University of Cyprus

Deliverable 7:

Evaluation of IP Architectures and Protocols of Concern and Proposed Improvements.

ENDIKTIS

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1 Introduction

The existing Internet architecture is based on the “best effort” model for delivering packets across the Internet. The current architecture delivers a packet at its best possible (best-effort) but doesn’t guarantee when it will be delivered. The demands of the users have changed dramatically since the creation of IP, where it was mostly used for email and ftp. Another new application is the WWW that has been widely used worldwide. WWW has created a new friendly interface for the user, and stimulated further demands from the network.

The existing architecture of IP is inadequate to handle new applications. Time critical applications such as video, audio and several others have created an even greater demand on the Internet. Lately, several new protocols and architectures are proposed to enable basic quality of service provision in Internet.

In this deliverable we include an overall evaluation of the results taken by conducting extensive experiments – in the form of simulations and pilot networks – in order to use the results to determine new improved techniques. We specifically concentrate on the differentiated services for the provision of quality of service in IP networks by examining existing active queue management schemes that provide congestion control. We propose new mechanisms that can provide effective and robust congestion control and adequate quality of service, in terms of high utilization, minimal losses and delays.

2 Overall Evaluation of the IP architectures and protocols of concern

Extensive experiments, in the form of pilot networks and simulations, were conducted and shown in Deliverable 6: “Measurements for the Evaluation of IP Architectures and Protocols of Concern”. We were concentrated mainly on the differentiated services for the provision of quality of service in IP networks by looking into the performance of congestion control and active queue management schemes.

The results shown in Deliverable 6 can help in the performance evaluation of the mechanisms of concern. Firstly, the use of differentiated services in IP networks is now a necessity that can help in the delivery of aggregated quality of service. The aim is to provide high network utilization with low loss rate and delay. To achieve these goals, active queue management schemes are used in the core routers of IP networks in order to regulate the queue at the bottleneck links. These schemes should respond quickly to load changes as well.

Under the experiments/simulations conducted, a number of representative queuing disciplines were used [1-5] to investigate the ability of such mechanisms to provide adequate quality of service in terms of high utilization, minimal losses and delays. The results, shown in Deliverable 6, indicates that there are still open research issues, like the improvement and development of new mechanisms that provide quality of service, such as congestion control algorithms and active queue management schemes.

The measurements taken show that, even though many mechanisms for active queue management have recently been proposed, these require careful configuration of non-intuitive control parameters, and show weaknesses to detect and control congestion under dynamic traffic changes, and a slow response to regulate queues. As a result they exhibit greater delays than the target mean queuing delay with a large delay variation, and large buffer fluctuations, and consequently cannot effectively control the router queue. This has a negative impact to the utilization of the bottleneck links as well. This behavior leads in an inadequacy to provide quality of service.

Furthermore, there is need for an adequate differentiation between assured and best-effort traffic classes of service in the presence of congestion, giving priority to assured-tagged traffic. The results from Deliverable 6, show a weakness to achieve an adequate discrimination between the two classes of service –preferentially dropping the lowest-priority best-effort packets, and giving priority-preference to assured-tagged traffic, while controlling the queue and providing quality of service.

3 Proposed improvements

The key issue is the provision of adequate quality of service in IP networks. This can only be accomplished with use of effective and efficient congestion control mechanisms.

The problem of congestion control in networks is a difficult task to achieve due to the difficulties in obtaining a precise mathematical model using conventional analytical methods. Therefore, we propose the use of computational intelligence, and specifically *fuzzy logic control*, to overcome the above mentioned problems. The application of fuzzy control techniques to the problem of congestion control in networks is suitable due to the availability of some intuitive understanding of congestion control.

Therefore, we present a new active queue management (AQM) scheme – Fuzzy Explicit Marking (FEM) – supporting explicit congestion notification, to provide congestion control in IP networks using a fuzzy logic control approach. The proposed scheme is implemented within both best-effort and differentiated services environments, providing quality of service (QoS). Furthermore, for achieving an adequate discrimination between assured and best-effort traffic classes in the presence of congestion a two-class FEM controller, called FEM In/Out (FIO), is also presented.

The proposed fuzzy logic approach for congestion control allows the use of linguistic knowledge to capture the dynamics of nonlinear probability marking functions, uses multiple inputs to capture the (dynamic) state of the network more accurately, and can offer effective implementation. A simulation study over a wide range of traffic conditions shows that both FEM and FIO controllers outperform a number of representative AQM schemes in terms of queue fluctuations and delays, packet losses, and link utilization. Furthermore, better QoS is provided to different types of data streams - aggregated flows - such as TCP/FTP traffic or TCP/Web-like traffic, whilst maintaining high utilization.

The proposed fuzzy control system is designed to regulate the queues of IP routers in a predefined level, by achieving a specified target queue length (TQL), in order to maintain both high utilization and low mean delay. A fuzzy inference engine (FIE) is designed to operate on router buffer queues, and uses linguistic rules to *mark* packets in TCP/IP networks.

In a Diff-Serv framework a two-class FEM controller is designed to operate on the core routers’ buffer queues, called FEM In/Out (FIO). Two identical FEM controllers are used, one for each traffic class (that is, assured and best-effort), and two different TQLs are introduced, one for each FEM controller.

The proposed fuzzy logic strategy is shown via simulations to be robust with respect to traffic modeling uncertainties and system nonlinearities, yet provide tight control. As a result, it can effectively regulate the queues of the bottleneck links, while achieving high utilization, low loss and delay. In a Diff-Serv environment it also achieves an adequate discrimination between the two traffic classes in the presence of congestion, by preferentially *marking* the lowest-priority packets, while controlling the queue at the predefined levels, and providing QoS.

3.1 Fuzzy logic: Implementation of proposed mechanism - FEM

Fuzzy Logic Control (FLC) may be viewed as a way of designing feedback controllers in situations where rigorous control theoretic approaches cannot be used due to difficulties in obtaining a formal analytical model, while at the same time some intuitive understanding of the process is available. The control algorithm is encapsulated as a set of linguistic rules. FLC has been applied successfully for controlling systems in which analytical models are not easily obtainable or the model itself, if available, is too complex and possibly highly nonlinear [6]. In recent years, a number of research papers using fuzzy logic investigating solutions to congestion control issues, especially to ATM networks, have been published (e.g. [7]).

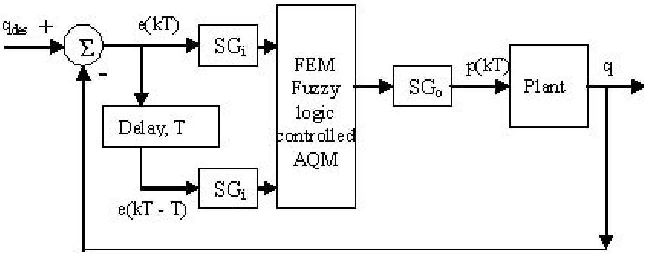

Figure 1. Fuzzy logic controlled AQM system model

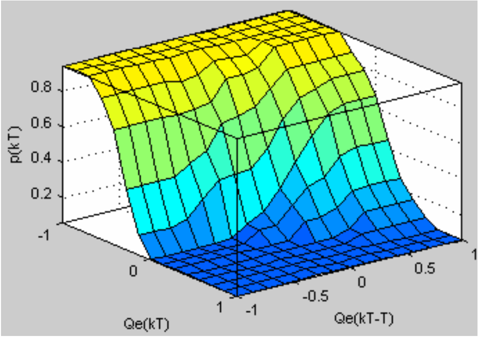

Figure 2. Decision surface of the fuzzy inference engine
The control surface is shaped by the rule base and the linguistic values of the linguistic variables.

Our design of a fuzzy control system is based on a fuzzy logic controlled AQM scheme to provide congestion control in TCP/IP networks, within both best-effort and Diff-Serv environments. The system model of FEM is shown in Figure 1, where all quantities are considered at the discrete instant *kT*, with *T* the sampling period, $e(kT) = q_{des} - q$ is the error on the controlled variable queue length, q, at each sampling period, $e(kT - T)$ is the error of queue length with a delay *T* (at the previous sampling period), $p(kT)$ is the *mark* probability, and SG_i and SG_o are scaling gains.

The proposed fuzzy control system is designed to regulate the queues of IP routers by achieving a specified desired TQL, q_{des}, in order to maintain both high utilization and low mean delay. A fuzzy inference engine (FIE) is designed to operate on router buffer queues, and uses linguistic rules to *mark* packets in TCP/IP networks. As shown in Figure 1, the FIE dynamically calculates the *mark* probability behavior based on two network-queue state inputs: the error on the queue length (i.e., the difference between the desired (TQL) and the current instantaneous queue length) for *two* consecutive sample periods (which can be interpreted as a prediction horizon). We have implemented FEM with *marking* capabilities, so that FEM routers have the option of either dropping a packet or setting its ECN bit in the packet header, instead of relying solely on packet drops. The decision of *marking* a packet is based on the *mark* probability, which is dynamically calculated by the FIE.

The scaling gains, SG_i and SG_o, shown in Figure 1, are defined as the maximum values of the universe of discourse of the FIE input and output variables, respectively. In order to achieve a normalized range of the FIE input variables from *-1* to *1*, the input scaling gain SG_i is set to be equal to $-1/(q_{des}-QueueBufferSize)$, if the instantaneous queue length is greater than the TQL; otherwise SG_i is equal to $1/q_{des}$. The output scaling gain SG_o is determined so that the range of outputs that is possible is the maximum, but also ensuring that the input to the plant will not saturate around the maximum. Following the approach in [2], SG_o is set to a value indicating the maximum *mark* probability that can also be adjusted in response of changes of the queue length.

The FIE uses linguistic rules to calculate the *mark* probability based on the input from the queues. Usually multi-input FIEs can offer better ability to linguistically describe the system dynamics. We expect that we can tune the system better, and improve the behavior of the queue, by achieving high utilization, low loss and delay. The dynamic way of calculating the *mark* probability by the FIE comes from the fact that according to the error of queue length for *two* consecutive sample periods, a different set of fuzzy rules, and so inference apply. Based on these rules and inferences, the *mark* probability is calculated more dynamically than other AQM approaches [1, 2, 3, 4, 5]. This point can be illustrated by observing the visualization of the decision surface of the FIE used in the FEM scheme (see Figure 2). The *mark* probability behaviour under the region of equilibrium (i.e., where the error on the queue length is close to zero) is smoothly calculated. On the other hand, the rules are aggressive about increasing the probability of packet *marking* sharply in the region beyond the equilibrium point. These rules reflect the particular views and experiences of the designer, and are easy to relate to human reasoning processes and gathered experiences.

In a Diff-Serv framework, we use two identical FEM controllers, one for each traffic class (that is, assured and best-effort), and we introduce two different TQLs, one for each FEM controller (The TQL for best-effort is lower than the one for assured traffic. That is, the best-effort packets are more likely to be *marked* than the assured ones). The idea behind this is to regulate the queue, if possible, to the lower TQL, in order to get a *mark* probability for the assured traffic closed to zero. In the presence of large amount of assured traffic, compared with the one of best-effort traffic, the queue can be regulated at the higher TQL (where the *mark* probability for best-effort traffic would be closed to one). Therefore, we can accomplish a bounded delay, by regulating the queue between the two TQLs, depending on the dynamic network/traffic conditions.

The design of FEM aims to generally provide better congestion control and better utilization of the network, with lower losses and delays than other AQM schemes [1, 2, 3, 4, 5], especially by introducing additional input variables and on-line (dynamic) adaptivity of the rule base (self-tuned).

3.2 Simulation results of the proposed mechanism

In this section we evaluate the performance and robustness of the proposed FEM AQM in a wide range of environments, and compare with other published results by taking some representative AQM schemes, namely A-RED [2], PI controller [3] and REM [4], in the case of a best-effort TCP/IP network, and RIO [5] in the case of a Diff-Serv TCP/IP network, using a recent version of NS-2 [8] simulator (Version 2.1b9a). We use AQM in the queues of the bottleneck link of the network topology used. We used both greedy sustained FTP applications, as well as web-like traffic. The simulation results are based on several scenarios-experiments that we have conducted. The performance of the AQM schemes under dynamic traffic changes is also examined, by providing some time-varying dynamics. We investigate the performance of AQM schemes under higher link capacities and propagation delays, and we examine the effect of the round-trip time (RTT) by increasing the propagation delay of the bottleneck link. We also investigate the effect of the traffic load factor, by increasing the number of active flows.

The performance metrics used to compare the AQM schemes are: Throughput/Goodput/Utilization, Loss Rate/*Mark* Rate, Mean Queuing Delay and its Standard Deviation. The results show the ability of FEM AQM to adequately regulate the queue length at the target values, and, consequently, controlling the queuing delay. FEM is very robust against the dynamic traffic changes and keeps very good response by successfully maintaining the queue length at the target value. The other AQM schemes examined are not as robust, as they are slower to settle down to the reference value, resulting in large queue fluctuation. Also, by increasing the RTT, the results show the superior steady performance of FEM with stable queue length dynamics, while other AQM schemes exhibit large queue fluctuations that result in degraded utilization and high variance of queuing delay. Furthermore, by increasing the load factor, FEM shows stable and low packet loss over large traffic load, and outperforms other AQM schemes on both high utilization and low mean delay, thus it exhibits a more stable, and robust behavior. In addition, extensive simulations have been conducted comparing RIO and FEM in a Diff-Serv environment. The performance metrics are kept the same, and similar results are obtained as above. It is clear, from the simulative results that FEM outperforms RIO in achieving higher utilization, lower packet loss, with a better discrimination between the best-effort and assured traffic in the presence of congestion, by *marking* more best-effort packets. The FEM controller can still regulate its queue at the predefined levels, while RIO is not as robust, as it exhibits large queue fluctuations, which results in degraded utilization, and high variance of queuing delay.

Details of the proposed QoS mechanism to improve the provision of quality of service in IP networks can be found in Appendices A - C, where the work done and the results obtained are widely accepted with journal publications and presentations in major conferences. Specifically, in Appendix A we present the paper “Fuzzy Logic Based Congestion Control in TCP/IP Networks for Quality of Service Provisioning” by C. Chrysostomou, A. Pitsillides, G. Hadjipollas, M. Polycarpou, and A. Sekercioglu, which is accepted for publication in the International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN'04) to be held in St. Petersburg, Russia, 2 - 6 February 2004. Appendix B presents the paper “Congestion Control in Differentiated Services Networks using Fuzzy-RED” by C. Chrysostomou, A. Pitsillides, L. Rossides, M. Polycarpou, and A. Sekercioglu, which is published in the Special Issue on "Control Methods for Telecommunication Networks" in IFAC Control Engineering Practice (CEP) Journal, Vol. 11, Issue 10, pp. 1153-1170, September 2003. Finally, Appendix C presents the paper “Fuzzy Explicit Marking for Congestion Control in Differentiated Services Networks” by C. Chrysostomou, A. Pitsillides, G. Hadjipollas, A. Sekercioglu, and M. Polycarpou, which is published in the Proceedings of the 8th IEEE Symposium on Computers and Communications (ISCC'2003), Antalya, Turkey, 30 June - 3 July 2003, Vol. 1, pp. 312-319.

4 Conclusions

This deliverable presented an overall evaluation of IP architectures and protocols of concern. Our main focus was on the differentiated services for the provision of quality of service in IP networks. In particular the behavior and performance of existing congestion control and queuing disciplines are evaluated in order to examine the ability of such mechanisms to provide adequate quality of service. The most critical characteristics of quality of service such as throughput capacity/utilization, losses and delay variations, are considered.

The results of the experiments and simulations show that the existing mechanisms in today’s Internet are not as robust and effective, in cases of dynamic network/traffic changes. Therefore, there is a need for further investigation, improvement and development of new mechanisms that can provide effective and efficient quality of service.

Therefore, a new mechanism for providing adequate quality of service in IP networks is proposed. We have presented a new AQM scheme, which we refer to as Fuzzy Explicit Marking (FEM), implemented in TCP/IP networks – within both best-effort and differentiated services (Diff-Serv) environments - using fuzzy logic techniques, to provide effective congestion control by achieving high utilization, low losses and delays. In a Diff-Serv environment, a two-class FEM controller, called FEM In/Out (FIO), is used. The proposed schemes, FEM and FIO, are contrasted with a number of well-known AQM schemes through a wide range of scenarios.

The proposed fuzzy logic approach for congestion control is implemented with *marking* capabilities (either dropping a packet or setting its ECN bit). We have successfully used the reported strength of fuzzy logic and have addressed limitations of existing AQM algorithms implemented in TCP/IP networks. This is clearly shown from the simulative evaluation. FEM and FIO controllers are shown to exhibit many desirable properties, like robustness and fast system response, and behave better than other AQM schemes in terms of queue fluctuations and delays, packet losses, and link utilization, with capabilities of adapting to highly variability and uncertainty in network. In the case of a Diff-Serv environment, FIO controller also achieves an adequate discrimination between the two traffic classes (assured and best-effort) by preferentially *marking* the lowest-priority packets, while controlling the queue at the predefined levels.

5 References

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Appendix A

“Fuzzy Logic Based Congestion Control in TCP/IP Networks for Quality of Service Provisioning” by C. Chrysostomou, A. Pitsillides, G. Hadjipollas, M. Polycarpou, and A. Sekercioglu.

Accepted for publication in the International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN'04) to be held in St. Petersburg, Russia, 2 - 6 February 2004.

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Appendix C

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Published in the Proceedings of the 8th IEEE Symposium on Computers and Communications (ISCC'2003), Antalya, Turkey, 30 June - 3 July 2003, Vol. 1, pp. 312-319.

Appendix D

"Personalized Portals for the Wireless User Based on Mobile Agents", C Panayiotou, G, Samaras. Technical Report TR-2003-06, University of Cyprus, 2003.