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Practical Fuzzy-CAC Realization for Effective Traffic Engineering in MPLS-TE Networks

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Introduction

Voice over IP (VoIP), and especially IPTV and Video on Demand (VoD) applications are gaining an ever increasing popularity these days [1], reinforced by the massive deployment of wide range of the fast access technologies. Supporting these applications requires the effective QoS provisioning at all the relevant points in the Internet. The application driven traffic control is needed to achieve fully dynamic resource management manner, as it is defined as a basic concept of the NGN.

MPLS-TE could serve as the brilliant solution for the future networks development strategy, which is mentioned to be QoS aware and concerning end-to-end provisioning, if the RSVP-TE were able to take into consideration possible application QoS requirements and network QoS potentialities. Today RSVP-TE uses classical threshold CAC algorithm while making decision whether to set-up new LSP or not, and is not able to provide selective flow control for dynamic LSP set-up.

As the CAC decisions are reliable for such traffic oriented performance objectives as packet loss, delays, throughput maximization, enforcement of service level agreements (SLA), packet delay jitter etc., we have to pay great attention to the CAC decision making mechanisms which are utilized in MPSL-TE networks.

The threshold CAC is not capable of making decisions in uncertain conditions, which are prevailingly persistent in the modern broadband networks [2]. The dynamic traffic demand in the fast changing environment and bursty background traffic practically eliminate the possibility of fast online reasoning, which in case of CAC decision making is even in the sub-second time scale [3]. Fuzzy logic serves as the excellent tool to cope with uncertain and multivariable data, this giving the flexibility and robustness for decision making while using IF-THEN fuzzy rules [4].

In this paper, we propose the practical fuzzy-CAC implementation to RSVP-TE protocol inside the MPLS-TE network, using fuzzy-CAC mechanism, which was introduces by authors of the current paper in multiple previous publications [5–7]. In papers mentioned above, one can find comprehensive description of fuzzy-CAC implementation based on simulation results, as well as fuzzy-CAC adaptation method descriptions for effective traffic control in MPLS/GMPLS network domains.

In this paper we focus purely on fuzzy-CAC practical realization in MPLS-TE test network and provide experimental testbed description as well as the summary of the general practical results.

Fuzzy inference system design

The fuzzy inference system (FIS) design was based on several predefined goals:

1. To maximize link utilization, while maintaining defined QoS restrictions (1):

$$\begin{cases} \max(util): \\ \forall\ \mathrm{Delay_{link}}: 0 \le \mathrm{Delay_{link}} \le \mathrm{Delay_{link}MAX}, \\ \forall\ \mathrm{Jitter_{link}}: 0 \le \mathrm{Jitter_{link}} \le \mathrm{Jitter_{link}MAX}, \\ \forall\ \mathrm{Drops_{link}}: 0 \le \mathrm{Drops_{link}} \le \mathrm{Drops_{link}MAX}, \end{cases} \tag{1}$$

where util $\in [0,1]$ is the utilization of the link under test; $\mathrm{Delay_{link}}$ are measured delays of the link under test; $\mathrm{Delay_{link}MAX}$ are maximally allowed delays on the link under test; $\mathrm{Jitter_{link}}$ is measured jitter of the link under test; $\mathrm{Jitter_{link}MAX}$ are maximally allowed jitter values on the link under test; $\mathrm{Drops_{link}}$ are measured packet drops of the link under test; $\mathrm{Drops_{link}MAX}$ are maximally allowed packet drop values on the link under test;

2. To achieve selective LSP set-up, with the intention of increasing high QOS class flow servicing;
3. To exclude LSP set-up occurrences in an inappropriate QoS conditions.

As the goals mentioned above, has to be achieved, while maintaining predefined QoS restrictions, the criteria for such a restriction selection was based on several big backbone network providers Service Level Agreements (SLA), as they outclass even most QoS sensitive multimedia applications, such as VoIP, QoS requirements.

NNT Europe, Sprint Network, Internap, Qwest and Verio SLAs were chosen, and in weighted-average they specify consequent QoS restrictions in SLA agreements (Table 1).

Table 1. NNT Europe, Sprint Network, Internap, Qwest and Verio SLAs weighted-average SLA restrictions

SLA QoS defined restrictions		
Packet delays	**Packet losses**	**Average jitter**
45 ms	0.20 %	1.0 ms

With the intention of maximal advance towards the believable QoS criteria restriction selection for the MPLS-TE network testbed (MNT) used by the authors, SLA restrictions given above (Table 1), were normalized using average hop number for connections inside large backbone network providers, such as Verison, AT&T and Sprint Networks, which are equal to ≈2.7 [8].

As seen from the Fig. 1, MPLS-TE network testbed, containing only 3 routers, allows just 2 hops to be made, while sending data flows through the network. As the result, subsequent changes were made to selected SLA data (2 and 3):

$$\frac{\text{SLA QoS data}}{\text{MNT QoS data}} = \frac{\text{Average hop number of providers}}{\text{MNT hop number}}, \quad (2)$$

$$\frac{\text{SLA QoS data}}{\text{MNT QoS data}} = \frac{2.7}{2}. \quad (3)$$

As a result, consecutive results were calculated and chosen as the FIS design restrictions, while searching for the maximum utilization of the link under test (Table 2).

Table 2. NNT Europe, Sprint Network, Internap, Qwest and Verio SLAs weighted-average SLA restrictions

SLA QoS defined restrictions		
Packet delays	**Packet losses**	**Average jitter**
33 ms	0.15 %	0.7 ms

For an appropriate FIS design selection heuristic approach was utilized, by trial and error, excluding multiple possible FIS variations, modelled in advance. As the results FIS structure with the following decision rules was chosen (See Fig. 1 and 2). The 33 rule IF-THEN knowledge base was selected.

For more details on fuzzy-CAC FIS structure, please examine previous author's publications [5–7].

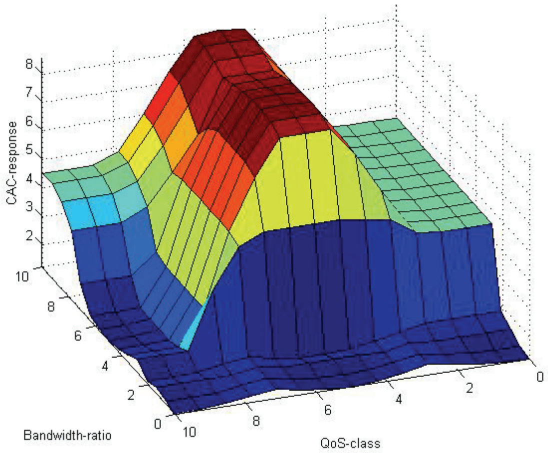

Fig. 1. Fuzzy-CAC FIS decision surface (Bw-ratio vs QoS-class)

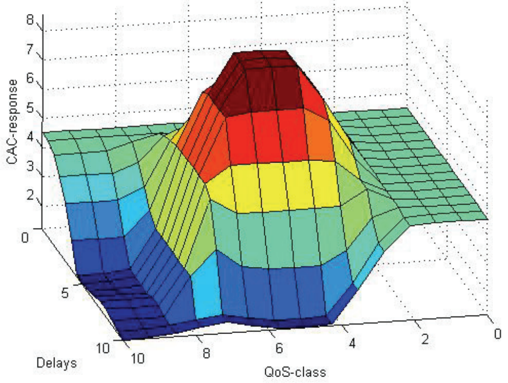

Fig. 2. Fuzzy-CAC FIS decision surface (Delays vs QoS-class)

Description of the MPLS-TE testbed

The current testbed uses 3 Cisco 2800 series routers in MPLS-TE configuration. The first router in the connection switches new LSP tunnels through the network. Router buffer configuration was set-up using default 40 packet threshold. The fuzzy-CAC decision for setting up a new LSP was achieved by using Matlab FIS, while generated traffic flows are being sent through the network in the case of the positive CAC decision. Packet losses, delays, jitter, buffer state of the router and states of the set-up LSPs are logged. Requested QoS levels and available bandwidth, at the time of the CAC decision, are also logged and analyzed.

Testing scenario descriptions

The best and the worst case scenarios were applied in the current research. The best case scenario defines the link under test to be completely empty at the start of the testing (see Fig. 3). Traffic flow requests and QoS levels were generated using fBm process generator [9].

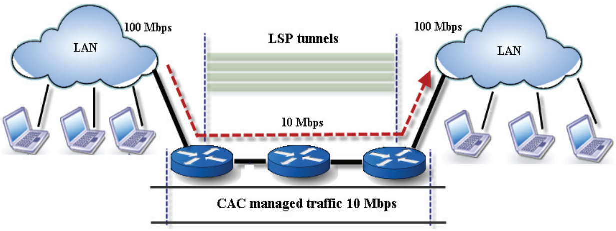

Fig. 3. Layout of the best case scenario

The same input data were used for classical threshold CAC algorithm and fuzzy-CAC implementation, and as a result comparable results were obtained. Link delay values were received using Cisco IOS IP SLA (Service Level Agreements) returned values.

10Mbps link, which is the bottleneck element of the tested network, is then filled with the LSP tunnels and real data flows, depending on CAC results, which are received sequentially form fuzzy-CAC and threshold CAC realizations. Traffic oriented performance indicators are then analyzed, such as packet losses and packet delays in the network, RSVP reserved bandwidth, buffer state of the router and jitter variations etc.

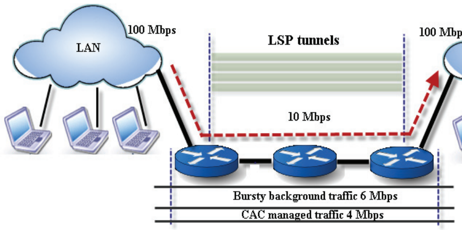

Fig. 4. Layout of the worst case scenario

The worst case scenario (see Fig.4) characterizes with the static 6 Mbps background traffic flow, which exhibits explicit burstiness. Such conditions perfectly show the ability of the proposed algorithm to provide robustness and enforced traffic flow selectiveness, while maintaining the requested QoS for LSPs set-up.

In both scenarios LSP tunnels are being torn-down one time for every 3 incoming traffic flow requests. This guarantee excess load conditions, which are at interest when testing fuzzy-CAC algorithm for viability and robustness.

General results

Below one can find general practical results achieved by utilising both, fuzzy and threshold CAC algorithms, with the same input variables for decision making and in the same conditions, described in section above. All the mean values are depicted for 3000 CAC decision making points. Figures depict values for 80 CAC decisions for graphic clearness.

RSVP reserved resources are depicted on Fig. 5 and 6 for best and worst case scenarios respectively. Threshold CAC allows link resources to be utilized almost to the top, irrespectively of the nature of incoming traffic flows and requested QoS levels. Fuzzy-CAC, on the other hand, is more selective and allows only connections that can be serviced in the proper manner, maintaining requested QoS level. In both scenarios fuzzy-CAC restrained resource distribution policy defined in the fuzzy IF-THEN rules, giving the tested link something similar to the “live jacket”, which is not allowing the link to be overutilized and is attaining considerable deterioration of the QoS parameters.

Fig. 7 and Fig. 8 depicts packet delays in the testbed network for best and worst case scenarios respectively. It is clearly seen, that under identical conditions fuzzy-CAC reduces mean packet delays from 77ms with the threshold-CAC to 22ms in best case scenario, and from 121ms to 46ms in worst case scenario.

Also mean buffer fill of the tested router was considerable reduced when using fuzzy-CAC algorithm – form 8 packets to 1 packet in best case scenario, and from 28 packets to 14 packets in worst case scenario.(See Fig. 9 and 10) The buffer size in this particular configuration was 40 packets.

Packet drop cumulative graphs are depicted on Fig. 11 and Fig. 12 for best and worst case scenarios respectively. While in the best case scenario fuzzy-CAC managed router drops were nearly nil, under the worst case scenario it provided more than double cut in dropped packets.

Fig. 13 and 14 depicts mean packet delay jitter values and values in decision making moments for best and worst case scenarios respectively. One can see, that fuzzy-CAC in both cases provides considerably lower variation in packet delay.

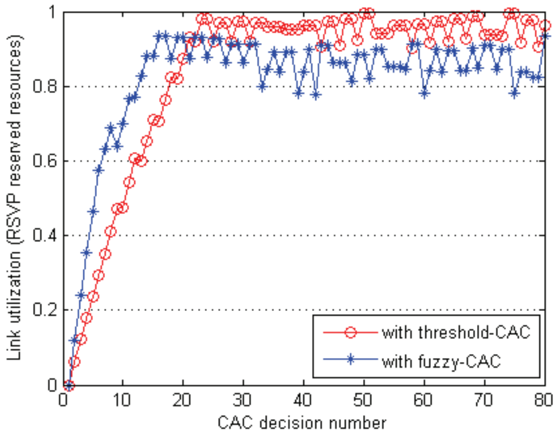

Fig. 5. Link utilization (RSVP reserved resources) – best case scenario.

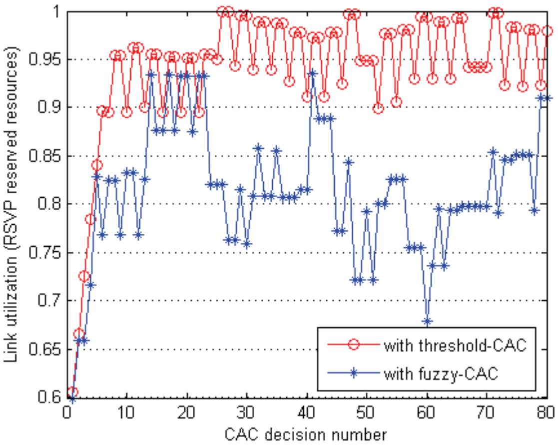

Fig. 6. Link utilization (RSVP reserved resources) – worst case scenario

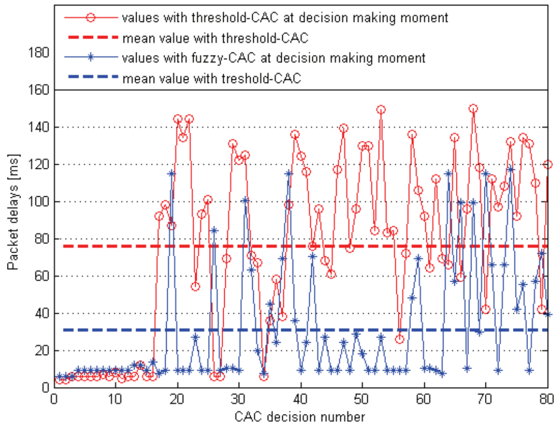

Fig. 7. Packet delays – best case scenario

In Tables 3 and 4 above the summarization is given of the results of this investigation - mean values for 3000 decision making samples.

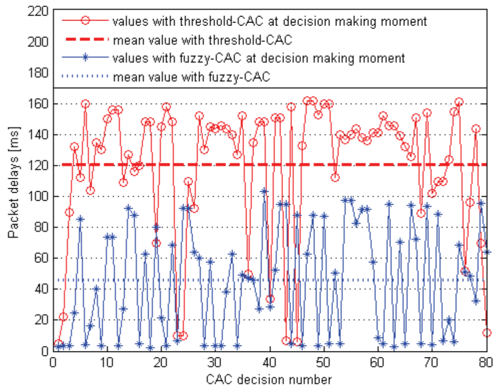

Fig. 8. Packet delays – worst case scenario

Table 3. Results for 3000 decision making samples - best case scenario

Results for 3000 decision making samples - best case scenario – mean values		
Parameters	***Threshold-CAC***	***Fuzzy-CAC***
Link utilization	0.94	0.84
Packet losses	3.10 %	0.10 %
Jitter	3.3 ms	0.6 ms
Buffer fill	8 packets	1 packet
Packet delays	77 ms	33 ms

Table 4. Results for 3000 decision making samples - worst case scenario

Results for 3000 decision making samples - worst case scenario – mean values		
Parameters	***Threshold-CAC***	***Fuzzy-CAC***
Link utilization	0.97	0.88
Packet losses	11.80 %	3.90 %
Jitter	4.0 ms	1.3 ms
Buffer fill	28 packets	14 packet
Packet delays	121 ms	46 ms

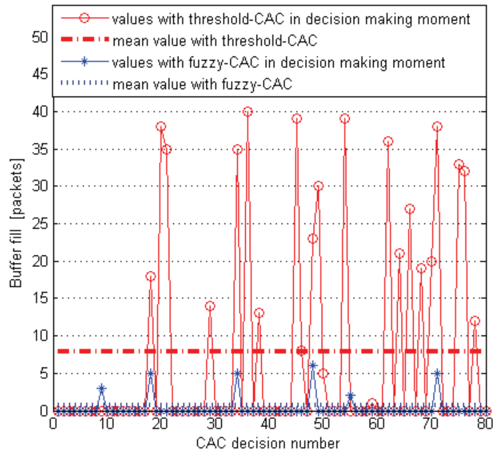

Fig. 9. Buffers fill of the tested router – best case scenario

As one can see from the results (Table 3 and 4), that fuzzy-CAC FIS heuristic selection, with the predefined goal of maximizing link utilization, while maintaining defined QoS restrictions resulted in less utilized link, as if compared to the classical threshold-CAC realization. This result demonstrates the trade-off between the link utilization and provision of the suitable QoS parameters.

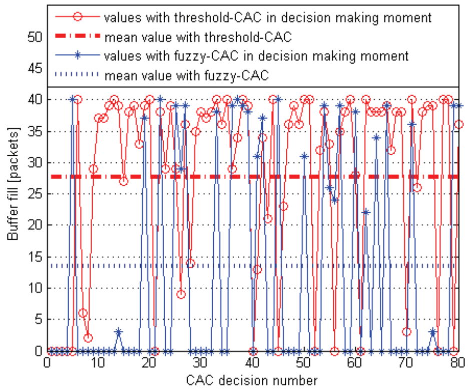

Fig. 10. Buffers fill of the tested router – worst case scenario

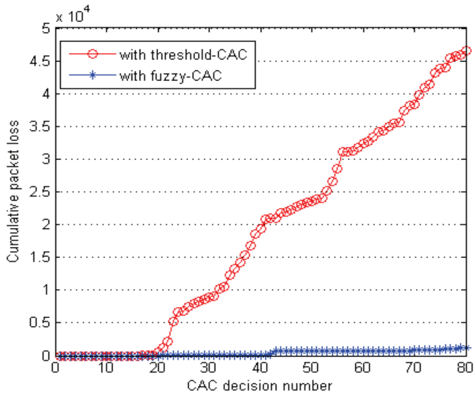

Fig. 11. Cumulative packet losses – best case scenario

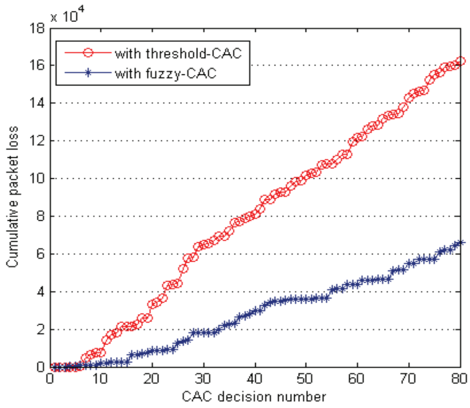

Fig. 12. Cumulative packet losses – worst case scenario

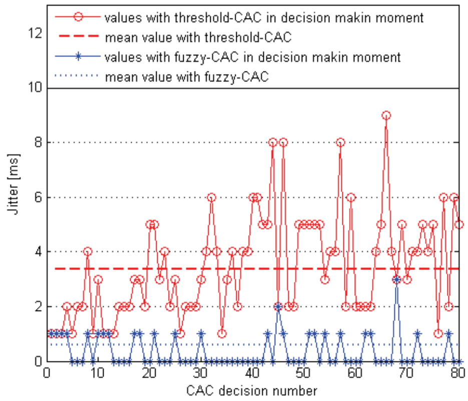

Fig. 13. Delay jitter – best case scenario

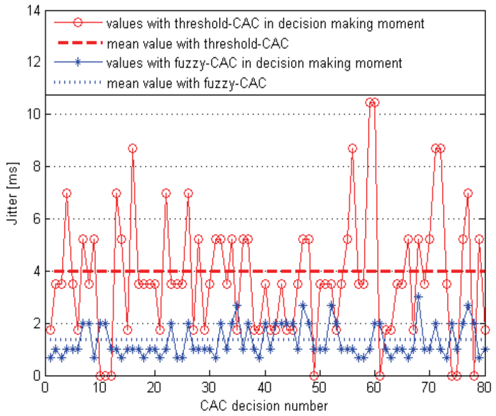

Fig. 14. Delay jitter– worst case scenario

Also not every SLA defined (See Table 1 and 2), criteria was reached to the margin, as attaining packet loss limit of 0.15%, packet delay mean value was still less then allowed 33 ms, and resulted in 22ms. Also jitter values resulted in mean value of 0.6 ms, which is close to the defined margin of 0.7 ms.

Conclusions

The proposed fuzzy CAC scheme shows promising results and can be used as the potential modification of the RSVP-TE CAC control mechanism to deal with multiple class traffic of next generation fast optical networks which are anticipated to operate under MPLS-TE control plane or GMPLS in the nearest future. The practical realization test results show that the performance of proposed algorithm is preferable to that of existing threshold CAC scheme of RSVP-TE and gives unfailing modification and improvement facilities for possible adjustments [7].

The future research anticipates fuzzy interface membership function and fuzzy rules to be dynamically modified to attain optimal decision making under uncertain network conditions as well as the decision firing threshold online modification. The curiously interesting appears the possibility of development of multiagent traffic management system based on fuzzy agents, to provide common knowledge base for certain network clusters and provide the interactivity to the knowledge bases to guarantee their online mode adaptation to the changing network environment.

Acknowledgment

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In this investigation the new Fuzzy-CAC algorithm practical implementation of RSVP-TE protocol development for use in MPLS-TE/GMPLS networks is presented. Fuzzy-CAC algorithm is tested on the MPLS-TE network testbed with 3 Cisco 2800 series routers, on which classical threshold CAC algorithm is compared to the Fuzzy-CAC algorithm implementation. Main QoS characteristics are analyzed, experimental data are depicted and future research subjects are described. Ill. 14, bibl. 9, tabl. 4 (in English; abstracts in English and Lithuanian).

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Atliktas RSVP-TE protokolo pritaikymas MPLS-TE/GMPLS tinkluose. Ištirtas neraiškiojo CAC algoritmo taikymas MPLS-TE tinkluose naudojant tris maršrutizatorius Cisco 2800. Tarpusavyje palyginti CAC ir neraiškusis CAC algortimai. Išanalizuotos paslaugos kokybės charakteristikos. Aprašyti tyrimo rezultatai, numatytas ateities tyrimų gairės. Il. 14, bibl. 9, lent. 4 (anglų kalba; santraukos anglų ir lietuvių k.).