Computational Intelligence in Management of ATM Networks: A Survey of Current State of Research

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Abstract

Designing effective control strategies for Asynchronous Transfer Mode (ATM) networks is known to be difficult because of the complexity of the structure of networks, nature of the services supported, and variety of dynamic parameters involved. Additionally, the uncertainties involved in identification of the network parameters cause analytical modeling of ATM networks to be almost impossible.

Consequently, some researchers are looking at alternative, non-analytical control system design and modeling techniques that have the ability to cope with these difficulties to devise effective, robust ATM network management schemes in which artificial neural networks, fuzzy systems and design methods based on evolutionary computation. In this survey, the current state of ATM network management research employing these techniques as reported in the technical literature are summarized, and their salient features are reviewed.

Keywords: Computational intelligence, ATM networks, fuzzy systems, neural networks, evolutionary computation

1 Introduction

Asynchronous Transfer Mode (ATM) based networks are designed to be scalable, high-bandwidth, manageable, and have the flexibility of supporting various classes of multimedia traffic with varying bit rates and Quality of Service (QoS) requirements. Thus, they have the potential to create a unified communications infrastructure that can transport services with widely different demands on the network (such services include real-time video and voice with no tolerance to delays, but some tolerance to loss, and data with some tolerance to delay, but no tolerance to loss).

An important difficulty of exploiting the potential of ATM optimally is the management and control complexity of the scheme itself (the basic concept is simple). Since ATM simultaneously attempts to support voice, data and video applications which all have differing performance and QoS requirements, optimal utilization of the network resources requires complex, nonlinear, distributed control structures. In order to achieve its potential, ATM networks will need to accommodate several interacting control mechanisms, such as call admission control, flow and congestion control, input rate regulation, routing, bandwidth allocation, queue scheduling, and buffer management.

The complexity of the ATM networks and multidimensionality of the control problems dictate that traffic control in ATM networks be structured. The control structure is most likely to be implemented in a multilevel architecture which partitions the solution into different levels of control with varying temporal decomposition in network, call, and cell levels (Figure 1).

Due to the complex nature of the above mentioned control issues, some researchers are looking for solutions by application of Computational Intelligence (CI) techniques to design intelligent control systems to various aspects of ATM network management, often supplementing the existing control techniques. Their motivation arises from the reported success of those techniques in various previously unsolvable or difficult control problems in many diverse fields.

The focus of this paper is CI applications in ATM network control. It seeks to update, merge and (inevitably) summarize the previous reviews of the literature (Habib, 1996; Douligeris and Develekos, 1997; Ghosh et al., 1998).

2 Computational Intelligence

Computational Intelligence (CI) (Bezdek, 1992; Bezdek, 1994; Pedrycz, 1998) is an area of fundamental and applied research involving numerical information processing (in contrast to the symbolic information processing techniques of Artificial Intelligence (AI)). Nowadays, CI research is very active and consequently its applications are appearing in some end user products.

The definition of CI can be given indirectly by observing the exhibited properties of a system that employs CI components (Bezdek, 1994):

> A system is *computationally intelligent* when it: deals only with numerical (low-level) data, has a pattern recognition component, and does not use knowledge in the AI sense; and additionally, when it (begins to) exhibit
>
> - computational adaptivity;
> - computational fault tolerance;
> - speed approaching human-like turnaround;
> - error rates that approximate human performance.

The major building blocks of CI are artificial neural networks, fuzzy logic, and evolutionary computation.

3 Applications of CI Techniques in Management of ATM Networks

The complexity of the ATM networks and multidimensionality of the control problems dictate that traffic control in ATM networks to be structured and most likely implemented in a multilevel architecture which partitions the solution into different levels of control with varying temporal decomposition in network, call and cell levels (see Figure 1) (Pitsillides, 1993, Chapter 2)(Nordström et al., 1995). Time constants involved are: in the cell level in the order of microseconds; in the call level in the order of seconds to minutes; and in the network level minutes to hours.

In the following sections, an overview of the reported research done to date to implement control methods which employ fuzzy logic, artificial neural networks and genetic algorithms on these levels is presented.

4 Network Level Control

The main objective of network level control is to enable the completion of the maximum possible number of successful B-ISDN service calls (Yoneda, 1990). An attempt is made to achieve this objective by implementing two main functionalities at the network level controls: fault management and resource management.

4.1 Fault Management

Fault management is concerned with the detection, isolation, and correction of acute failures that interrupt the availability of network resources. Besides acute failures, some failures may be manifested intermittently, or malfunctions may subtly degrade network performance while network resources remain available (for example, corruption of virtual path identifier (VPI)/virtual channel identifier (VCI) translation tables may cause misrouting for certain connections). It is the role of fault management to continually monitor the

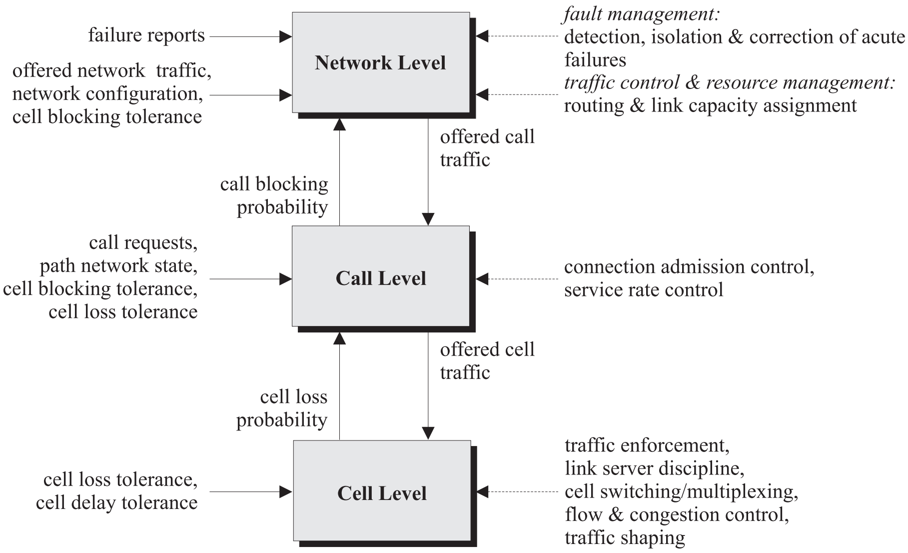

Figure 1: Multilevel traffic control in ATM networks.

network facilities to detect degradations in performance caused by such conditions, and respond with appropriate actions in order to minimize the effect on offered services (Chen and Liu, 1994). This responsibility is fulfilled by Operations and Management (OAM) in ATM networks.

In the area of fault management in communication networks, reported research on applications of CI is very limited in scope. Applications of AI in network management have been surveyed and reported by Smith and Fry (Smith and Fry, 1995).

4.2 Routing and Link Capacity Assignment

In the absence of faults and malfunctions, efficient utilization of network resources is maintained by the traffic control and resource management functions which involve routing and link capacity assignment. At the network level, route selection and link capacity assignment to virtual paths are performed by using offered call traffic and tolerated call blocking probability information.

First major function at the network level control in ATM networks is route selection. In B-ISDN networks, links have to be described in terms of multiple metrics, including QoS and policy constraints, which makes routing with multiple requirements a difficult problem to solve (for example, see (Aboelela and Douligeris, 1997)).

Second major function of network level control in ATM networks is the optimal allocation of bandwidth to virtual paths (Chen and Liu, 1994; Pitsillides et al., 1997a). Effective implementation of this function is very important for a number of reasons:

1. By reserving capacity in anticipation of the virtual channels which will belong to a virtual path, the processing effort required to establish individual virtual channels can be minimized.

2. Virtual paths may be used as a means of logically separating traffic types having different QoS requirements while allowing virtual channels to be statistically multiplexed.

3. Virtual paths allow groups of virtual channels to be managed and policed more easily.

4. Dynamic routing control at virtual path level should lead to designing effective network reconfiguration mechanisms.

5. Effective allocation of bandwidth to virtual paths would lead to a more efficient and effective network.

Aboelela and Douligeris (Aboelela and Douligeris, 1997) have studied the application of fuzzy control for the route selection in ATM networks. Park and Lee (Park and Lee, 1995b; Park and Lee, 1995a) have worked on optimized routing using recurrent ANNs.

The application of combination of evolutionary programming with fuzzy logic could be very beneficial to solve multiobjective optimization problems such as bandwidth allocation to virtual paths. Heuristics have been proposed to reach near-optimal solutions (Vasilakos et al., 1997; Vasilakos et al., 1998). In the study presented in (Vasilakos et al., 1998) the researchers have used evolutionary-fuzzy prediction in inter-domain routing of broadband network connections with QoS requirements in the case of an integrated ATM and SDH networking infrastructure. In their method, a subset-interactive autoregressive model is used to predict link utilization levels, based on experience from both static traffic observations as well as dynamic knowledge, acquired during the network's operation. Based on these, the shadow cost of allowing the connection through each feasible path is calculated, which is then used to select the "best" path. The shadow cost is calculated in such a way as to lead the network to states which exhibit the lowest expected blocking probabilities in regard to information about user's demand - thus aiming to match network state with demand at all times.

Early results of a study for VP bandwidth allocation using evolutionary programming techniques has been published by Pitsillides et al. (Pitsillides et al., 1997a).

5 Call Level Control

5.1 Connection Admission

Connection Admission Control (CAC) is defined as a set of actions, performed at connection set-up phase, to determine whether or not the virtual path (VP) or virtual channel (VC) requesting the connection can be accepted. The decision is based on the connection's anticipated traffic characteristics, the requested QoS, and the current state of the network. The anticipated traffic characteristics of the connection are determined by a source traffic descriptor, and the user terminal declares these source traffic descriptor values to the network when the connection set up is requested. If the request is accepted, network resources are implicitly allocated to the connection.

To attain high utilization of VPs while meeting the QoS requirements, CAC must determine whether to accept a new VC by considering its anticipated traffic characteristics, the QoS requirements of existing VCs, the availability of the network resources, and current utilization of the links. There are many demanding problems waiting to be solved for the development of an effective CAC algorithm, especially

- The statistical behavior of several sources of different types multiplexed on an ATM link is difficult to predict. Therefore, deciding how to allocate resources for multiple QoS requirements is hard to solve.

- Developing accurate analytical models to evaluate QoS services could be very difficult.

Application of CI techniques appears to be appropriate, and several researchers have attempted to solve the problem by using artificial neural networks and fuzzy logic control techniques.

Hiramatsu has studied ANN based ATM CAC (Hiramatsu, 1990) and has published his work on training techniques for ANN applications in ATM (Hiramatsu, 1995). Ramalho and Scharf (Ramalho and Scharf, 1994) have used a method for learning the behavior of the traffic in an ATM link. Park and Lee (Park and Lee, 1995b; Park and Lee, 1995a) also have published their work on adaptive call admission control using feedforward ANNs.

Uehara and Hirota (Uehara and Hirota, 1997) have proposed a method based on estimation of the possibility distribution of cell loss ratio (CLR). They use fuzzy inference for the estimation of CLR of new connections. The mechanism operates this way: Each call request is placed into a transmission rate class depending on its declared parameters. Then, by using the number of active connections for each class, a CLR estimation is made by the inference engine. If the estimate exceeds the required CLR, the connection request is rejected. The fuzzy sets representing the values of the fuzzy numbers of the rule base are shaped by a learning mechanism and observed CLR data which gives the scheme its adaptation capability.

Scheffer and Kunicki have studied the application of fuzzy logic techniques for accurate modeling of voice and video sources, and prediction of their behavior (Scheffer and Shaw, 1993; Scheffer and Shaw, 1994;

Scheffer et al., 1994). They have proposed a CAC scheme which uses a fuzzy logic based traffic prediction algorithm (Scheffer and Kunicki, 1996).

Cheng and Chang (Chang and Cheng, 1994; Cheng and Chang, 1996) have devised a fuzzy control system which combines CAC and a feedback mechanism. The mechanism sends back coding rate control signals to video sources, and congestion control signals to data sources. In this scheme, fuzzy sets representing the linguistic values are selected by evolutionary techniques. Unlike the other schemes mentioned in the previous section, the system does not have the capability of real-time adaptability but, since it has the ability to adjust the cell transmission rate of the sources, and subsequently traffic density at the switches, it can still maintain QoS for the connections.

Early results of a study whose aim is the application of CI techniques to ATM CAC problem and development of a simulation testbed has been published by Czezowski (Czezowski, 1998).

6 Cell Level Control

6.1 Usage Parameter Control

Usage parameter control (UPC), or in other words, traffic enforcement or policing, is a very important function in ATM networks. Its task is to ensure that traffic sources stay within the limits of the negotiated traffic parameters which are declared during the call setup phase. Traffic enforcement functions are performed by the network provider at the virtual circuit or virtual path level and corrective measures are taken if a traffic source does not stay within the declared limits. The measures could be as drastic as blocking the traffic source or could be less severe such as selectively discarding the violating cells or tagging violating cells that could be discarded in downstream nodes if necessary.

The ideal UPC mechanism should have these desirable characteristics: accurate detection of any traffic situation violating the negotiated values, and separating those connections from the ones that stay within the negotiated limits; fast response to violations; implementation simplicity and cost effectiveness. Designing a UPC mechanism encompassing these features could be a daunting task. For example, well studied mechanisms such as leaky bucket and window mechanisms cannot achieve the ideal UPC characteristics but only provide a trade-off between the above requirements.

Catania et al. (Catania et al., 1995; Catania et al., 1996a; Catania et al., 1996b) and Ascia et al. (Ascia et al., 1997) have proposed a UPC mechanism based on fuzzy logic control which displays characteristics close to ideal UPC, and have also implemented the algorithm as a VLSI chip. The mechanism they propose ensures that a bursty source conforms to its agreed average cell rate. It is a window based control mechanism. It allows short term fluctuations of the source cell rate around a negotiated average value, as long as the source respects this value over the long term, and at the same time it is capable of recognizing a violation immediately. The maximum number of cells which are considered to be non-violating in a fixed period is dynamically updated by a set of fuzzy inference rules. The set of rules is shaped to guarantee transparency to a compliant source by assigning a credit value of allowable cells which is higher than the negotiated value agreed at call set up phase. This credit value represents the number of cells that the source can send during a particular transmit window. If a source has a high flow of traffic, the UPC intervenes to enforce a reduction of the bit rate of the source. To do so, it reduces the assigned credit to lower the allowable cell rate threshold and identifies any cells that exceed this threshold as violating cells.

The parameters describing the behavior of the source consist of the average number of cell arrivals per window since the start of the connection, the number of cell arrivals in the last transmit window, and current value of the maximum allowable cells that can be transmitted. By using these three parameters, the fuzzy UPC mechanism determines the value of the threshold to be used in the next transmission window.

A UPC mechanism particularly designed for policing voice sources has been proposed by Ndousse (Ndousse, 1994). Since voice cells are characterized by a high degree of burstiness, utilization of a classical control approach faces difficulties. Ndousse proposes an intelligent implementation of the leaky bucket cell rate control mechanism which yields a lower cell drop rate than the leaky bucket algorithm under similar circumstances.

The fuzzy leaky bucket is implemented as a two-level fuzzy logic controller (FLC) by connecting three fuzzy associative memories (FAMs) (Kosko, 1992, pages 299–338). In the first level, there are two FAMs, each taking two input variables and generating an output variable which is supplied to the second level FAM. The output of the FLC determines the number of special tokens in the token buffer in the next sampling interval. These special tokens are used to tag the violating cells. Therefore, depending on the availability of the network resources, violating cells are not discarded straight away, but can have a chance of transmission. The FLC dynamically determines the number of special tokens allocated in the token buffer by monitoring the buffer occupancies and buffer growth rates in the token buffer and channel buffer allocated to the voice connection.

6.2 Flow, Congestion and Rate Control

In early stages of B-ISDN development, prevailing belief among the research community was, preventive (or, in other words open-loop) type congestion control at the edge is necessary due to the large bandwidth delay product, and would be sufficient for ATM networks. But, outcomes of subsequent studies have shown that, because of the variety of the traffic to be supported in B-ISDN networks, open-loop congestion and flow control is rendered to be ineffective in ATM networks. Today, the shift is towards closed-loop congestion controls (within the network).

In ATM networks, depending on the nature of the traffic sources, the closed-loop congestion control issue can be approached in two ways:

- For *delay tolerant traffic*, which basically comprises of TCP / IP type traffic, switches can send feedback signals to the sources leading them to reduce the rate at which they release cells to the network. Then excess traffic is queued at the traffic source and consequently delayed.

  The ATM Forum has introduced a service category, called available bit rate (ABR), in order to allocate bandwidth dynamically within an ATM network, while simultaneously minimizing the cell losses, and has selected a feedback control framework to achieve these aims (ATM Forum, 1996). The framework allows downstream nodes or intermediate ATM switches to periodically send information to the traffic sources relating to maximum cell rates that they can handle. The cell rate information is carried by a stream of resource management (RM) cells generated by the traffic sources and relayed back to the sources by the destination end systems. During their round-trip, while these cells pass through the switching nodes, the cell rate information contents of these cells are dynamically updated by these intermediate systems. For the calculation of rate, several algorithms have been proposed.

- On the other hand, since delay tolerance of *video/voice traffic* is very low, congestion control is performed by sending coding rate signals to these types of sources. In the presence of congestion, the sources can vary their coding rate, and so reduce the frequency of cells generated by using this feedback information. Lower coding rate inevitably reduces the image / sound quality at the receiver but network utilization and quality of offered service rate are maintained at higher levels by minimizing the cell losses and delays due to congestion.

Following sections summarize the research utilizing CI techniques for implementation of congestion and rate control algorithms in ATM networks.

Tarraf, Habib and Saadawi (Tarraf and Habib, 1994; Tarraf et al., 195; Tarraf et al., 1995b) have investigated extensively how ANNs can be used to solve many of the problems encountered in the development of coherent traffic control strategies in ATM networks. In (Tarraf et al., 1995b) they present congestion control schemes for ATM networks. Also, they investigate a reinforcement-learning based neural network for congestion control in ATM networks (Tarraf et al., 1995a). Liu and Douligeris have published the results of a comparison study on the performance of static and adaptive feedback congestion controllers which uses ANNs (Liu and Douligeris, 1995).

Huang and Yan (Huang and Yan, 1996) use a recurrent neural network for the dynamic control of communication systems, particularly dynamic congestion control in ATM networks. Mhrvar and Le-Ngoc (Mehrvar and Le-Ngoc, 1995) apply a neural network scheme for congestion control in packet switch OBP satellite systems.

Pitsillides et al. (Pitsillides et al., 1995; Pitsillides et al., 1997b), have proposed the Fuzzy Explicit Rate Marking (FERM) algorithm, and analyzed its performance regarding fairness, responsiveness, resource utilization and cell loss in LAN and WAN environments. FERM operates on switching nodes and by periodically monitoring the buffer utilization and queue growth rate, determines a cell rate which is used to update the maximum cell rate information carried by the RM cells passing through the virtual connection.

Douligeris and Develekos (Douligeris and Develekos, 1995) have studied a FLC which is based on the short term observation of the network status to predict the near future cell discarding behavior of the switching nodes. This prediction is then fed back to traffic shapers in the sources to minimize cell losses.

Jensen (Jensen, 1994) has proposed a three-step FLC for controlling the transmission rate of sources to protect links against overload in the case of connections exceeding their negotiated traffic parameters. The scheme operates as follows: At the call admission stage a service dependent priority is assigned to each connection. This priority is kept as a fixed value for the whole life time of the connection. Also, in the switching node, a certain buffer capacity is allocated to the connection. The FLC generates the cell service rate control signals for each buffers. Input parameters of the FLC are: a) allocated priority level; b) current buffer occupancy level; c) bandwidth utilization at the output link of the node; and d) the difference between the effective bandwidth at which the source is transmitting the cells and the declared bandwidth negotiated during the call set up stage.

Hu and Petr (Hu et al., 1996) have studied an adaptive traffic controller based on Sugeno's self-tuning fuzzy control methods.

6.3 Cell Switching and Multiplexing

In an ATM network, cell queuing is required to alleviate congestion at switching nodes. Congestion occurs when multiple cells simultaneously attempt to access an output link in a switch. Cell queuing can be arranged either by placing buffers at input ports (called input queuing), or by placing cell buffers at the output ports (called output queuing). Output queuing yields better performance in terms of cell delay and throughput, but computationally more demanding to operate than input queuing. On the other hand, in input queuing, if the head-of-line blocking problem can be solved, comparable performance can be achieved. One way of solving this problem is to employ a mechanism called bypass queuing. When bypass queuing is used, a controller module schedules the cells in an optimal fashion to enhance the switch throughput. Additionally, cells can be dispatched optimally if they are assigned priorities, with higher priorities assigned to real-time traffic such as voice and video (due to rigid delay requirements) and lower priorities assigned to data traffic, by an intelligent scheduling mechanism.

Liu and Douligeris (Liu and Douligeris, 1996) have proposed a fuzzy scheduler to optimize the cell servicing sequences to reduce cell losses. In their mechanism, each traffic class in the switch has its own portion of the dedicated buffer and a fuzzy scheduling algorithm manages the server. Park and Lee (Park and Lee, 1995b; Park and Lee, 1995a) have also worked on optimal scheduling and published their study on application of recurrent ANNs to this problem.

7 Discussion and Concluding Remarks

Research on applications of CI in telecommunication systems, particularly in ATM networks, is being pursued by an active research community, and methods are being developed simultaneously. However, unlike consumer applications, there are no commercially deployed applications as yet. The reasons could be

- The lack of comprehensive performance comparisons between the best traditional techniques and the ones involving CI applications. The comparisons performed in the research studies usually have been undertaken in simplified networking scenarios, and testing on real hardware has not been undertaken yet except for some partial implementations such as in (Ascia et al., 1997). Before the applications of CI techniques to high speed communication networks become accepted, it will be necessary to place a greater emphasis on rigorous demonstration of the advantages to be gained. To achieve this, it may be necessary to set a *common simulative framework (CSF)* and a *common testbed framework (CTF)*. This is the issue that we strongly recommend to be undertaken first.

- The reluctance to adopt new technologies by telecommunications companies and equipment manufacturers. This issue is closely related to the lack of comprehensive performance studies mentioned above.

- Inability of CI proponents to socialize and demonstrate, in realistic systems, merits of CI approach and its sound theoretical foundations.

As a final note, we would strongly encourage a thorough study of an integrated control structure implementing a multilevel control strategy spanning the network, call and cell levels. Currently, there exists a large number of published works solving isolated (individual) control functions. The integration can be achieved by appropriate reformulation of these existing, separately designed strategies in a new multilevel fuzzy logic structure, and / or conceiving new ones, with their coordination achieved via a fuzzy logic based supervisor, taking care of the overall "goodness" of the network and handling any interactions among the control functions, at the same or different levels.

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