diff-Serv.* 2003.

50. Fragouli, C., V. Sivaraman, and M.B. Srivastava. *Controlled Multimedia Wireless Link Sharing via Enhanced Class-Based Queuing with Channel-State-Dependent Packet Scheduling*. in *INFOCOM 98*. 1998. San Francisco, USA: IEEE.

51. Kuzmanovic, A. and E. Knightly. *TCP-LP: A distributed Algorithm for low priority data transfer*. in *INFOCOM 2003*. 2003. San Francisco, USA: IEEE.

52 Etemadinezhad, G. and M.H. Beheshti. *Congestion control in differentiated service Networks: Fuzzy PID approach*. in *ATNAC 2003*. 2003. Melbourne, Australia.

53. Zhang, R. and M. Jian. *A Fuzzy Approach to the Balance of Drop and Delay Priorities in Differentiated Services Networks*. in *SCI 2003*. 2003. Orlando, Florida.

54. Regehr, J. and J. Stankovic. *Augmented CPU Reservations: Towards Predictable Execution on GeneralPurpose Operating Systems*. in *RTAS 2001*. 2001. Taipei, Taiwan: IEEE.

55. Jones, M. and J. Regehr, *The Problems You're Having May Not Be the Problems You Think You're Having:*
Results from a Latency Study of Windows NT. 1999.

56. Regehr, J. and J. Stankovic. *HLS: A Framework for Composing Soft RealTime Schedulers*. in *RTSS 2001*. 2001. London, UK: IEEE.

57. Murray, J., *Real-Time Systems with Microsoft Windows CE*. 1997, Microsoft Corporation: Technet.

58. Sloan, J., *Network monitoring tools*, in *Network troubleshooting tools*, R. Denn and M. Loukides, Editors. 2001, O'Reilly & Associates. p. 205 - 216.

59. Case, J., et al., *Simple Network Management Protocol (SNMP)*. 1990, IETF.

60. Ramakrishnan, K. and S. Floyd, *A proposal to add Explicit Congestion Notification (ECN) to IP*. 1999, IETF Network Working Group.

61. Garg, P., R. Doshi, et al. (2003). Using 802.11e MAC for QoS over wireless networks. IPCCC 2003, Phoenix, Arizona, IEEE.

62. Masters, T., *Practical Neural Network Recipes in C++*. 1 ed. 1993: Academic Press. 493.

63. Leland, W., et al., *On the Self-Similar Nature of Ethernet Traffic (extended version).* ACM Transactions on Networking, 1994. **2**(1): p. 1 - 15

64. IEEE Working Group, I. W. (2001). IEEE 802.11 WG, Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service. 2001.

65. Soud, D. and H.B.Kazemian. *A Fuzzy approach to active Usage Parameter Control in 802.11b wireless systems.* To be published in Expert Systems Journal Nov. 2004

66. Frey, T., *The Effects of the Atmosphere and Weather on the Performance of a mm-Wave Communication Link*, in *Applied Microwave & Wireless - ceased.* unknown, Lockheed Martin Tactical Aircraft Systems.

Appendix 1

Environmental management in wireless systems

A.1 effects of atmospheric conditions on RF transmission

The effects of atmosphere on RF transmission influence the overall performance of wireless systems. However, transmission media are affected differently, be it low/high-frequency radio, microwave radio, or laser transmission. The wavelength of each transmission determines the effects. The three most significant conditions that affect radio transmission are absorption, scattering and scintillation (shimmer). All three conditions can reduce the Received Signal Strength Indication (RSSI) and affect bit error levels.

Absorption

When microwaves impinge on a dielectric material, part of the energy is transmitted, part reflected and part absorbed by the material where it is dissipated as heat. Absorption is caused primarily by water vapour and carbon dioxide in the air. The density of water and carbon dioxide are conditioned by humidity and altitude. Gases that form in the atmosphere have many resonant bands, called transmission windows, to allow specific frequencies of light to pass through. These windows occur at various wavelengths. The window we are most familiar with is that of visible light. The near-infrared wavelength of light (830 nm) used in laser transmission occurs at one of these windows; therefore absorption is not generally a big concern in an infrared laser transmission system. Work done on absorption of water vapour and its effect on microwave transmission indicates that for frequencies below 30 GHz the effect on signal transmission is minimal. The assumption has always been that there needs to be a minimum rate of 30mm/hr before water vapour has any effect on radio signals below this threshold.

Scattering

Scattering has a greater effect than absorption. The atmospheric scattering of light is a function of the wavelength of the light and the number and size of scattering elements in the air. The optical visibility along the path is directly related to the number and size of the scattering particles. Common scattering elements in the air that will affect laser beam or RF transmission are rain, fog and smog. Fog appears when the relative humidity of air is brought to an appropriate saturation level. Some of the nuclei then grow through condensation into water droplets. Attenuation by fog is directly attributable to water droplets less than a few microns in radius. The result of the scattering is that a reduced percentage of the transmitted light reaches the receiver. Smog's effects are similar to those of fog, but not as severe because of the difference in radius of the particulate matter. Although the liquid content of a heavy shower is denser than fog, the radius of a raindrop is approximately 1000 times that of a fog droplet. This is the primary reason that attenuation during rainfall is much less than that in foggy conditions.

Scintillation

At low altitudes, scintillation effects arise from temperature differences between the ground and air and the resulting heat exchange. The index of refraction of air changes with temperature and the heat exchange causes local index variations that affect the laser propagation. Different optical effects arise from different scintillation event sizes. Scintillation has a greater effect on frequencies in the visible light spectrum.

Global solar irradiance

Global solar irradiance is electro-magnetic energy radiated from the sun. The level of irradiance is dependent on the season of the year and time of day. The beam solar irradiance reaches its peak at the zenith of the sun's course, and then reduces towards evening. Solar irradiance can be affected by high moisture content in the atmosphere. There is evidence to suggest that the global solar irradiance may also reduce the transmitted power of a radio device in the 2.4 GHz range

A.2 Influence of environment on RF systems in the 2.4 GHz frequency

A.2.1 Effect of irradiance on signal quality

The graph in Fig A.1 below demonstrates a steady reduction in signal quality during a 12 hour period from 9 am to 9 pm. on July 10th 2003. The record for that date shows a peak temperature of 34 degrees centigrade with a clear sky the night before. These conditions of low relative humidity persisted over the next few days resulting in clear evenings and nights. During this period the received signal remained high though the drop during the day was not so steep as that shown in the graph of July 10th as can be seen in Fig A.2.

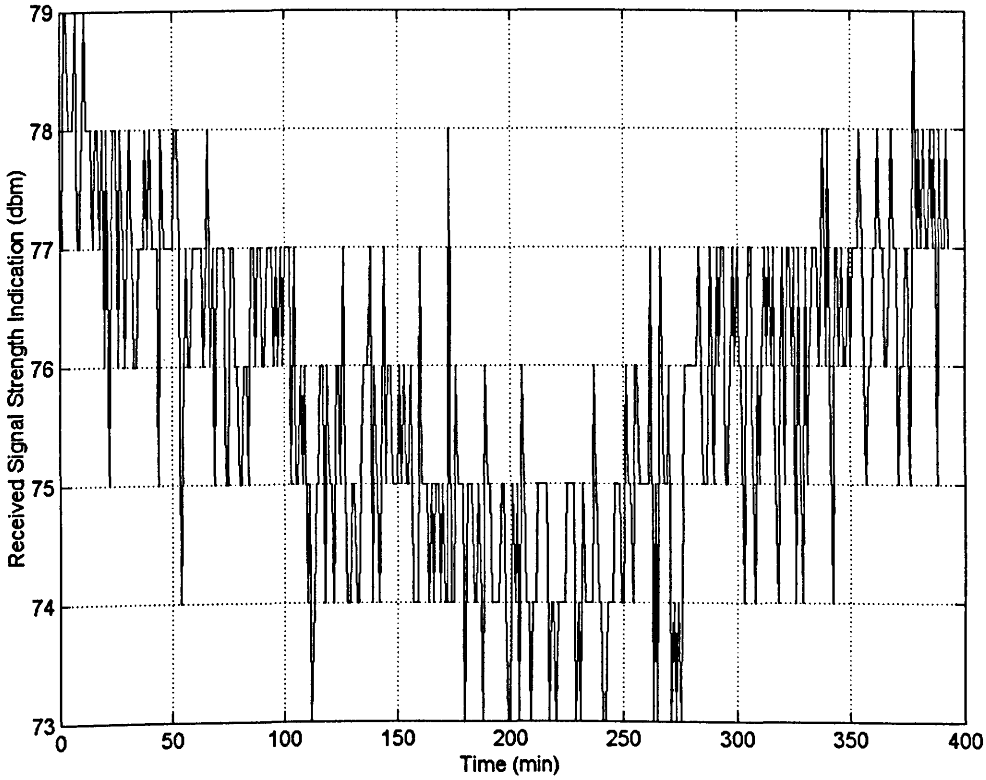


Fig A.1. Signal quality on July 10th 2003

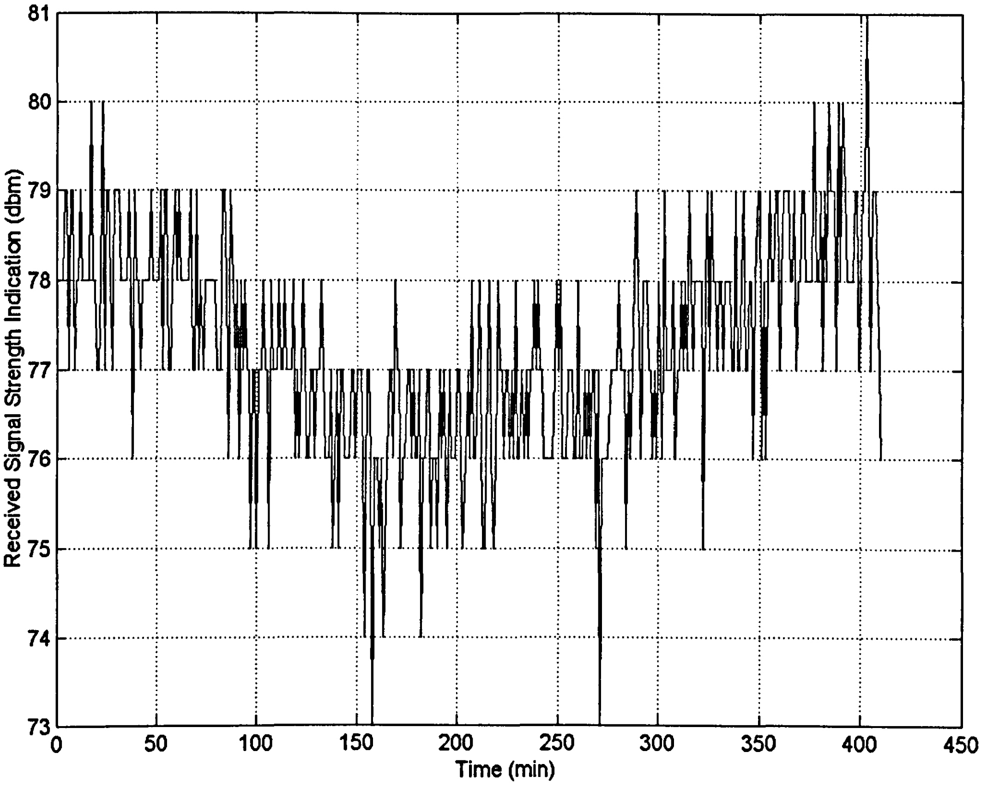


Fig A.2 Signal quality on July 12th 2003

The next two graphs are further examples of how the RSSI varies in fine weather conditions.

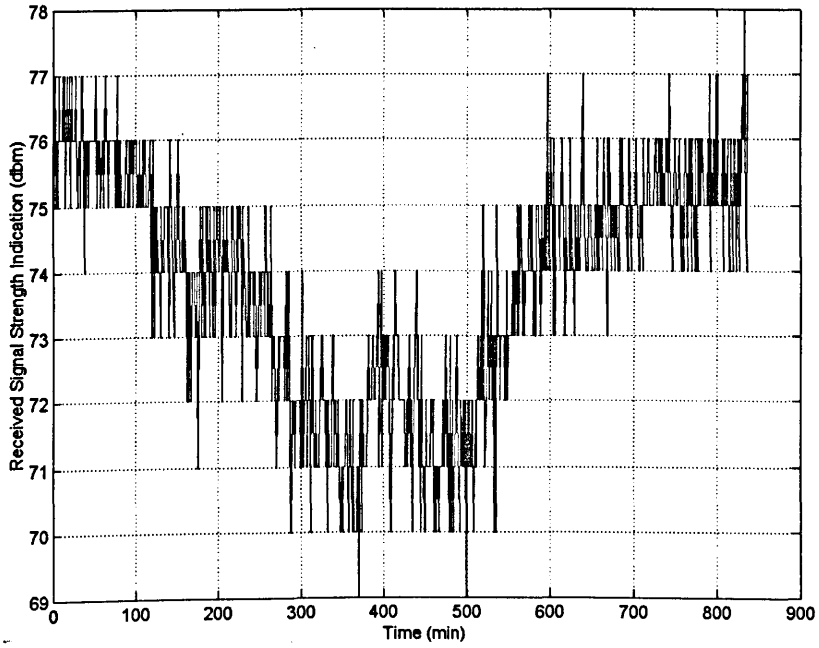


Fig A.3 Signal quality on April 7th 2004

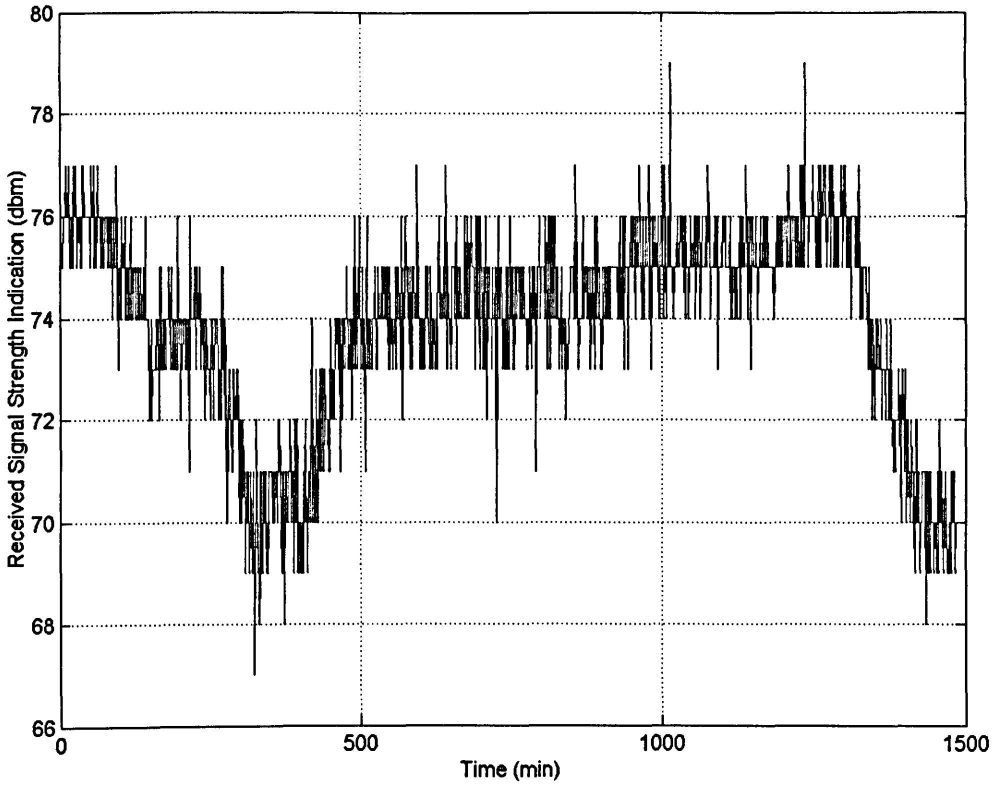


Fig A.4 Signal quality on April 8/9 2004

In Figure A.4 the plot extends into the next day. Observe how the signal improves during the night then drops as the sun rises the next day. In both cases '0' indicates 9.00 am.

A.2.2 Effect of direct global solar irradiance in summertime

The fine weather produces an unusual pattern of RSSI readings. The RSSI seems to reduce as the sun rises to its highest point. Once past the midpoint of the day, the opposite occurs and the RSSI improves. In the afternoon the RSSI climbs up to its highest point. On cloudy days and nights the signal quality stays lower without the steep daytime declines. This could be the diffuse solar irradiance exerting a dampening effect. The effect lingers through the night since the overall signal quality is lower on overcast days. Contrast the quality with that measured on August 18th 2003 (Fig A.5). On the day to which the data in the figure below relates the temperature was at least as high as July 12th, though the previous night was overcast the signal strength however is much lower.

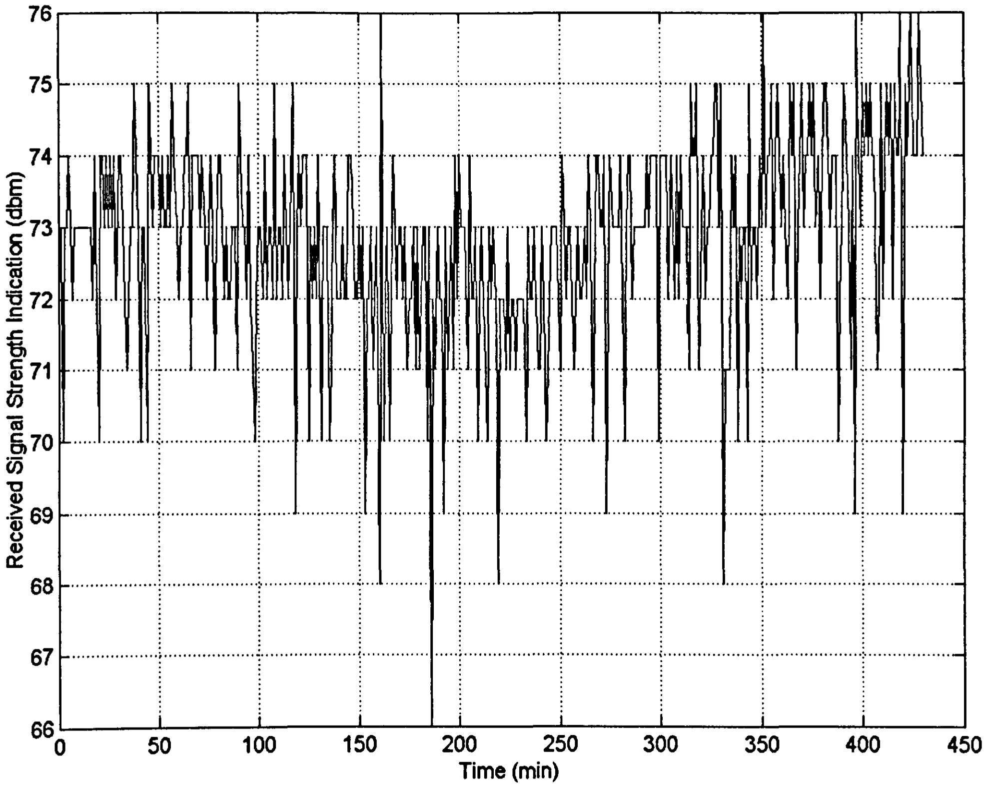


Fig A.5 Signal quality on Aug 18th 2003

A.2.3 Effect of direct global solar irradiance in winter

These phenomena are not confined to the summertime. Similar readings have been observed in winter as well. The common factor is that signals measured are always higher when the previous night and following day contain no cloud cover. A humidity range during the day of greater than 30% indicates a bright cloudless day. As an example March 1st 2004 (Fig A.6) exhibits a similar pattern to July 10th 2003. In both cases the previous nights were clear and on the following day, conspicuous drops in signal quality occurred.

A.2.4 Other causes of signal loss

It is possible that these effects could arise from other causes. The most likely candidates are:-

- Absorption leading to signal attenuation following an increase in humidity.
- Change in the dielectric constant of the air due to changes in relative humidity
- Additive white gaussian noise from increased temperature (AWGN)

Losses due to absorption can be discounted since the absolute humidity does not vary over the periods where the signal readings are taken. This can be established from measurements of the dew point taken from July 10th to August 18th and also from March 1st to March 5th. If the dielectric constant had any effect then the inverse pyramid demonstrated in the readings taken on July 10th 2003 and March 1st 2004 would be repeated for all dates with similar though not so pronounced relative humidity. Below in Figs A.7 and A.8 are the readings for relative humidity for July 10th and August 18th. It can be seen that though these are similar, the signal quality on these dates varied dramatically.

Eliminating the effect of AWGN as a result of rising temperature is tricky. It could be argued quite reasonably from figure A.1 above that noise increased proportionally to temperature. If this were always the case however, the readings obtained in Fig. A.6 below could not exist since the temperature in both cases varies widely! The temperature/ humidity chart for March 1st can be seen in Fig. A.9 for comparison. Also the noise would continue increasing through the day peaking when the wireless equipment was warmest. One view is that a rising temperature may be instrumental in increasing AWGN but further research needs to be undertaken to determine its extent. If these readings are however due to the effect of Brownian noise it would suggest that existing methods of estimating noise might need to be revised[1] as they may not be appropriate to wireless equipment.

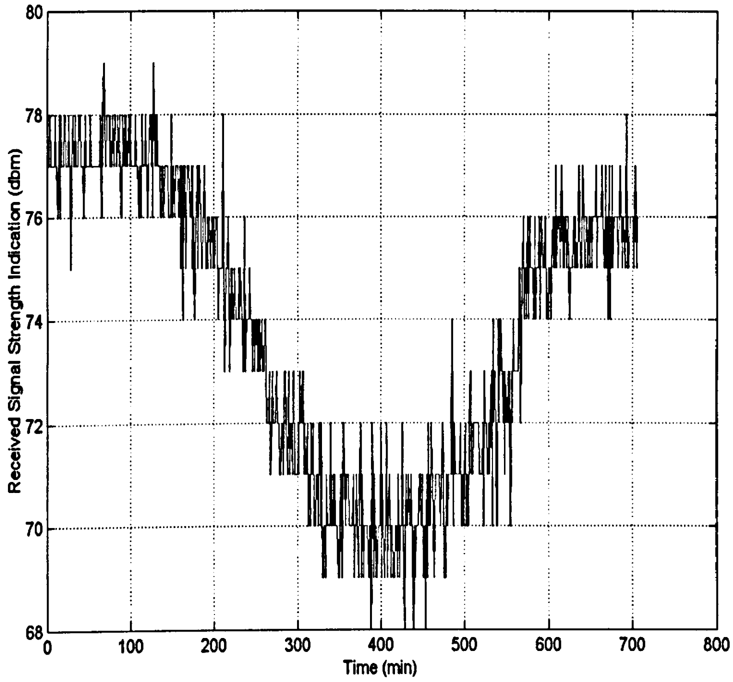


Fig A.6 Signal quality on Mar 1st 2004

---

[1] Estimate noise in a wireless signal N = Nf KTB
Where Nf = noise at the receiver; KTB is random fluctuation caused by temperature

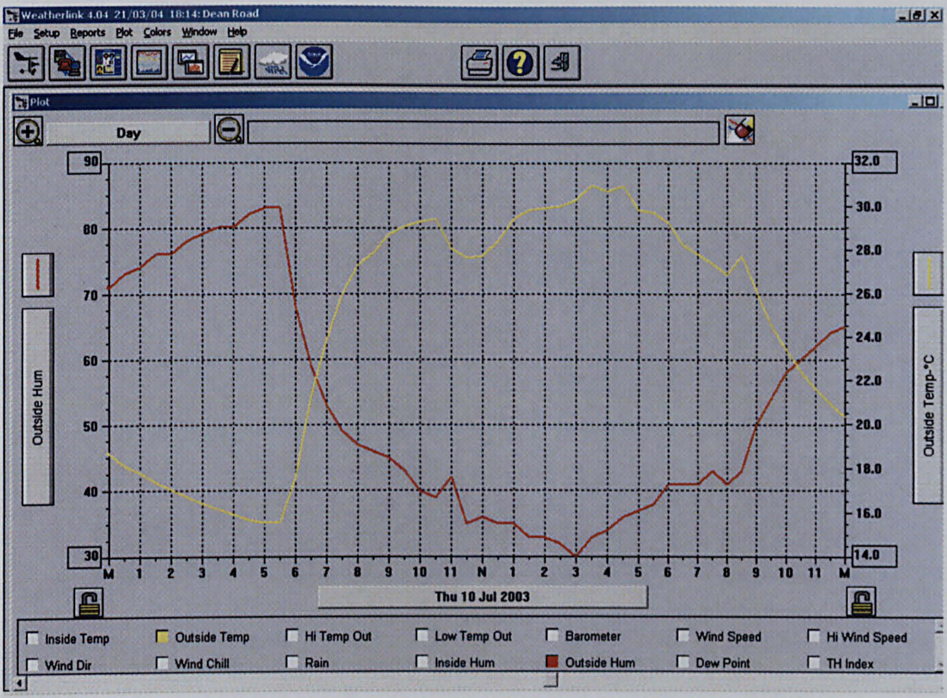


Fig A.7 Temperature and humidity readings for July 10th 2003

Fig A.8 Temperature and humidity readings for August 18th 2003

Fig A.9 Temperature and humidity readings for March 1st 2004

A.2.5 Implications of solar irradiance effects

What is the importance of these findings and how may they contribute to research on microwave technologies? If confirmed it would have significant implications for climatology and wireless computing. Firstly it could provide us with a low cost and accurate measure of solar irradiation. Current methods involve the fabrication of costly pyranometers that lack sensitivity and accuracy. It suggests also that current methods of measuring solar irradiance could bear further scrutiny. Climatologists would be presented with a new set of tools for monitoring changes caused by solar radiation. As far as the wireless community is concerned, it would permit the prediction of wireless quality in advance, this would lead to more accurate provisioning and reduced power consumption. The UK alone uses over 40 million mobile phones drawing up to 7 watts of power on a daily basis, excluding the 35000 base stations supplying signals transmitting an average 500 mW power (source *OFCOM*). If any savings can be generated they are likely to be significant. Robust transmission codes can be developed to eliminate the error caused by solar irradiation. Such codes can be applied using fuzzy logic in order to reduce power increases initiated by signal inhibition from increasing solar irradiance.

Appendix 2

Network hardware and layout

Schedule of wireless equipment

Description	Access type	Transmit power	Maximum transmit speed	Mode
Breezecom SA10D1	Bridge	50 mA	3 Mb/s	FHSS
Breezecom SA10D2	Bridge	50 mA	3 Mb/s	FHSS
Breezecom SA10D3	Bridge	50 mA	3 Mb/s	FHSS
Breezecom SAPCR1	Wireless card	100 mA	3 Mb/s	DSSS
Breezecom AP10D1	Access point	50 mA	3Mb/s	FHSS
Breezecom AP10D2	Access point	50 mA	3Mb/s	FHSS
3COM Office connect	Access point	100 mA	10 Mb/s	DSSS
3COM Office connect	Wireless card	100 mA	10 Mb/s	DSSS

Schedule of fixed equipment

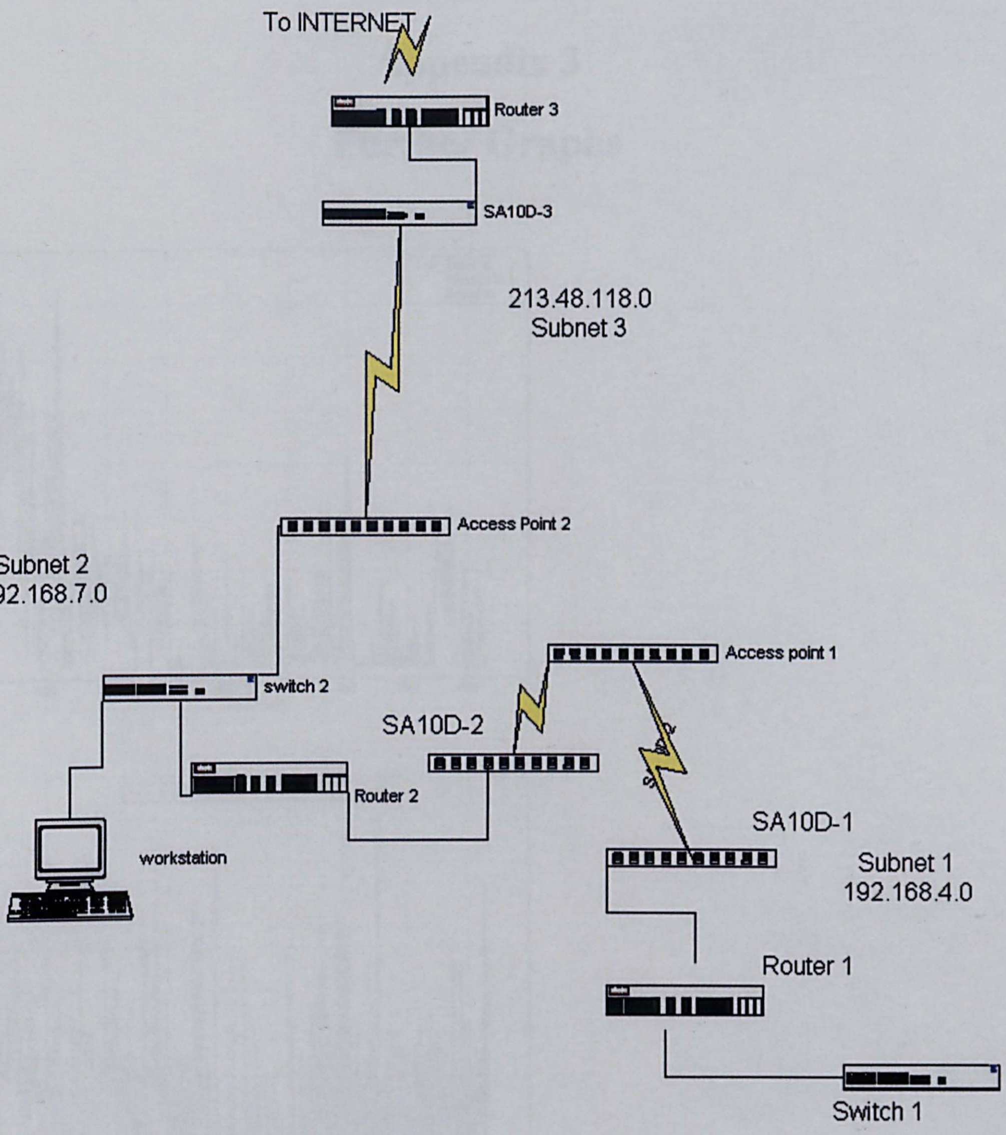
Description	Manufacturer	Operating system	Port speed	Flash memory	Subnet
2620 access router	CISCO	12.1	100Mb/s	32 MB	213.48.118.0
2514 access router	CISCO	12.1	10Mb/s	8MB	192.168.7.0
2514 access router	CISCO	11.1	10Mb/s	4 MB	192.168.4.0
24 port switch	Intellinet	N/a	100 Mb/s	N/a	192.168.7.0
24 port switch	Intellinet	N/a	100 Mb/s	N/a	192.168.4.0

Appendix 2

Deployment of wireless network

Subnet number	IP network	Link	Distance Km
1	192.168.4.0	SA10D1 to AP10D 1	2.5
2	192.168.7.0	SA10D2 to AP10D 1	2.0
3	213.48.118.0	SA10D3 to AP10D 2	3.0

Appendix 2

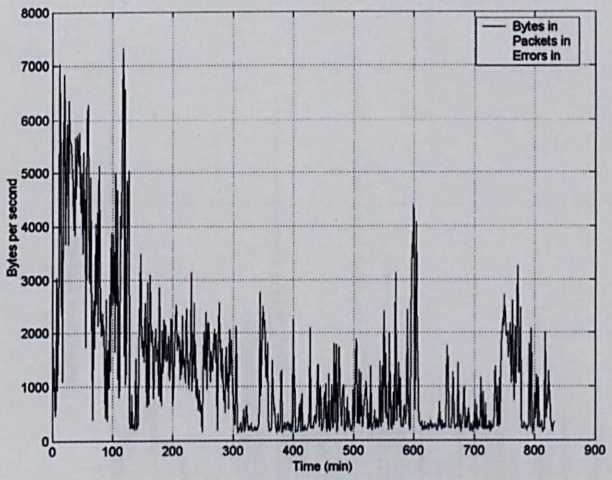


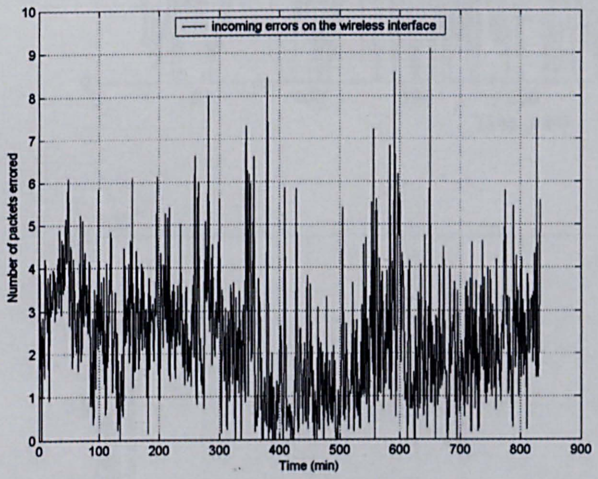
Project Wireless network

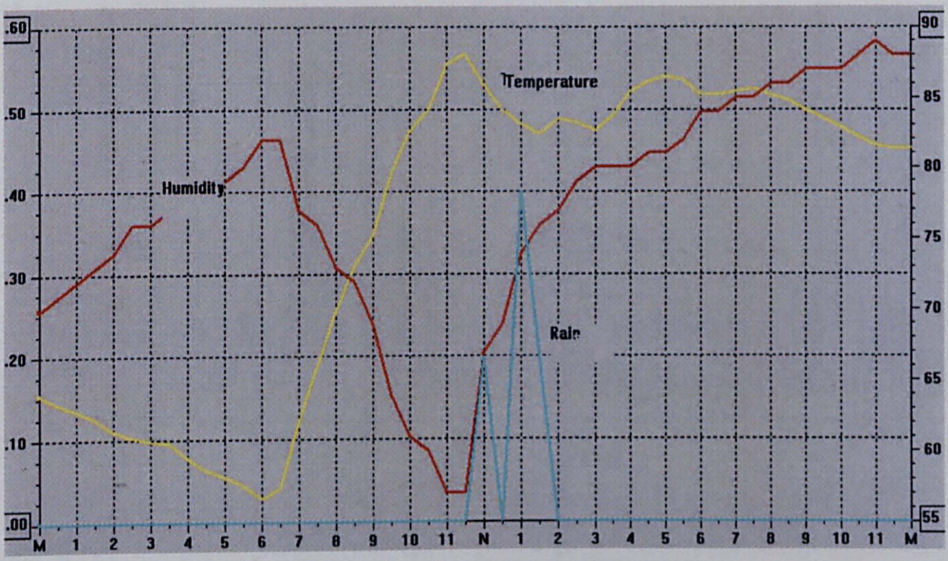
Schematic of network showing deployment

Appendix 3

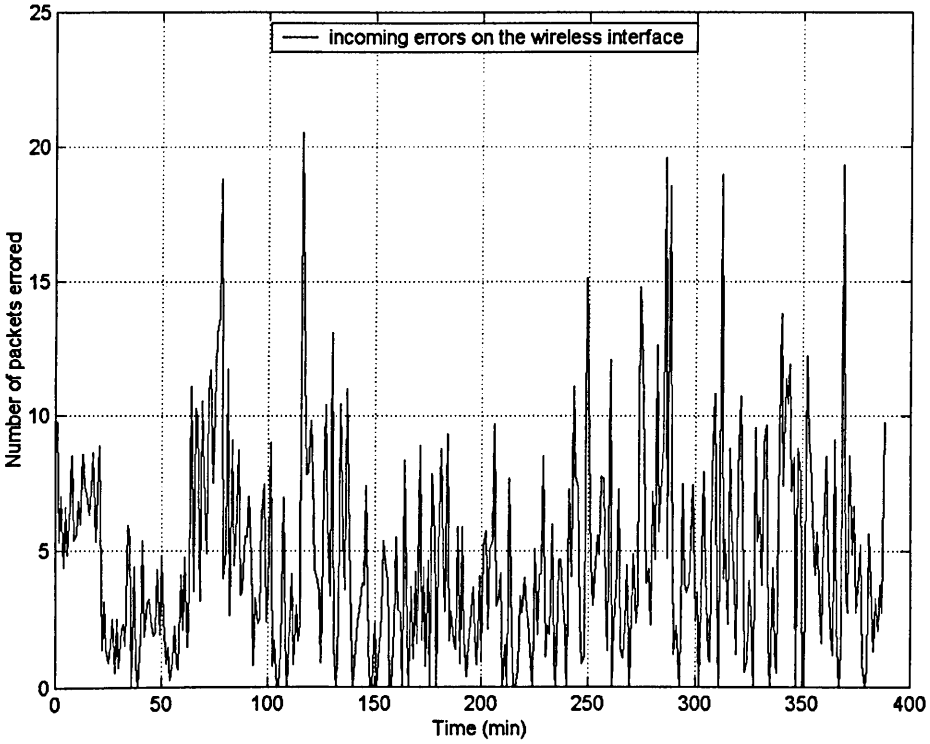
Further Graphs

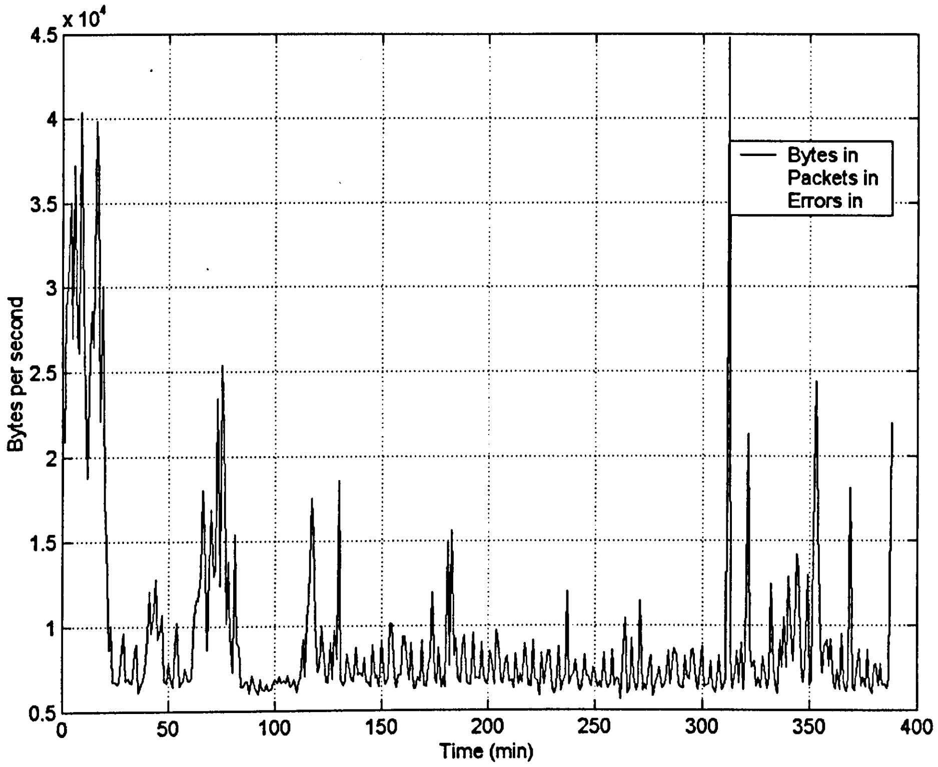




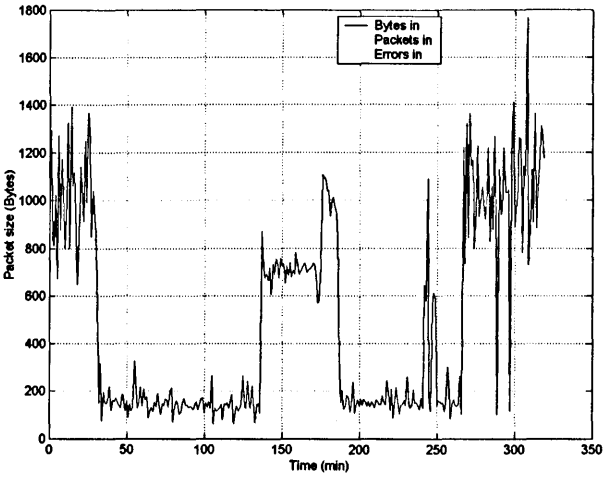


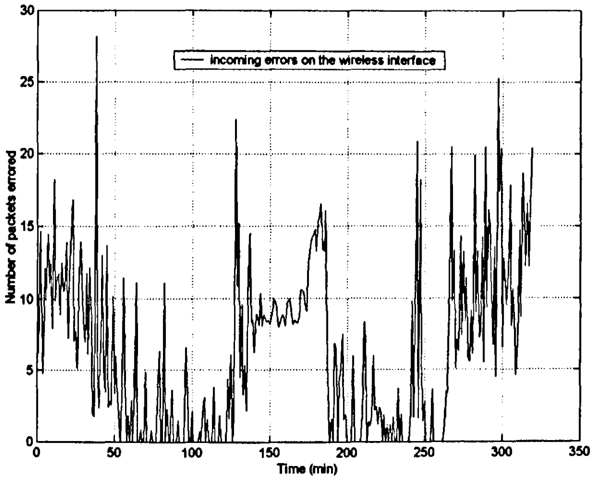
Relationship between load, errors & atmospheric conditions





Relationship between load and errors





Relationship between load, errors and packet size