CHAPTER 1

Introduction

1.1 ATM Congestion Control

Asynchronous Transfer Mode (ATM) is emerging as one of the most promising technology in the area of high-speed data communication networks. ATM uses a very flexible method to carry broadband information between devices on a local or wide area network. ATM network transmits information using small, fixed-length (53-byte) data packets, called cells over high-speed transmission facilities. The 53-byte cell consists of 48 bytes of payload and 5 bytes of header. The use of fixed-length cells reduces the variance of delay making the networks suitable for integrated traffic consisting of voice, video and data [1].

ATM resources such as bandwidth and buffers are shared among users of the network. These resources are allocated to users only when they have something to transmit. Due to this, the network uses statistical multiplexing to efficiently share transmission resources and to improve on effective throughput. However, because of the different characteristics of traffic sources, the task of providing the desired quality of service for each user is more complex. To ensure fairness and efficient operation of the networks, proper traffic management is needed.

Traffic management is concerned with ensuring that users will get desired quality of service. Problems arise when the traffic load increases to the extent where the network is unable to accommodate. Since the traffic demand cannot be predicted, congestion is unavoidable under these circumstances. Whenever the total input rate is more than the output rate, congestion will occur. This results in buffer overflow and users experiencing cell loss. To overcome this, congestion control is necessary to ensure that users get the quality of service they requested. That is why congestion control is viewed as the most essential part of traffic management [1].

ATM congestion control measures are very much different from existing congestion control schemes available in packet switching or frame relay networks. The is due to the type of traffic pattern as well as the transmission characteristics for ATM networks that are different from other switching networks. Because of the high-speed and small cell size, ATM networks present difficulties in effectively controlling congestion not found in other types of network. Implementation of some form of control over the flow of user cells is difficult because there is only limited amount of overhead bits available in the cell header. The area of congestion control in ATM is still under intense research. New approaches to traffic and congestion control are still evolving and being tested.

In discussing the development of ATM technology and standards, we should mention the contributions made by the ATM Forum. The ATM Forum, a nonprofit international industry consortium, was created with the goal of accelerating the development of ATM standards. To this day, the ATM Forum has published numerous specifications to accelerate efforts for ATM standardization. The ATM Forum has also published a set of specifications regarding traffic management in *The ATM Forum Traffic Management Specification Version 4.0* [2]. It describes the traffic management framework and important traffic control functions in ATM networks.

1.2 Issues in ATM Congestion Control

A number of traffic control functions has been specified by the *Traffic Management Specifications*. The first line of defense is Connection Admission Control (CAC). Its task is to evaluate and determine whether a connection can be accepted or should be rejected. When a user requests for a connection, the user must specify the service required for that particular connection. Decision is made based on the information in the traffic contract and the condition of the network. If resources are available to support the quality of service and bandwidth requested, the connection is accepted. Otherwise, the connection will be rejected to protect the network from excessive loads.

After the connection is accepted, congestion may still occur in the ATM network. This is because a connection can potentially exceed the negotiated values in the traffic contract during CAC setup. Thus, a function must be introduced to monitor the connections to ensure that each conforms to the traffic contract. Usage Parameter Control (UPC) is the function defined in the ATM Forum *Traffic Management Specifications* to monitor cell streams during the entire active phase of the connection. UPC's job is to restrict the cells originating from a traffic source to the traffic descriptors negotiated in the traffic contract. Actions must be taken against those connections that violate the traffic contract. The most obvious step would be to discard all cells for which a violation of the traffic contract is detected. Another method is to selectively discards cells which have a lower priority. Various approaches and algorithms have been developed to perform UPC's functions.

However, both the connection admission control and usage parameter control suffers from some fundamental limitations. Firstly, it is difficult for a network to acquire complete statistics of the input traffic accurately [3]. Some of the characteristics of the traffic may not be known with required accuracy during connection setup and some of them may be modified before the cells reach the UPC function. Furthermore, the UPC functions dependence on monitoring traffic parameters such as peak cell rate, mean cell rate and burst size have some limitations as well. These parameters are not sufficient to completely describe the behavior of all ATM sources. Coupled with less than satisfactory accuracy, these uncertainties result in a significant probability that the UPC makes a wrong decision and discard cells originating from a compliant source. This will affect overall network performance and jeopardize the quality of service requested by users. In short, a network is forced to make a decision based on incomplete information and the decision process is full of uncertainties.

Recently, fuzzy logic systems have been widely applied to control nonlinear, time-varying, and ill-defined systems [4]. Fuzzy logic controllers (FLC) are used extensively in industrial environment such as automotive engineering and medical process. The widespread use of FLC in these areas is due to its incredible flexibility and adaptability. The success of FLC in handling nonlinear and complex systems has attracted the interest of researchers involved in ATM congestion control. These characteristics of FLC are seen desirable in developing a possible solution to effectively control congestion. Currently, a lot of work has already been done to utilize the FLC in congestion control. Papers have been published that produce some favorable results when compared with conventional methods [3-8]. The next section will present some of the previous works done in this area.

1.3 Previous works on Fuzzy Logic Control in ATM Network

As indicated earlier, numerous works has been done on utilizing fuzzy logic approach to perform traffic and congestion control functions in ATM networks. Papers have been published which showed that the performance of fuzzy control is at least on par, if not better, when compared to existing algorithms.

In this section, a few approaches are discussed to better understand the significance of introducing fuzzy logic control in performing ATM traffic and congestion control functions.

In [3], two existing policing mechanisms, namely the *Modified Leaky Bucket* mechanism and the *Moving Window* mechanism are incorporated into a Fuzzy Rule-based System to perform traffic policing functions. It has been found that conventional policing schemes relied on traffic parameters that may not be available with the required accuracy in making policing decisions. These traffic parameters may be modified at a later stage due to cell delay variation or may be inaccurate because of the short samples of values being taken. All these factors have attributed to the possibility that the policing function may penalize a compliant connection or source. They have reviewed existing policing schemes such as the *Leaky Bucket, Jumping Window, Triggered Jumping Window, Exponential Weighted Moving Average* and *Moving Window* mechanisms. Their studies showed that the *Leaky Bucket* mechanism stood out among the rest, however, it is proven to be very difficult to dimension. The policing of mean rate and policing of peak rate requires completely different dimensioning in terms of the leak rate and bucket size. Therefore, it is difficult to dimension the *Leaky Bucket* to monitor both the peak and mean rate. Also, the *Leaky Bucket* is less responsive in the sense that it will not react to severe violation until the counter exceeds its limit. This situation might affect other existing connections in the network. Thus, they have set out to search for a solution to this problem.

They proposed the utilization of *Modified Leaky Bucket* together with *Moving Window* mechanism to provide input data to a Fuzzy Rule-based system. The *Modified Leaky Bucket* mechanism is a modified version of the conventional *Leaky Bucket* mechanism. It has a threshold value which is larger than the bucket size, to limit the increasing counter value for incoming cells. Thus, it can shut off violating sources and reserved available bandwidth to other compliant sources. In the *Moving Window* mechanism, the number of cells that can be accepted within a fixed interval time is bounded by the window size. Incoming cells that exceed the window size will be rejected. The interval is set to the time needed to transmit a specified number of cells at peak rate. This mechanism will keep track of the number of cells in the window during the fixed interval of time.

Both the *Modified Leaky Bucket* mechanism and the *Moving Window* mechanism is combined, with the former dimensioned to police mean cell rate, while the latter monitors the peak cell rate. For each cell arrival, the counter value and the number of cells in the window obtained via the above two mechanisms are fed into the Fuzzy Rule-based decision making system. The Fuzzy Rule-based system will then decide on accepting or discarding cells, based on inputs from both mechanisms, and its fuzzy rule-base. Therefore, the proposed fuzzy implementation utilizes information from two existing policing mechanisms in policing incoming cells. The simulation results showed that the proposed approach is effective in monitoring mean rate and peak rate violations. It also surpassed the other mechanisms in detecting violations quickly.

However, the proposed method focused solely on inputs from policing function without taking into account the state of the network. During congestion period, a different approach to policing may yield a better performance and help relieve the situation. Therefore, the proposed fuzzy control might not be able to make more appropriate policing actions when congestion does occur. Also, the inputs from the two traditional policing mechanisms may suffer from inaccuracy as described earlier, and thus degrades the performance of the proposed fuzzy method.

A fuzzy policer is proposed in [5] that aims to detect violation of negotiated traffic parameters efficiently and reduces the probability of false alarm. Their studies showed that existing policing mechanism could not meet all the requirements of an ideal policing mechanism at the same time, i.e. ability to detect violation efficiently, low response time to parameters violation and simplicity. This has led them to use fuzzy logic to overcome the limitations of traditional mechanisms. Their proposal is a window-based control mechanism, in which the maximum number of cells that can be accepted in a specific window of certain length, is a threshold that is dynamically updated by inference rules. The objective of the fuzzy policer is to restrict a source or connection to its negotiated parameters over the duration of a connection. Short-term fluctuation of the monitored parameter is allowed as long as it complies with the mean value negotiated in the long term.

In the proposal, decision is based on global evaluation of the behavior of source from the beginning of connection to the instant in which the decision is made. A period of high transmission rate is tolerated as long as the mean rate calculated since the beginning of connection does not exceed the negotiated values. Additional period of temporary violation is permitted according to the credits earned, by increasing its control threshold. Credits can be obtained if the source has complied with the negotiated values in the past. On the contrary, the credit is reduced if the source has exceeded the negotiated values, by decreasing the control threshold.

Among the inputs to the proposed fuzzy policer are: the average number of cell arrivals per window since the beginning of the connection, the number of cell arrivals in the last window, and the value of the control threshold in the last window. The first input gives the long-term trend of the behavior of the source, the second input indicates the current behavior, while the third input shows the present tolerance given to the source. The fuzzy policer, after evaluating the inputs given and its fuzzy rule base, will output a control action in the form of a variable that updates the control threshold for the next window. The output represents the variation that needs to be made to the control threshold. Thus, the fuzzy policer is able to increase or reduce the number of cells that can be accepted by modifying the control threshold value. This enabled the fuzzy policer to monitor and restrict a source to its negotiated parameters while protecting other compliant sources.

Simulation is carried out to compare the performance of the fuzzy policer with the *Leaky Bucket* and *Exponential Weighted Moving Average* mechanisms. The performance measures used were the ability to detect violation and responsiveness of the mechanisms. Simulation results showed that the proposed fuzzy policer outperforms both mechanisms in these areas. They also tested the fuzzy policer under different violation situation and once again the fuzzy policer performed better than traditional policing methods.

If examined carefully, the proposed method depends on the average rate of the connection in both short and long term, and the tolerance/credits earned by the source when making policing decisions. This approach is more efficient in the sense that it considers the behavior of the source in the past. However, if a source is constantly transmitting below the negotiated values, it will earn credits up to the maximum control threshold value. The source will then have a greater tolerance period to transmit at a higher rate. Problems arise when the network operator needs to reduce or limit the tolerance period because of resource management requirements. This will require adjustments to be made to the fuzzy policer for this kind of situation. Also, during congestion period, it might be better to be more strict in making policing decisions to help prevent the spread and intensity of the congestion. This approach will inevitably improve the fuzzy policer's performance especially during congestion period.

In [6], work has been done to analyze existing queue management schemes in ATM networks. The use of finite-sized buffers with queue management schemes is one of the many approaches to congestion management in ATM networks. This approach aims to provide an efficient balance between the network throughput and network performance. Network throughput is depicted by the number of cells propagated through the network without being dropped, while network performance is indicated by the delay incurred to cells when propagating through the network.

They have reviewed various methods previously proposed for queue management in ATM networks. Their studies showed that although the methods proposed earlier does provide some solution the problem, but all suffered from some fundamental limitations. The limitations exist due to the fact that most of the common approaches for queue management uses binary thresholds or different level of cell priorities to handle the discarding of cells.

Binary thresholds have been used to indicate the onset and relieve of congestion. When the buffer occupancy exceeds a specified upper threshold, actions are taken to discard incoming cells. On the other hand, priorities are sometimes assigned to cells, with a higher priority given to real-time traffic while lower priority being associated to data traffic. Higher priority cells have precedence over lower priority cells and hence, lower priority cells will first be dropped when the queue is full. In addition, the use of different sets of thresholds corresponding to different priorities has also been proposed. Problems arise because conventional queue management schemes are generally unable to determine effective threshold settings accurately and dynamically. Moreover, the principles underlying the choice and nature of thresholds under uncertain dynamic conditions are still unclear. Due to this, they proposed a fuzzy solution to overcome the limitations of existing queue management schemes.

In their proposal, they suggested the use of fuzzy thresholds, instead of the widely used fixed thresholds, to manage queues in ATM networks. They argued that traditional binary thresholds are too restrictive in nature, while the use of priorities also depends upon thresholding. Fuzzy thresholds provide soft control, which is able to characterize imprecise values such as buffer occupancy and capture linguistic rule base control strategies. Buffer queues will have greater ability to adapt to dynamic conditions and exhibit robustness. They have used the idea of selective cell-blocking, where a switch deliberately refuses entry to a fraction of incoming cells from a source switch into the buffer queue. Decision is based on certain criteria and conditions observed by the switch. The remainder of the cells which are blocked, have to be rerouted by the sending switch to other switches, and may incur delay in the process. However, the notion of cell blocking has some impact on the concept of virtual circuits in ATM networks. ATM networks utilize connection-oriented approach, which requires some adjustments to include the option for selective cell blocking. For example, some form of message fragmentation, cells reordering at destination, and algorithms to route blocked cells have to be considered.

A fuzzy thresholding function is used to decide how many of the incoming cells have to be blocked. In contrast, fixed thresholds uses binary thresholds to either accept or refuse entry of cells based on the occupancy of the buffer. The fuzzy thresholding function is a continuous function of the current buffer occupancy level. Note that only cells that are already in the buffer are subjected to being dropped when buffer overflows for both fuzzy and fixed schemes. To develop a more realistic view of buffer occupancy and provide a robust decision making, two fuzzy states have been identified to characterize the buffer occupancy level. The terms "getting FULL" and "not getting FULL" provide a soft transition between full and empty state of the buffer. The proposed scheme avoids abrupt changes associated with using a single threshold value to decide on accepting or blocking cells.

The input to the fuzzy system is the current buffer occupancy level. The fuzzy control rule base reflects the cell blocking strategy employed. Based on the rules, it then decides on the fraction of cells to be blocked from entering the switch. Output is in the form of the percentage of incoming cells to be refused entry into the buffer. These cells will have to be rerouted by the sending switch to other switches.

The performance of the fuzzy versus fixed threshold schemes has been analyzed through simulations. Various scenarios are used to test both schemes under simulated congested traffic conditions. The throughput, number of cells blocked, and number of cells dropped are recorded for performance evaluation. Simulation results showed that the fuzzy scheme adapts better than traditional, fixed cell blocking scheme to changes in maximum burstiness, cell arrival rates and traffic volume. They concluded that the fuzzy scheme offers a more robust queue management scheme than conventional fixed threshold approach.

Considerations however, need to be made on the impact of selective cell blocking, used in the proposed fuzzy approach. The impact of fuzzy blocking on ATM virtual paths and fuzzy thresholds on the degree of message fragmentation presents some obstacles in real world implementation. As discussed earlier, further work needs to be done to overcome the issues above.

Another fuzzy-based policer is proposed in [7] as an alternative to the *Leaky Bucket* algorithm. In their work, they have studied the performance of the *Leaky Bucket* algorithm in policing mean rate. Two parameters control the behavior of a *Leaky Bucket* policer, i.e. the leak rate and bucket size. To achieved the ideal throughput in policing mean rate, the *Leaky Bucket* policer needs to be dimensioned as follows; leak rate being set equal or within a close range to the negotiated mean rate, while the bucket size needs to be very large. With these settings, the *Leaky Bucket* policer is very sensitive to mean rate violations and can accommodate short bursts. However, a large bucket size results in poor response time to long bursts. On the other hand, setting the leak rate to be slightly greater with a smaller bucket size to monitor mean rate can restrict long bursts, but affects the performance of policing mean rate as well as short bursts. Hence, their analysis revealed that the *Leaky Bucket* policer is ineffective in policing bursty traffic.

In view of the limitations of *Leaky Bucket* policer, they have proposed an alternative in the form of a fuzzy policer. Their objective is to design a fuzzy policer that is able to simultaneously monitor mean rate and reject bursts, thus providing a solution to the above problem. The proposed fuzzy policer performs its task by continuously computing the drop rate imposed on incoming cells, based on collective evaluation of compliance/violation level of two parameters: ratio of up-to-date mean burst length to negotiated mean burst length, and ratio of up-to-date mean rate to negotiated mean rate. Decision to either pass or discard cells is then made based on the compliance/violation level of the two parameters and its fuzzy rule base. The idea is to ensure that the most appropriate decision is made during different bursty situations.

The fuzzy policer accepts two inputs: ratio of up-to-date mean burst length to negotiated mean burst length, and ratio of up-to-date mean rate to negotiated mean rate. Up-to-date mean is obtained through the mean value of a random process. The fuzzy control rule base consists of a set of linguistic rules constructed from knowledge of policing experts. The fuzzy policer will output a control action, in the form of drop rate being imposed on arriving cells. This drop rate will be sent to a pass/drop switch, which then discards a portion of cells held in the memory based on the value received.

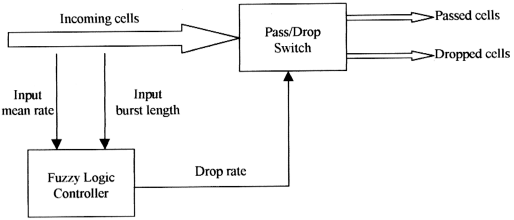

Figure 1.1: Model of fuzzy policer (adapted from [7])

A model of the proposed fuzzy policer is presented in Figure 1.1 above for illustration purposes.

Comparison is made between the fuzzy policer and *Leaky Bucket* policer in terms of throughput performance obtained by both schemes. *Leaky Bucket* policers with various combinations of leak rate and bucket size are tested in parallel with the fuzzy policer. Two traffic types, being packetized voice and still images are used. The simulation is performed on both violation of mean rate and burst length. Simulation results showed that the fuzzy policer outperformed all *Leaky Bucket* policers in the policing of traffic sources. The results also showed that the proposed fuzzy policer excelled in policing bursty traffic when compared to the *Leaky Bucket* policers.

As mentioned earlier, the fuzzy policer's decision depends upon the compliance/violation level of the mean rate and burst length. However, the state of the network, which affects the overall network performance in terms of throughput is not taken into consideration in the decision process. When congestion occurs, the fuzzy policer may not perform as well as during congestion free period in improving throughput of the network. A stricter policing decision is more desirable in this situation. Therefore, it might be better to use a different set of discarding policy during congestion period to help relieve the situation.

In [8], a number of approaches for evaluating and predicting the cell loss ratio (CLR) have been studied. The CLR is a very important parameter in ATM network design and management. CLR is used in connection admission control functions to decide whether to accept or reject a new call given the available transmission resources. Therefore, an accurate estimation of the CLR is very important to avoid incorrect decision, or overestimation of bandwidth reserved for the new connection. Besides that, an accurate estimation of CLR in ATM multiplexers is also important to other network management procedures such as network resources dimensioning, congestion control and routing.

Existing algorithms for estimating the CLR suffer from some limitations. Some involves complex, time-consuming numerical algorithms. While the approaches are efficient in predicting the CLR in ATM multiplexer, computation complexity increases and memory problem arises when the system size becomes large. The system size in this context relates to either the multiplexer buffer size, number of connected users or link capacity.

In view of the shortcomings in existing algorithms, they proposed a fuzzy-based algorithm to predict the CLR in large-sized systems. An adaptive fuzzy system is used whereby the CLR is viewed as a function of a real variable which can be the buffer size, number of connections or link capacity. The fuzzy system predicts the CLR with the actual value of the real variable based on a set of CLR values when the variable is small. For example, a set of CLR values is obtained with a small buffer size or small link capacity. These values are obtained by either real-time measurement when the traffic characteristics are unknown or from analytic model when the traffic characteristics are given. The predicted CLR is then refined by taking into account the asymptotic behavior of the CLR function. This results in a good approximation of the CLR as a function of the buffer size, number of users or link capacity.

The operation of estimating the CLR is as follows: The fuzzy system receives a set of input-output pairs, where the inputs are represented by the CLR values from the previous and the current states, while the output is the difference between the next and current CLR values. By obtaining a few input-output pairs (with the CLR values known), the fuzzy system can be built. The process continues until the CLR for the desired size of the system is obtained. These input-output pairs would be used to define the new fuzzy system. To estimate the

CLR, the fuzzy system will output a value that represents the increment/decrement made to the CLR with respect to the previous value. Therefore, an estimation of the CLR can be obtained. However, the prediction is poor when the CLR values are very small due to accumulation of small prediction errors. Thus to improve the estimation, they proposed to take into account the asymptotic behavior of the CLR function. Numerical results demonstrate that the fuzzy system can give very good approximations.

The estimated CLR can be applied in connection admission control functions to decide on accepting or rejecting new connections. It served as an indication of whether the bandwidth requested by the new connection can be provided without affecting the bandwidth of existing connections. They proposed a measurement-based connection admission control mechanism that uses the fuzzy-based algorithm to predict the CLR for a given number of connections. Based on the prediction and the estimated bandwidth required by a new connection, an accurate estimation of the aggregate required bandwidth is obtained. The aggregate bandwidth is then used to decide whether to accept or reject the new connection. The proposed mechanism is illustrated in Figure 1.2 below:

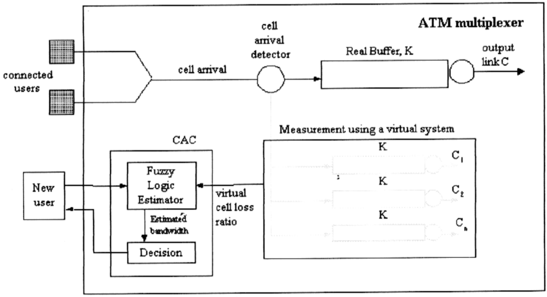

Figure 1.2: Fuzzy based CAC mechanism (adapted from [8])

The mechanism above comprises two components. The first component consists of a set of virtual buffers (counters) with reduced service capacity to observe very high cell loss with a small variance within a short measurement time interval. The second component contains the fuzzy approximation algorithm and the decision process. The fuzzy algorithm determines the required bandwidth for current ongoing connections. The decision process will then decide on accepting or rejecting a new connection based on output from the fuzzy algorithm, available bandwidth and the bandwidth required by the new connection.

The fuzzy based mechanism above makes the assumption that all the connections require only a static bandwidth allocation. It means that no re-negotiation of the bandwidth is allowed during the whole duration of the connection. Otherwise, it may result in inaccurate CLR measurements being taken and thus affects the estimation of the CLR.

Other fuzzy based approach in performing connection admission control includes the work done in [9]. A fuzzy logic technique is used in [9] to infer the required bandwidth for a new source. The information obtained will be used by connection admission control to decide whether to accept or refuse a new connection into the ATM network. To accept a new connection, the connection admission control function must ensure that the cell loss requirements of existing connections are preserved while allocating the required bandwidth to the new connection.

Difficulties in making the decision arise because ATM networks use statistical multiplexing to achieve higher utilization of network resources. Due to different types of traffic, it is often difficult to predict the statistical behavior of several sources of different types multiplexed on an ATM link. On the other hand, the use of stochastic theory may not be a feasible solution due to complexity in computation. Thus, they have proposed the use of fuzzy logic techniques to overcome the above problems.

In their proposal, a two-level algorithm is utilized in performing connection admission control functions. The lower level module decides on accepting or rejecting a new connection request based on a conservative approach such as peak rate allocation. Once the connection is accepted, the higher level module comes into place and it will calculate more accurately the bandwidth required by the new connection in the current traffic scenario. Bandwidth is then allocated to the new connection and the available bandwidth of the link will be updated to reflect a more accurate value. The proposed algorithm uses the parameters declared by the user, namely the peak rate and mean rate.

The higher level module employs fuzzy logic techniques in predicting the bandwidth requirements of a new connection. Knowledge of the system under controlled is represented through fuzzy variables and fuzzy sets, while a fuzzy inference model based on the knowledge acquired is used to infer the bandwidth for the new connection.

The proposed fuzzy system is a learning system that updates its knowledge base with knowledge extracted from a set of examples (input-output pairs) collected from the ATM network traffic. The examples contain information on the current traffic pattern in the network. Using fuzzy reasoning, the system will infer a value for the bandwidth required for the new connection, when the connection is exhibiting the current traffic pattern. There are mainly two phases in the operation of the fuzzy system: the learning phase and the inference phase. The learning phase involves matching the example of data collected from network traffic with the fuzzy sets of the system's fuzzy variables. The fuzzy variables expressed information related to a specific connection such as effective bandwidth, burstiness and cell loss probability. The learning process updates the knowledge base with a new set of selected rules given the set of examples from the system. The new set of rules is selected from a list of all possible combinations of rules.

The updated knowledge base will later be use in the inference phase when a new connection is accepted. The inference phase take place each time a new connection is accepted. It will output the bandwidth required by the new connection to fulfill its negotiated cell loss requirements, and then allocates the inferred bandwidth to this new connection. Also, the available bandwidth value is updated so that the lower level module can use the updated value to decide on accepting new connections in the future. The inputs to the inference process are the source traffic characteristics of the new connection and its cell loss requirements, and the traffic characteristics of existing connections.

In their proposal, they have identified four fuzzy variables for the fuzzy systems. The fuzzy variables that describe the inputs are mean offered load, mean to peak ratio (for new connection) and cell loss ratio (for new connection). The output is the effective bandwidth for the new connection. Mean offered load refers to the summation of mean bit rate for all connections divided by the link capacity. Effective bandwidth depicts the value between the mean and the peak bit rate.

Simulation is carried out to study the performance of the proposed fuzzy system. They have used homogeneous on-off sources to model video sources. An example set containing a set of inputs and output pairs are obtained using a cell-rate simulator. This example set is fed into the fuzzy system so that the fuzzy system can learn from it. A simulation is performed to determine the best effective bandwidth value to achieve the cell loss requirements, in different average load conditions. It has been found that the multiplexing gain is much greater with bursty sources, and the effective bandwidth should be closer to mean bit rate for loads less than 0.8. Simulation results showed that the fuzzy approach could output accurate results provided that the set of examples chosen reflects correct information about the network traffic.

The shortcomings of the fuzzy system relate to the example sets being chosen. If the examples collected have some inconsistencies or are imprecise, it will greatly affect the accuracy of its output. Also, further work needs to be done to tune the fuzzy system for different types of traffic characteristics, preferably real traffic in the network.

From the previous works discussed above, it can be seen that various approaches have been adopted in proposing a fuzzy solution to the traffic and congestion control problems in ATM networks. Fuzzy systems have been proposed to perform different functions of congestion control. For example, some have focused on utilizing fuzzy algorithms to perform connection admission control functions. Others have ventured into the usage parameter control, whereby fuzzy systems have been proposed as alternatives to conventional policing algorithms. Also, research has been done to study the effectiveness of fuzzy control in queue management as opposed to conventional schemes. Overall, the results published showed promise in using fuzzy logic approach in traffic and congestion control. Performance of these fuzzy approaches is much better or at least on par, compared to the conventional methods currently being employed.

In this thesis, a fuzzy logic traffic controller is proposed to perform traffic and congestion control functions. It consists of a Fuzzy Policer and a Fuzzy Congestion Controller. The Fuzzy Policer's task is to perform traffic policing functions while the Fuzzy Congestion Controller manages the queue in the buffer of the network node.

The proposed Fuzzy Policer in this thesis is an enhancement over the fuzzy approach in [7]. The difference lies in the inputs to the fuzzy system. The proposed Fuzzy Policer considers the state of the network before making policing decisions. This information is vital due to its influence to the overall network throughput. If the network is congested, a stricter discarding policy may help relieve the situation. Therefore the addition of an input to the Fuzzy Policer which depicts the state of the network gives a definite advantage over the original approach. Similarly, the approach in [5] and [3] which performs policing functions does not take into account the condition of the network. Hence, the proposed Fuzzy Policer edges out in comparison, especially during congestion period because it can apply a different policing strategy when the need arises.

In addition, the approach in [3] accepts inputs from conventional policing schemes such as *leaky bucket* algorithm, which may be inaccurate due to limitations as describe in the earlier section. In contrast, the proposed Fuzzy Policer utilize up-to-date value that considers all the previous values of the traffic parameters, and therefore able to represent a more accurate view of the traffic characteristics of a connection. Thus, this provides added advantage to the Fuzzy Policer in making correct policing decisions.

As for the proposed Fuzzy Congestion Controller, comparison can be made to the fuzzy approach in [6]. The Fuzzy Congestion Controller also uses fuzzy thresholds to indicate the onset or relieve of congestion, but receives an extra input depicting the queue length change rate. In comparison, it can be seen that different actions are taken by both fuzzy schemes. The fuzzy approach in [6] uses selective cell blocking to refuse entry to a fraction of incoming cells when it detects congestion. Cells that are blocked have to be rerouted by the sending source to other switches and may incur delay in the process. This fuzzy approach requires some adjustments to be made so that the network can include the option of selective cell blocking. Some form of control and protocols need to be implemented to perform tasks such as message fragmentation, cells reordering at destination and routing of blocked cells. On the other hand, when congestion arises, the Fuzzy Congestion Controller sends a rate control signal to notify the sources to adjust its transmission rates. The source will then decrease its current transmission rates to reduce the intensity of the congestion. The transmission rates will be restored when the network is relieved from congestion. The advantage of the Fuzzy Congestion Controller is that it does not require the addition of certain form of control in the network that might impact the ATM virtual paths, and hence offers a simpler implementation.

The fuzzy schemes in [8] and [9] deal with the connection admission control functions. The results obtained through these schemes demonstrate the feasibility of fuzzy based approach as an alternative to conventional algorithms. Since the proposed Fuzzy Policer and Fuzzy Congestion Controller covers the traffic policing and queue management tasks, therefore direct comparison with the fuzzy connection admission control schemes is not possible. However, from another point of view, their work gives a very good hint about the incredible flexibility and adaptability of fuzzy based schemes in handling complex and ill-defined systems.

Further details of the proposed fuzzy logic traffic controller will be presented in Chapter 4.

1.4 Motivation

Due to the lack of complete information regarding input traffic and the unpredictable traffic flows, congestion control has become a great challenge for ATM network design. The types of data carried in ATM networks have different characteristics and therefore posed completely different requirements on the network.

Numerous research and studies [10-12] had developed various algorithms and schemes to tackle the problematic issues of implementing efficient congestion control in ATM networks. Many have produced promising results.

In other developments, fuzzy based systems have been proposed to perform traffic and congestion control functions in ATM networks. As described earlier, the characteristics of fuzzy logic control suggested that it may offer a possible solution to the problem. Fuzzy based schemes have the potential to overcome the limitations of conventional algorithms. Besides that, fuzzy schemes have been shown to exhibit flexibility and adaptability to changing conditions. These features fulfilled the requirements for an efficient congestion control scheme. In view of this, a lot of work has been done to utilize fuzzy systems in performing traffic and congestion control functions. The results obtained overall demonstrates the efficiency of fuzzy based systems as opposed to conventional algorithms.

This recent development has prompted me to look into possibility of exploiting fuzzy set theory and fuzzy logic control in ATM networks. In this thesis, the design of a fuzzy logic based traffic controller for ATM networks has been proposed. It aims to overcome the limitations of existing algorithms and improve on previous fuzzy based schemes. The fuzzy logic based traffic controller main task is to perform congestion control functions and resolve any uncertainties that may arise. Uncertainties in this context relate to possibility that the traffic parameters (e.g. peak rate, mean rate) may not be known with required accuracy or may be modified.

The proposed fuzzy logic based traffic controller is a type of FLC that incorporates experience of human experts in making wise decisions to control congestion.

1.5 Scope of the Thesis

As mentioned earlier, ATM traffic management is very important to ensure that users get the desired quality of service in a fair and controlled manner. Any new user entering the network will be given the desired quality of service without affecting existing users. Proper traffic and congestion control functions are required so that resources can be effectively and efficiently utilized, and congestion can be controlled or even avoided.

The aim of this thesis is to propose the design of a fuzzy logic based traffic controller for ATM network. This thesis deals mainly with how to utilize fuzzy logic control in performing ATM traffic control functions. The focus is on the usage parameter control and congestion control functions. Existing algorithms are studied and comparison is made with the proposed fuzzy approach.

1.6 Organization of the Thesis

This thesis is organized as follows:

Chapter 2 describes the notion of fuzzy logic and its differences with conventional logic. Fuzzy set theory and operations on fuzzy sets are then discussed. Next, a detail explanation of fuzzy logic controller and its components are given. The advantages of fuzzy logic controller and its applications are presented at the end of the chapter.

Chapter 3 begins with an introduction to ATM network. The basic principles of ATM are also presented. Next, ATM traffic and congestion control is discussed. At the end of the chapter, descriptions about the ATM traffic and congestion control functions will be presented.

In Chapter 4, the proposed fuzzy logic based traffic controller for ATM network is introduced. Its main components, the Fuzzy Policer and Fuzzy Congestion Controller are discussed in detail. The operation of the fuzzy logic based traffic controller is explained at the end of the chapter.

In Chapter 5, the simulation model and related traffic source model are introduced. Details on how the simulation is performed and the simulation parameters are presented. Simulation results are given to compare the performance of the proposed fuzzy approach with existing algorithms. The results illustrate the performance gained in utilizing the proposed fuzzy traffic controller.

The thesis ends with conclusion and future directions in Chapter 6