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Fuzzy Logic Approach for QoS Routing Analysis

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1. Introduction

One of the main challenges nowadays for managing IP networks is guaranteeing quality of service. One of the proposed solutions is traffic management with MPLS protocol. However, requirement characterization and the network state are very difficult tasks, taking into account that requirements for different services are random, where as a result the network condition varies dynamically and randomly. This is reason why researches have used fuzzy logic for solving a lot of problems that can occur in very dynamic networks. In this chapter we will analyze MPLS network routing metrics using fuzzy logic. We will pay attention the most appropriate defuzzification methods for finding the path that fulfills the QoS requirements for multimedia services.

One of the key issues in providing end-to-end quality of service (QoS) guarantees in today's networks is how to determine a feasible route that satisfies a set of constraints. In general, finding a path subject to multiple constraints is an NP-complete problem that cannot be exactly solved in polynomial time. Accordingly, several heuristics and approximation algorithms have been proposed for this problem. Many of these algorithms suffer from either excessive computational cost or low performance.

Selecting feasible paths that satisfy various QoS requirements of applications in a network is known as QoS routing [1]. In general, two issues are related to QoS routing: state distribution and routing strategy. State distribution addresses the issue of exchanging the state information throughout the network. Routing strategy is used to find a feasible path that meets the QoS requirements. In this chapter we will present the fuzzy logic approach for QoS routing analysis in a network which is able to offer multimedia services, such is MPLS network [2] [3] [4] [5] [6]. Fuzzy sets offer powerful mathematical structure that has to do with non-preciosity and uncertainty of real word. Linguistic variables allow representation of numerical values with fuzzy sets. Knowing that networks nowadays are very dynamic, which means that networks have parameters that are affected from unexpected overloads, failures and other concerns, fuzzy logic offers promising approach for addressing different network problems [7] [8]. Applying of fuzzy logic in telecommunication networks is done lately and is proved to be a very economic and efficient method compared with other methods used in automatic control. Recent researches on application of fuzzy logic in telecommunication networks have to do with: packet queuing, buffer management, call acceptance, QoS routing, channel capacity sharing, traffic management etc.

Some problems can occur during multimedia service transmission, therefore it is a good idea to design some control mechanisms for solving such problems. As a result of the complex nature of control mechanisms, more and more is being done in designing intelligent controlled techniques. One of the intelligent controlled techniques that will be part of this chapter is Fuzzy Logic Controller, a technique that is based on fuzzy logic. In this chapter we will use main metrics of MPLS network as input parameters of FLC, and we will try to choose the most appropriate defuzzification method for finding better crisp values in aspect of link utilization, in the output of Fuzzy Logic controller.

In this chapter we will firs explain shortly QoS routing principle, MPLS technology in aspect of QoS routing metrics. Also, here we will give the main attention to the fuzzy logic approach, especially FLC used for QoS routing analysis in MPLS network. In this aspect we will try to find the best defuzzification method for gaining better crisp values for link optimization in MPLS network.

2. QoS routing

The main goal of QoS based routing is to select the most suitable path according to traffic requirements for multimedia applications. Selection of suitable transmission paths is done through routing mechanisms based on existing network resources and QoS requirements. Multimedia applications might suffer degradation in quality in traditional networks such as Internet [9]. This problem can be solved in networks that contain dynamic path creation features with bandwidth-guaranteed and constrained delays [10]. Real–time applications impose strict QoS requirements. These application requirements are expressed by parameters such as acceptable and end-to-end delays, necessary bandwidth and acceptable losses. For example, audio and video transmissions have strict requirements for delay and losses. Wide bandwidth must be guaranteed for high capacity transmission. Real time traffic, video in particular, quite often utilizes most important quantities of network resources**.** Efficient management of network resources will reduce network service cost and will allow more applications to be transmitted simultaneously. The task of finding suitable paths through networks is treated by routing protocols. Since common routing protocols are reaching their acceptable complexity limits, it is important that complexity proposed by QoS based routing [11] should not damage scalability of routing protocols. MPLS is a multiple solution for a lot of current problems faced by Internet [12]. By a wide support for QoS and traffic engineering, MPLS is establishing itself as a standard of the next generation's network.

3. MPLS network

MPLS is a data transmission technology which includes some features of circuit switched networks through packet switched network. MPLS actually works at both Layer 2 and Layer 3 in OSI model and it is often referred to as a Layer 2.5 technology. It is designed to provide transport possibilities of data for all users. MPLS techniques can be used as a more efficient tool for traffic engineering than standard routing in IP networks. Also, MPLS can be used for path control of traffic flow, in order to utilize network resources in an optimal way. Network paths can be defined for sensitive traffic, high security traffic etc, guaranteeing different CoS (Class of Service) and QoS. Main MPLS feature is virtual circuit configuration through IP network. These virtual circuits are called LSP.

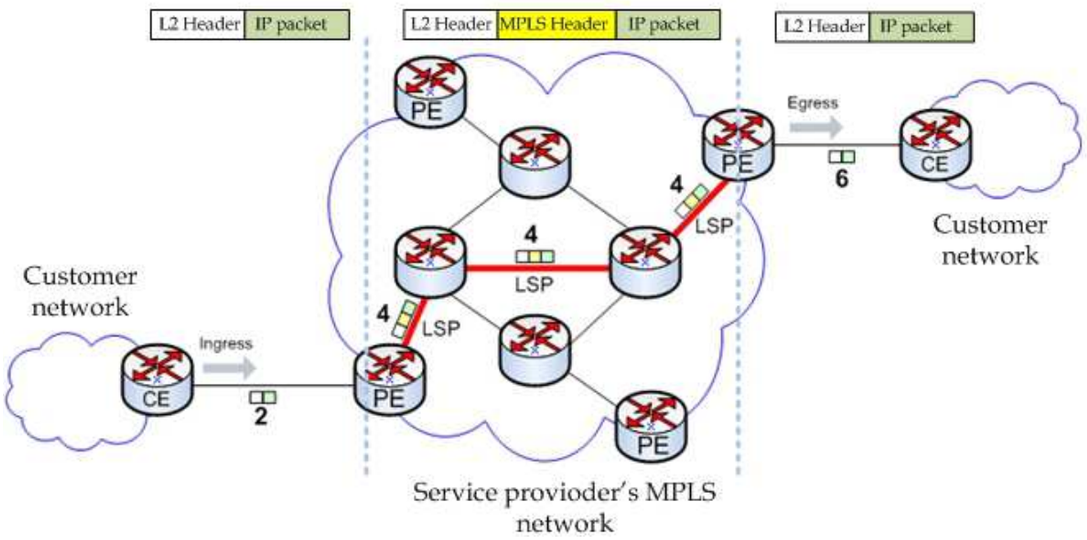


Fig. 1. MPLS network

MPLS supports traffic engineering for QoS provision and traffic prioritization, for example: provision of wider bandwidth and lower delays for gold customers who are able to pay more for better quality services. Another example a lot of paths can be defined through edge points by ensuring lower levels of interferences and backup services in case of any network failure. This is like using routing metrics in IP network to enforce traffic flowing in one or another direction, but in this case MPLS is much more powerful. An important aspect in MPLS is the priority concept of LSP [13]. LSPs can be configured with higher or lower priority. LSPs with higher priority have advantages in finding new paths compared with those of lower priority.

Figure 1 shows MPLS network and its corresponding elements. The core part represents the MPLS network. MPLS combines the advantages of packet forwarding which is based on layer 2 and routing properties of the 3'd layer. MPLS also offers traffic engineering (TE). TE is process of selecting suitable routes for data transmission on the network, that has to do with efficient use of network resources and improving network performance, thus increasing network revenue and QoS. One of the main goals of TE is efficient and reliable functionality of the network. Also, TE calculates the route from the source to the destination based on different metrics such as channel capacity (bandwidth), delays and other administrative requirements.

4. Routing metrics in MPLS network

Routing metrics have a significant role, not just in complexity of route calculation but also in QoS. The use of multiple metrics is able to model the network in a more precise way, but the problem for finding appropriate path can become very complex [9] [10]. In general, there are 3 types of metrics:

- Additive,
- Multiplicative and
- Concave.

They are defined as below:

If m (n_1, n_2) are metrics for link (n_1, n_2). For one path $P = (n_1, n_2, \ldots, n_i, n_j)$, metric m is (n_1, n_2, …, n_i, n_j):

- Let d (i, j) be a metric for link (i, j).

For any path $p = (i, j, k, \ldots, l, m)$, we say metric d is additive if:

$$d(p) = d(i, j) + d(j,k) + \ldots + d(l, m) \quad (1)$$

- We say that metric d is multiplicative if:

$$d(p) = d(i, j) \times d(j,k) \times \ldots \times d(l, m) \quad (2)$$

- We say that metric d is concave if:

$$d(p) = min[d(i, j), d(j,k), \ldots d(l, m)] \quad (3)$$

In MPLS network there are a lot of metrics that we can take into consideration, but in this chapter, for sake of simplicity, we will consider three main metrics: delay, losses and bandwidth. Those metrics play a direct role in quality of service in MPLS network. In order to consider multiple metrics simultaneously, we will use fuzzy logic controller. FLC is intelligent technique that can manipulate with two or more input parameters simultaneously without any problem.

5. Soft computing

Soft Computing is more tolerable in uncertainty and partial truth than Hard Computing. The model in which soft computing is based in human mind. The main components of soft computing are: Fuzzy Logic, Neural Networks, Probabilistic reasoning and Genetic algorithms. The most important component of soft computing is Fuzzy logic, which will be part of this chapter. Fuzzy logic will be used for a lot of applications. Applications of fuzzy logic in telecommunications networks are recent. Fuzzy Logic is organized into three main efforts: modeling and control, management and forecasting, and performance estimation.

5.1 Fuzzy logic

Idea for fuzzy logic has born in 1965. Lotfi Zadeh has published one seminar for fuzzy which was the beginning for fuzzy logic [14]. Fuzzy logic is tolerant in imprecise data, nonlinear functions and can be mixed with other techniques for different problems solving. The main principle of fuzzy logic is using fuzzy groups which are without crisp boundaries.

6. QoS routing analysis using FLC – Fuzzy Logic Controller

As we have mentioned above, for QoS routing analysis we will use FLC as intelligent controlling technique. A Fuzzy Logic Controller [15] is a rule based system in which fuzzy rule represents a control mechanism. In this case, a fuzzy controller uses fuzzy logic to simulate human thinking. In particular the FLC is useful in two special cases [15]:

- When the control processes are too complex to analyze by conventional quantitative techniques
- When the available sources of information are interpreted qualitatively or uncertainly.

Fuzzy logic controller consists of: fuzzifier, rule base, fuzzy inference and defuzzifier (see Figure 2).

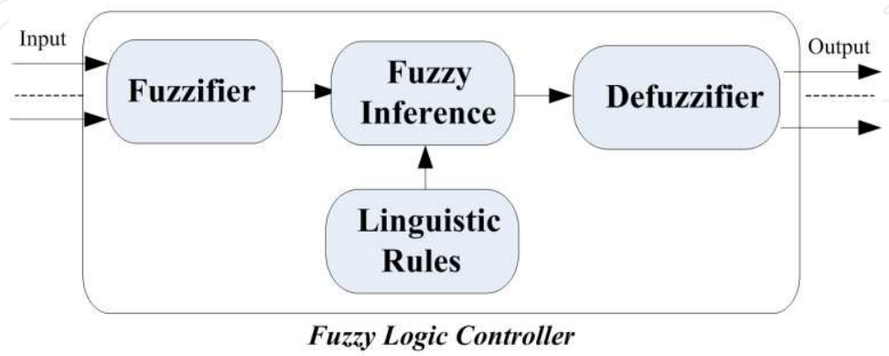


Fig. 2. Fuzzy Logic Controller

Fuzzifier: A fuzzifier operator has the effect of transforming crisp value to fuzzy sets. Fuzzifier is presented with $x=fuzzifier(x_0)$, where x_0 is input crisp value; x is a fuzzy set and fuzzifier represents a fuzzification operator.

Rule-Base (Linguistic Rules): Contains IF-THEN rules that are determined through fuzzy logic.

Example: if x is A_i and Y is B_i the Z is C_i, Where x and y are inputs and z is controlled output; A_i, B_i and C_i are linguistic terms, like: low, medium, high etc.

Fuzzy Inference: Is a process of converting input values into output values using fuzzy logic. Converting is essential for decision making. Fuzzy Inference process includes: membership functions and logic operations

Defuzzifier: can be expressed by: $y_{ou}=defuzzifier(y)$, where y identifies fuzzy controller action, y_{ou} identifies crisp value of control action and defuzzifier presents defuzzifier operator. Converting process of fuzzy terms in crisp values is called defuzzification. There are some defuzzification methods: COG (Centre of Gravity), COGS (Centre of Gravity for Singletons), COA (Centre of Area), LM (Left Most Maximum) and RM (Right Most Maximum).

7. MPLS network metrics and membership functions

For solving QoS routing problem, we will use fuzzy logic approach. Fuzzy logic is proved to be very effective in a lot of applications, such as intelligent control, decision making process etc. Fuzzy logic is based in a set of metrics which can be or not connected with each other. Calculating the best route cannot be done using complex mathematical solutions, but is based in intuitive rules.

Fuzzy logic applies to all those routes that are candidates for being chosen whereas the chosen path in this way is the path that has better quality. In this chapter we will use the Fuzzy logic controller for solving QoS routing problems and the routing algorithm refers to the fuzzy logic (fuzzy routing algorithm). This algorithm is able to choose the path with better transmission parameters. For solving such a problem using fuzzy logic, first we have to take into consideration some input parameters, acting at the entrance of FLC, which in our case must be the MPLS network metrics. These input variables can be crisp or fuzzy values. Whereas the main disadvantageous of MPLS network consist in: losses, delay and bandwidth, then these three metrics will be taken as network parameters. These metrics match with the main factors which affect for choosing the best route for transmission of multimedia services. Each network metric has the value from 0 to 1. These metrics are:

a. Channel capacity (B)

Channel capacity is one of the main MPLS network parameters. In this chapter, channel capacity is combined with linguistic data for selecting the optimal route from the source to destination. In this particular case we took three membership functions that indicate the potential scale of the channel capacity: LOW, MEDIUM and HIGH. Channel capacity is presented by triangular membership functions. Figure x shows the membership function for the channel capacity. Triangular number $B = (b_1, b_2, b_3)$ in limited in his left hand with value b1 and in his right hand with the value b_3. In this way, decision taker can calculate that channel capacity in a certain link cannot be smaller than b_1 or greater than b_2. Figure 3 shows the fuzzy set of linguistic data for channel capacity.

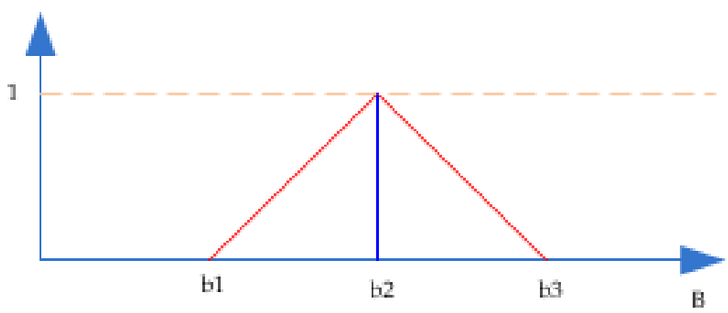


Fig. 3. Fuzzy Triangular number for channel capacity - B

It can be seen from the figure x that each value has the upper and lower limit.

b. Delays (D)

For most applications, especially real time applications, the delay for transmission of information between two points is one of the most important parameters for meeting QoS requirements. For delay we set 3 membership functions in triangular form to show the potential scale of the delays: ACCEPTABLE, TOLERABLE and INTOLERABLE. Figure 4 represents the membership function $\mu_s(D_s)$ for the delay. From this function it is indicated that the greatest value of membership is (=1) for $D_s = d_s$.

c. Losses (L)

For losses we will use 3 membership functions. For two membership functions we will use triangular form (ACCEPTABLE and TOLERABLE), while for one of membership functions we will use rectangular form (INTOLERABLE).

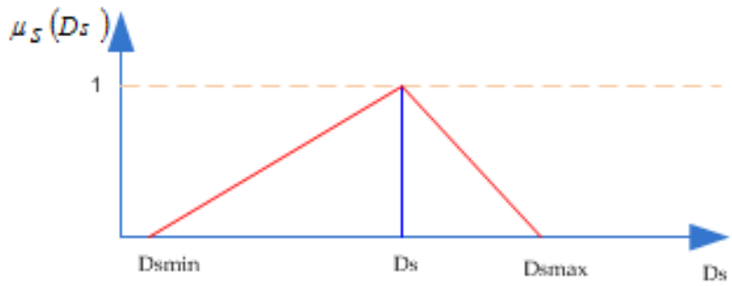


Fig. 4. Fuzzy triangular number for delay-D

In table x are given details about metrics in the input of the fuzzy system and fuzzy sets corresponding such inputs.

Input parameters for MPLS network	**Fuzzy sets**
Channel capacity (bandwidth)	{LOW, MEDIUM, HIGH}-*Mbps*
Delays	{ACCEPTABLE, TOLERABLE, INTOLERABLE}- *ms*
Losses	{ ACCEPTABLE, TOLERABLE, INTOLERABLE }-%

Table 1. Input parameters and fuzzy sets

Mathematical relations of 3 input parameters can be given by the below expression:

$$f(p) = \frac{B(p)}{D(p) x L(p)} \tag{4}$$

Where p is the calculated path, $B(p)$ is channel capacity, $D(p)$ is the delay among transmission, and $L(p)$ is the probability of packet loss.

8. Limits of fuzzy sets for MPLS network parameters

Packet switching networks commonly are used for transmission of multimedia services. This trend continued in MPLS network also. Real time traffic is sensitive to delays, such as: voice, video etc, constitute an important part of real time traffic. Such traffic has more strict requirements for quality of service (QoS), especially in the aspect of delays between two end points and packet losses. The table below shows standard requirements for QoS for multimedia services.

	Maximum rate	**Average rate**	**Probability of packet loss**
Voice	32 KBits/sec	11.2 KBits/sec	0.05
Voice	11.6 MBits/sec	3.85 MBits/sec	10**(-5)

Table 2. Bit rate for voice transmission

According to ITU recommendations for delay, packet loss and channel capacity, we have defined the boundaries of fuzzy sets.

Delays in one direction	**Characterization of quality**
0 to 150 *ms*	Acceptable for most of applications
150 to 400 *ms*	May impact in some applications
Above 400 *ms*	Unacceptable for most of applications

Table 3. ITU recommendation for delays

Delays

Delays up to 150 ms are acceptable
Delays between 150 and 400 ms are tolerable for special applications
Delays higher than 400 ms are intolerable

Packet loss percentage

Lower than 2% - acceptable
From 2 – 6% - tolerable
Higher than 6 % - intolerable

Channel capacity:

Low: from 0 *Mbps* to 200 *Mbps.*
Medium: from 180 *Mbps* to 500 *Mbps.*
High: from 470 *Mbps* to 1000 *Mbps.*

9. Fuzzy logic toolbox in Matlab software

Fuzzy logic tool in Matlab is used for solving different problems dealing with Fuzzy Logic. Fuzzy logic is a very valuable tool for planning because it makes a very good for problems that have high importance and require high precision – something that human beings have done long time ago. Fuzzy logic tool allows users to do important jobs, but the most important thing is to allow users to create fuzzy conclusions (fuzzy inference). It is also possible to use fuzzy logic tool through command line, but in general it is easier to build a system through the GUI. There are five primary GUI tools for building, editing and reviewing systems in fuzzy logic toolbox:

1. FIS (Fuzzy Inference System) editor
2. Membership function editor
3. Rules editor
4. Rule Viewer
5. Surface viewer

The interactions of these tools can be seen in the figure below (Figure 5).

Rule viewer and surface viewer are used for survey, compared with FIS editor, which is used for editing. So, they are read-only tools. These GUI dynamically are connected with each other and changes in FIS can be seen in other open GUIs.

Membership function for channel capacity, delays, losses and the output of the fuzzy system will be seen in the following figure (where the values are taken for real tie applications). Based on the above limits for fuzzy sets, using Matlab software we can create the membership functions main parameters of the MPLS network.

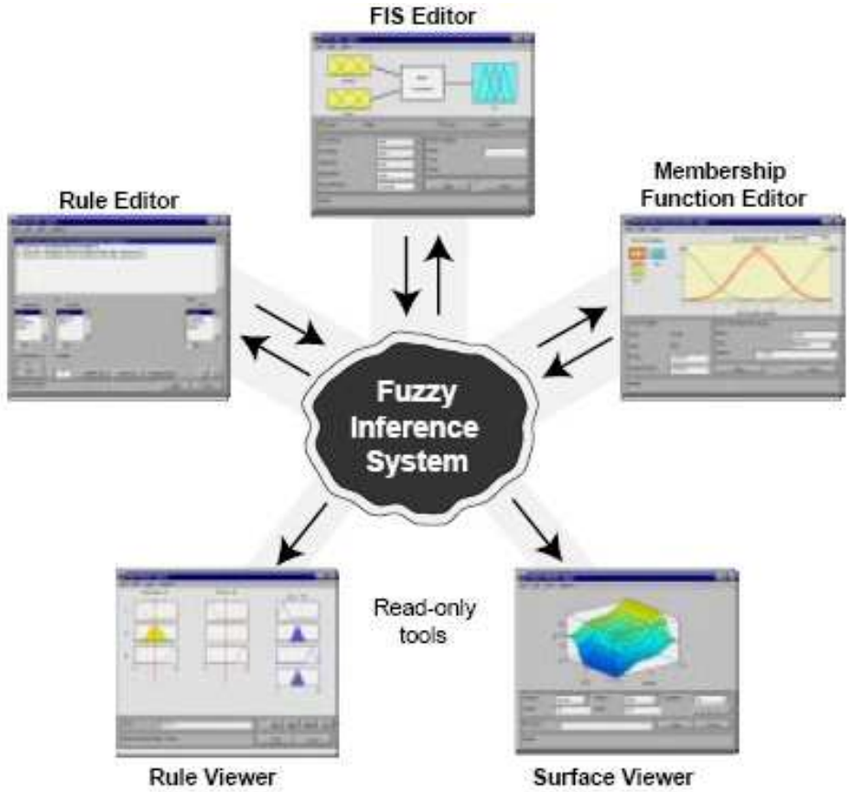


Fig. 5. Fuzzy system and its integral components in MATLAB software

[System]
Name='fuzzy_link'
Type='mamdani'
Version=2.0
NumInputs=3
NumOutputs=1
NumRules=4
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='Centre of Gravity'

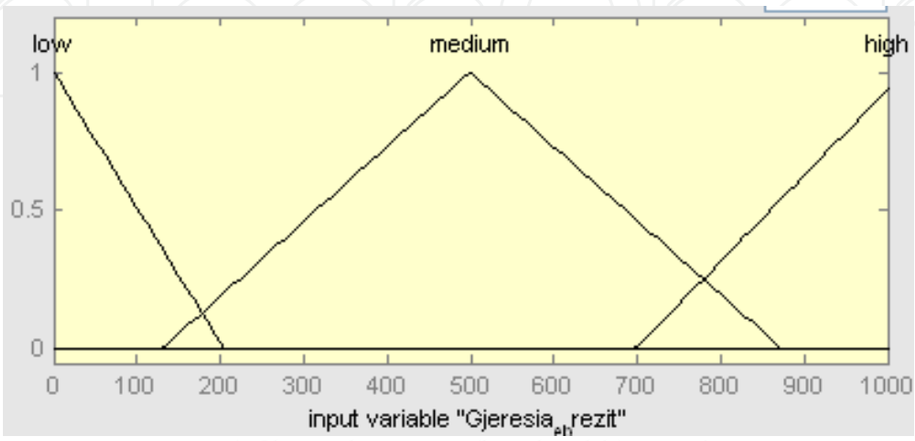
[Input1]
Name='bandwidth'
Range=[0 1000]
NumMFs=3

MF1='low':'trimf',[-400 0 400]
MF2='medium':'trimf',[100 500 900]
MF3='high':'trimf',[600 1000 1400]

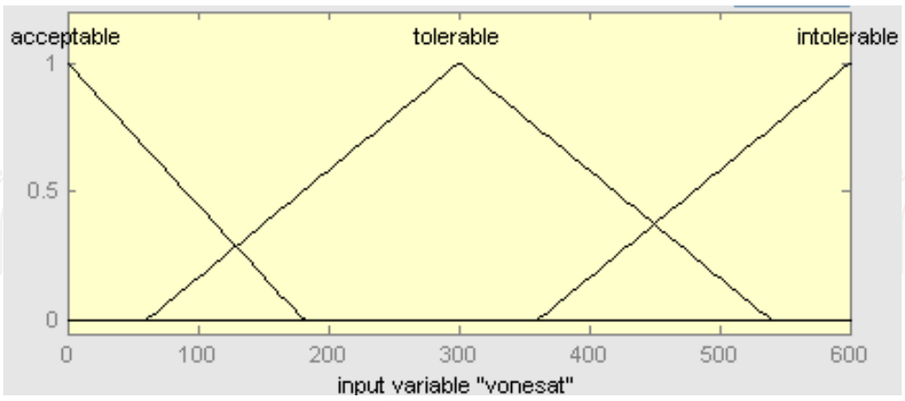
[Input2]
Name='delays'
Range=[0 600]
NumMFs=3
MF1='acceptable':'trimf',[-240 0 240]
MF2='tolerable':'trimf',[60 300 540]
MF3='highintolerable':'trimf',[360 600 840]

[Input3]
Name='losses'
Range=[0 10]
NumMFs=3
MF1='acceptable':'trimf',[-4 0 4]
MF2='tolerable':'trimf',[1 5 9]
MF3='intolerable':'trimf',[6 10 14]
[Output1]
Name='link optimization'
Range=[0 100]
NumMFs=3
MF1='low':'trimf',[-40 0 40]
MF2='medium':'trimf',[10 50 90]
MF3='high':'trimf',[60 100 140]

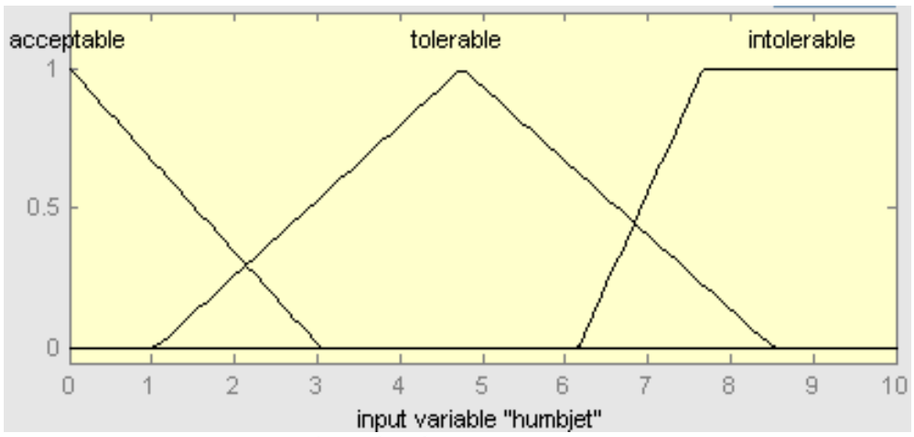
[Rules]
1 1 1, 1 (1) : 1
2 1 1, 2 (1) : 1
3 1 1, 3 (1) : 1
3 2 3, 1 (1) : 1



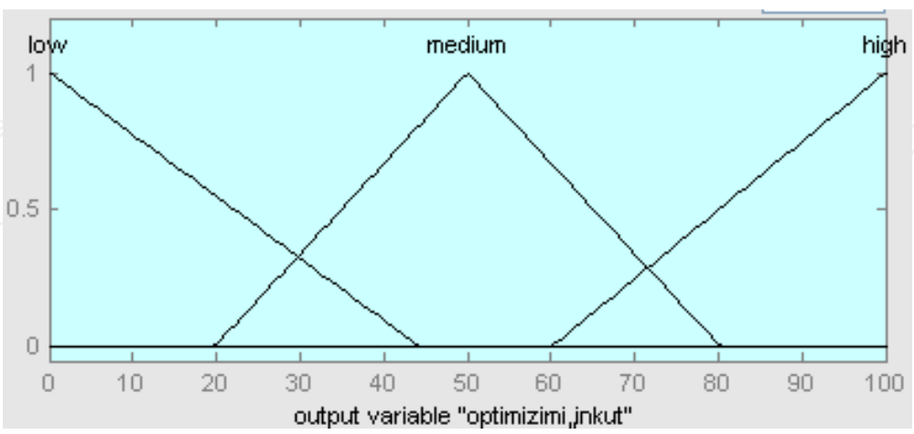
a) Channel capacity (bandwidth) in **Mbps**



b) Delays in **ms**



c) Packet loss percentage



d) Output of fuzzy system

Fig. 6. a) Membership function of channel capacity, b) delays, c) packet loss percentage and d) output of fuzzy system

With this simple program are created the membership functions for abovementioned parameters. These membership functions are seen in the figure 6 (a, b, c and d)

Once the variable and membership functions are assigned, fuzzy rules can be written for corresponding variables.

Some of the fuzzy rules derived from Rule editor (Matlab) are listed as below:

Rule 1: *If (bandwidth is low) and (delay is acceptable) and (loss is acceptable) then (link optimization is Low)*

Rule 2: *If (bandwidth is Medium) and (delay is acceptable) and (loss is acceptable) then (link optimization is Medium)*

Rule 3: *If (bandwidth is High) and (delay is Acceptable) and (loss is Acceptable) then (link optimization is High)*

Rule 4: *If (bandwidth is Low) and (delay is Tolerable) and (loss is Acceptable) then (link optimization is Low)*

Rule 5*: If (bandwidth is Medium) and (delay is Tolerable) and (loss is Tolerable) then (link optimization is Medium)*

Rule 6*: If (bandwidth is High) and (delay is Tolerable) and (loss is Intolerable) then (link optimization is Medium)*

Rule 7*: If (bandwidth is Low) and (delay is Intolerable) and (loss is Acceptable) then (link optimization is Low)*

Rule 8*: If (bandwidth is Medium) and (delay is Intolerable) and (loss is Tolerable) then (link optimization is Low)*

Rule 9*: If (bandwidth is High) and (delay is Intolerable) and (loss is Intolerable) then (link optimization is Low)*

10. Fuzzy relations for QoS routing analysis

Here we will illustrate the relation between input fuzzy value and required output. The figure below shows the structure of the proposed solution. So, in the figure is shown fuzzy controller comprising of: inputs (which react in the input), fuzzy rules and outputs. Parameters acting on the input of this controller are: channel capacity (bandwidth), delays and losses.

Three input parameters are noted as:

$$\mu A(B) \tag{5}$$

Where $A = \{Low, Medium, High\}$

$$\mu B(D) \tag{6}$$

Where $B = \{Acceptable, Tolerable, Intolerable\}$

$$\mu C(L) \tag{7}$$

Where $C = \{Acceptable, Tolerable, Intolerable\}$

While, $\mu A(B)$, $\mu B(D)$ and $\mu C(L)$ are membership functions for channel capacity, delays and losses.

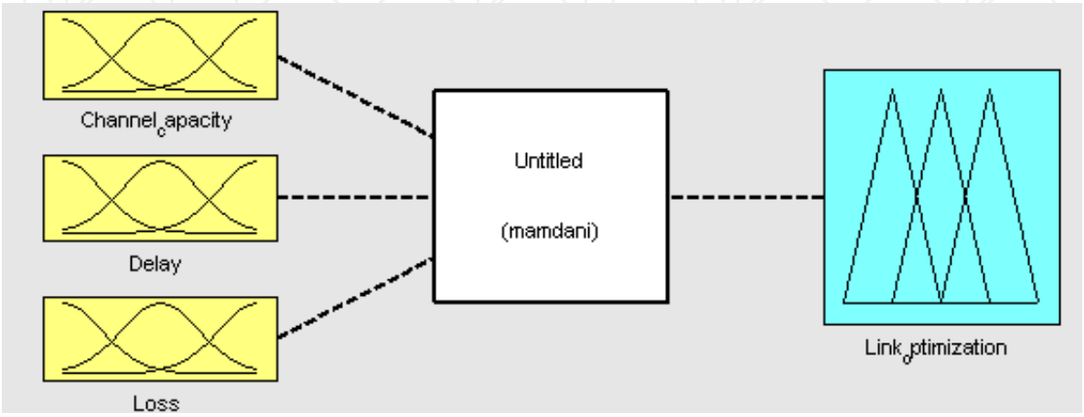


Fig. 7. The structure of the fuzzy controller system for MPLS network analysis

The role of Linguistic rules is to connect these input parameters with output of fuzzy system, which in our case is link optimization. The output comprises from three membership functions: LOW, MEDIUM and HIGH. Each rule determines one fuzzy relation. In our case, each rule represents the relation between 3 input parameters and required output that is written as:

$\mu_O(L)$ - Membership function for output of the fuzzy system.

Where $O = \{Low, Medium, High\}$

Fuzzy controller considered here is Mamdani type and consists of: Fuzzifier, fuzzy inference, linguistic rules and defuzzifier. This fuzzy controller is shown in figure x.

11. Defuzzification process

It is well known that in some cases the output of fuzzy process needs to be a single scalar value. Defuzzification is the process of converting the fuzzy quantity to a precise value. The output of a fuzzy process can be the union of two or more fuzzy membership functions. To see this better, we will take into consideration one example. Let suppose a fuzzy output comprises from two parts: 1) Triangular membership shape and 2) Triangular membership shape. The union of these two membership functions means that we will use the max operator, which graphically will look like in figure below.

There are a lot of methods that have been proposed recently as defuzzification methods. We will explain shortly each of these methods and we will analyze which one is the best for gaining more accurate values in the output.

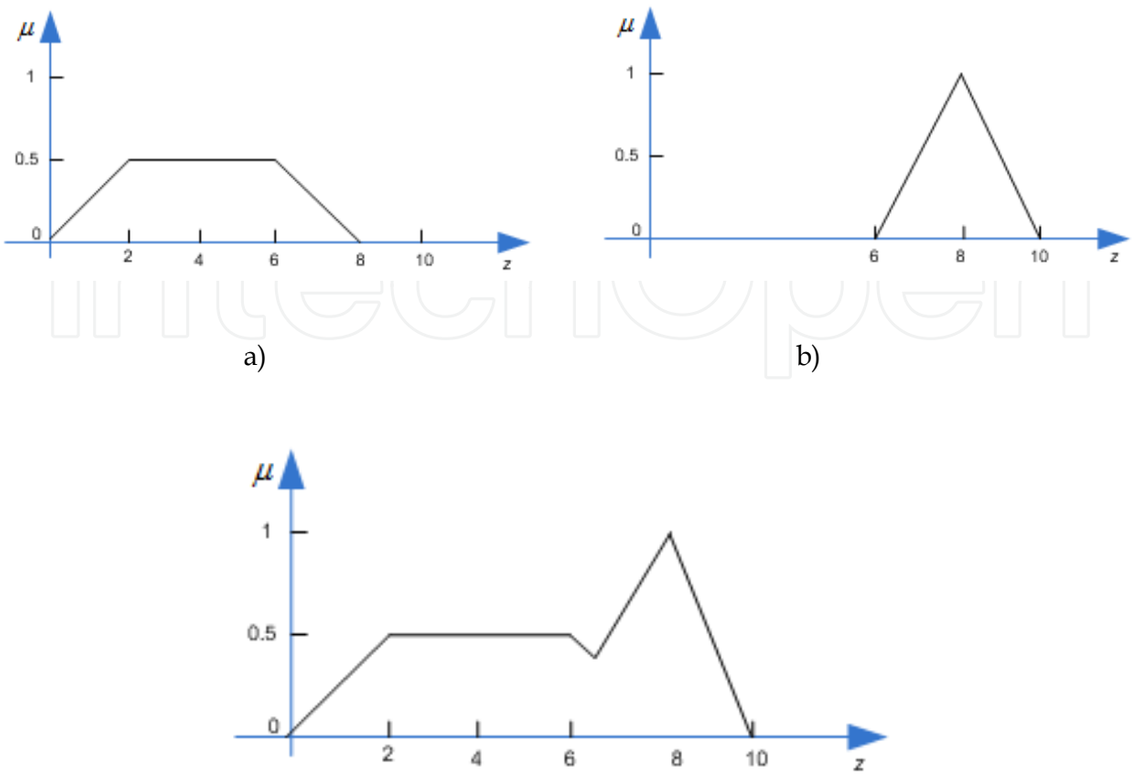


Fig. 8. a) Triangular membership shape, b) Triangular membership shape c) The union of these two membership (a and b)

12. Selection of defuzzification method for finding crisp value for link optimization

For finding the appropriate path for transmission of multimedia services one important role plays selection of defuzzification method. Using fuzzy logic technique, the "not accurate" data are presented by linguistic values which depend on user preferences.

There are 5 defuzzification methods: Centre of Gravity (COG), bisectorial, LOM (largest of maximum), MOM (middle of maximum) and SOM (smallest of maximum). Three most important methods are: COG, MOM and LOM. It is important to find which method gives better results in aspect of link optimization in MPLS network. To see which method is most suitable for defuzzification, first we will explain shortly each abovementioned method .

12.1 Centre of gravity

This method determines the centre of zone that is gained from membership functions with AND and OR logic operators. Formula with which we can calculate the defuzzified crisp output *U* is given:

$$U = \frac{\int_{Min}^{Max} u\ \mu(u)du}{\int_{Min}^{Max} \mu(u)du} \tag{8}$$

Where U is defuzzification result, u = *output variable*, μ = *membership function* , *Min=minimum limit for defuzzification*, *Max=maximum limit for defuzzification*

With formula (1) we can calculate the surface of zone that is shown in figure below and also we can find one central point in this zone. Projecting this point in the abscissa axis determines the crisp value after defuzzification.

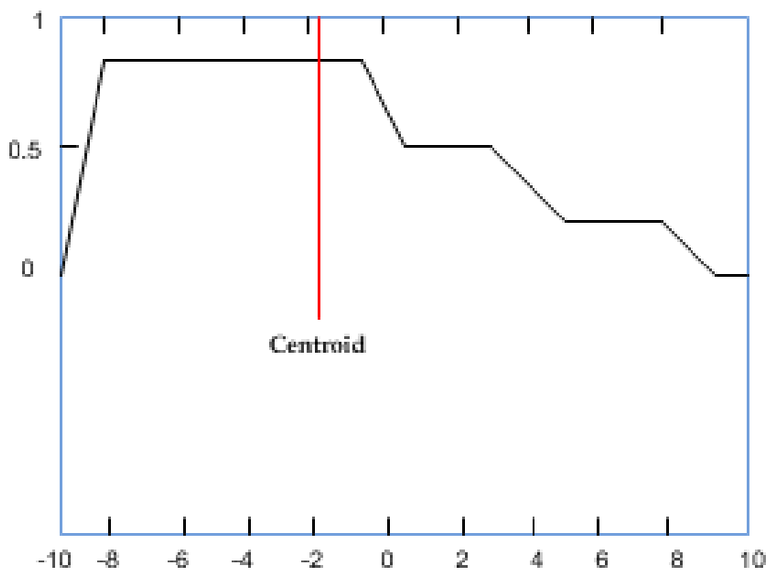


Fig. 9. COG method

12.2 Bisectorial method

This method divides a certain zone into two equal regions by a vertical line. This can be seen in figure below (Figure 10).

12.3 Middle, smallest and largest of maximum methods

In some cases MOM and LOM methods are better than COG method, but in general, for the most of cases, no matter what zone we will have, COG method shows better results. In this chapter we will analyze which method is better with MATLAB software in 3 D. LOM method determines the largest of maximum value in the zone that is obtained from membership functions with AND and OR logic operators whereas MOM method determines Middle of maximum value in that zone.

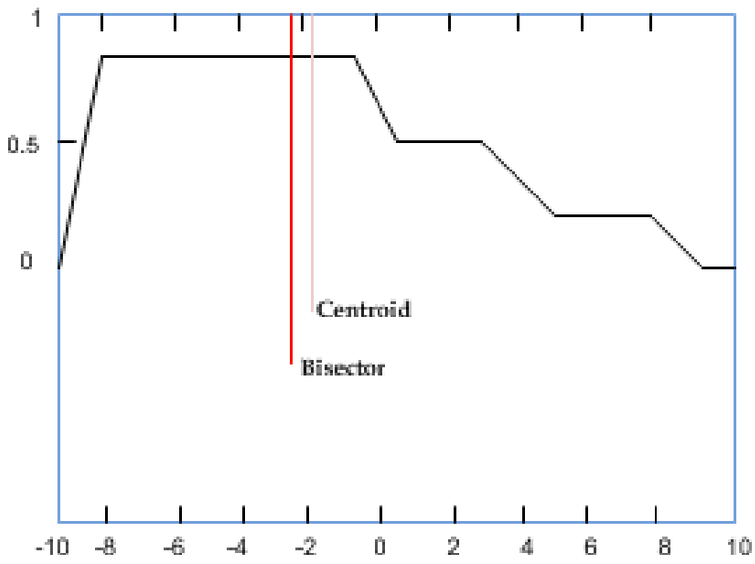


Fig. 10. Bisectorial Method

These three methods have to do with the maximum value of the sum of membership functions. In this example, since in this graph (figure x) is a flat curve at the maximum point, then these three methods have different values from each other. In case when we have a single maximum point, then three methods have the same value.

Finding defuzzification values using the above-mentioned methods can e done like below:

```
x3 = defuzz(x,mf1,'mom')
x4 = defuzz(x,mf1,'som')
x5 = defuzz(x,mf1,'lom')
set([h2 t2],'Color',gray)
h3 = line([x3 x3],[-0.7 1.2],'Color','k');
t3 = text(x3,-0.7,' MOM','FontWeight','bold');
h4 = line([x4 x4],[-0.8 1.2],'Color','k');
t4 = text(x4,-0.8,' SOM','FontWeight','bold');
h5 = line([x5 x5],[-0.6 1.2],'Color','k');
t5 = text(x5,-0.6,' LOM','FontWeight','bold');
x3 =    -5
x4 =    -2
x5 =    -8
```

These values are represented graphically like in figure 11.

Methods that are used mostly for defuzzification are: COGM MOM and LOM. Although, in some cases MOM and LOM methods give very favorable values, COG method gives better results whatever the case that we are analyzing. The performance comparison offered by three methods can be better seen through examples by surface viewer in 3D.

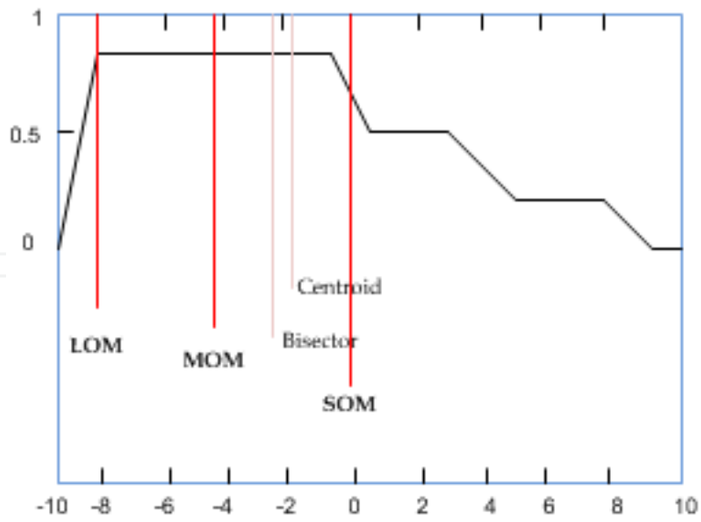


Fig. 11. LOM, MOM and SOM defuzzification methods

13. Analysis and examples for different defuzzification methods

Here we will use some examples taking different rules derived from rule editor of Matlba's toolbox. Also we will analyze which of the defuzzification method is better and which of the rules gives us better result in aspect of link utilization.

If we use rule number 3 (derived from rule editor):

If (bandwidth is High) AND (delay is Acceptable) AND (loss is Acceptable) THEN (link optimization is High)

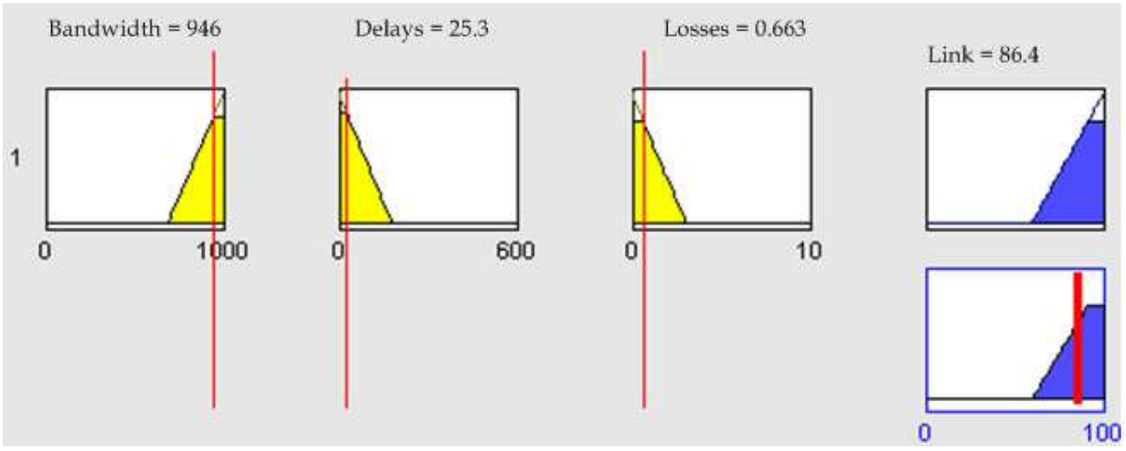


Fig. 12. Rule viewer when it is used COG method

Whereas, if we take the values for channel capacity (bandwidth) as "high" (946 Mbps), Delays 25.3 ms and losses 0.663 %, then link optimization for MPLS network will be 86.4 %. This can be shown graphically using rule viewer. So, from this figure, it is clearly seen that link optimization is high (according to determination of link optimization using

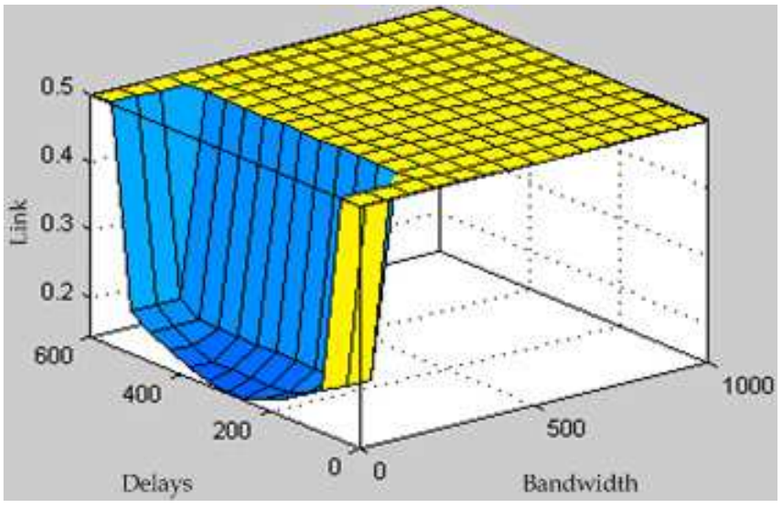
membership functions). This value is obtained using COG method. Based on the results obtained here, we will conclude that this method is very effective.

The 86.4 % value represents the value after defuzzification. While, the surface viewer in 3D for three main defuzzification methods will look like in figure below.

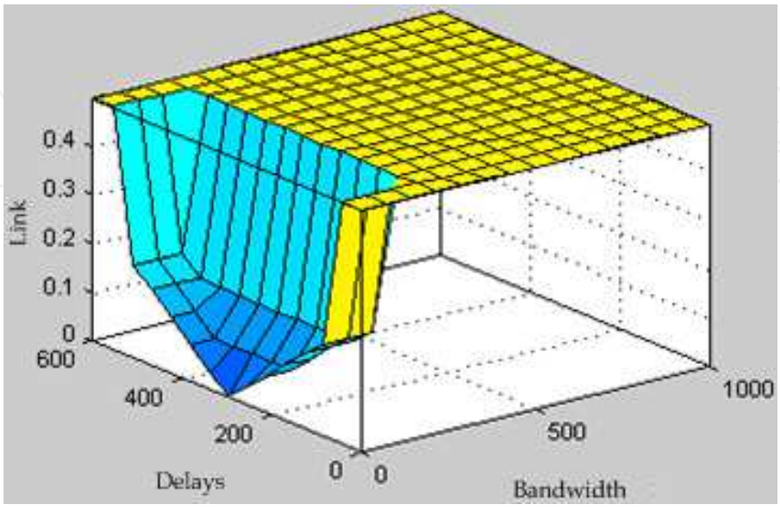
If we use rule number 9 (derived from rule editor):

If (bandwidth is High) AND (delay is Intolerable) AND (loss is Intolerable) THEN (link optimization is Low)

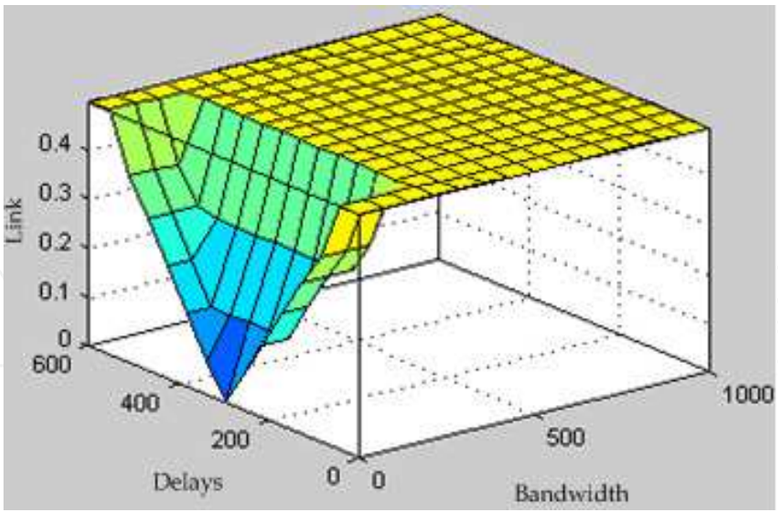
Then, link optimization will be 20 % (see Figure 14). As we can see, in this case, link optimization is very low. So we can freely conclude that in a case when we have intolerable delays and intolerable losses, we will not have high QoS. The reason is because multimedia applications are very sensitive in delays and losses.



a) COG Method



b) MOM Method



c) LOM Method

Fig. 13. Surface viewer for 3 defuzzification methods: a) COG, b) MOM and c) LOM

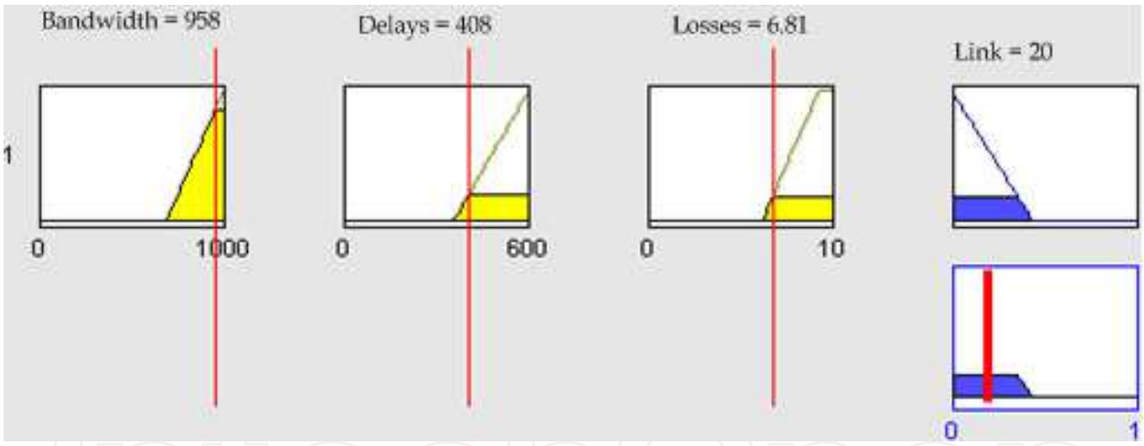


Fig. 14. Rule viewer when it is used COG method for rule 9

While, 3 D surface viewer using three main defuzzification methods is the same and is depicted in the figure below. From this graph, it is clearly seen that we have high bandwidth, but delays and percentage of packet losses are also high, resulting thus in low link optimization.

In this case we have a very low link usage, and this is the reason why surface viewer is approximately same for three defuzzification methods (low link optimization).

If we use rule number 5 (derived from rule editor):

If (bandwidth is Medium) and (delay is Tolerable) and (loss is Tolerable) then (link optimization is Medium)

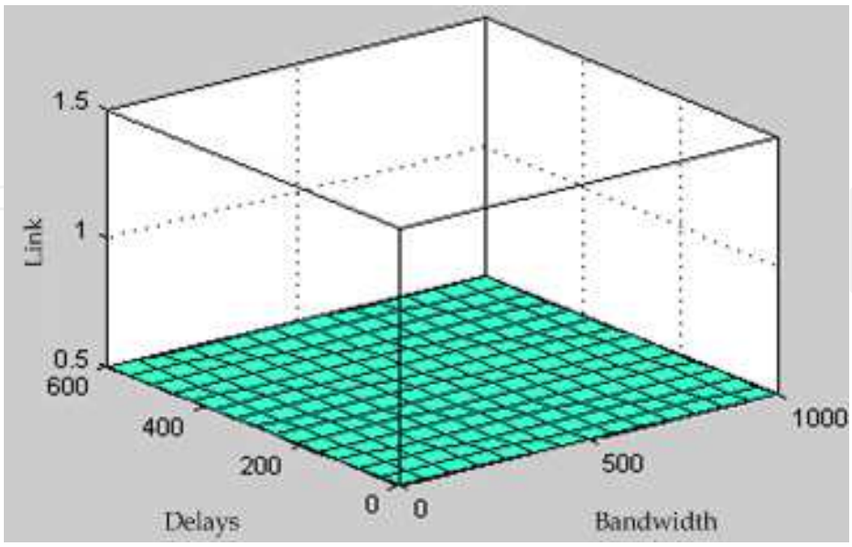


Fig. 15. Surface viewer for rule 9, for defuzzification methods: COG, MOM and LOM

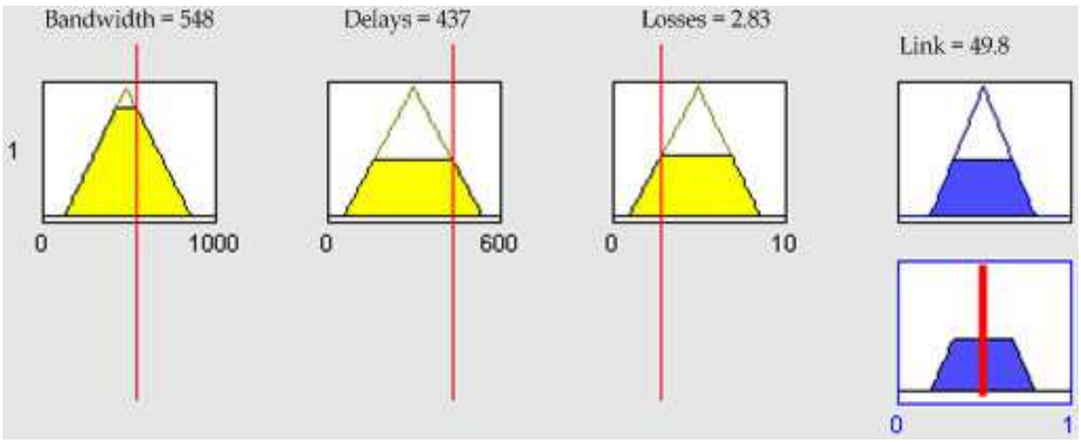
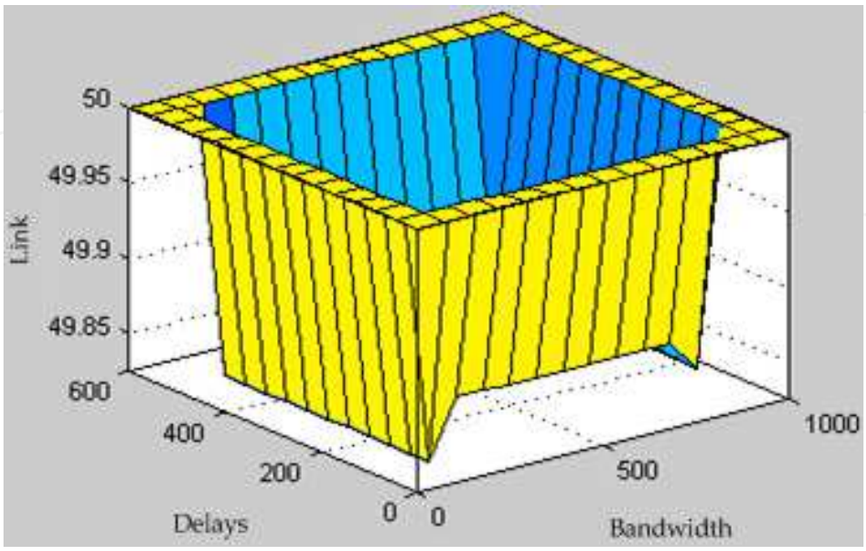


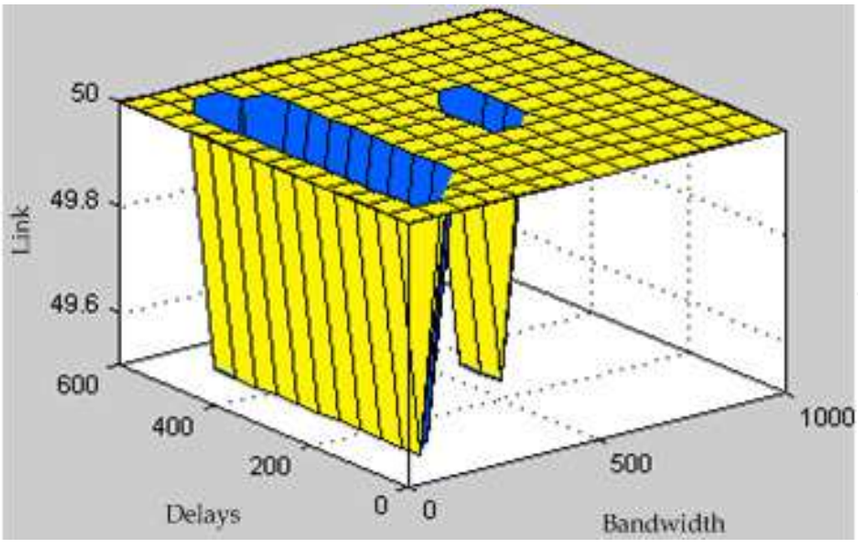
Fig. 16. Rule viewer when we use COG method for rule 5

In this case, the value for bandwidth is 548 Mbps, delays = 437 ms (tolerable) and losses are tolerable (2.83%). From the analysis we have shown that the link optimization is medium. This means that using the parameters above, we can transmit almost every multimedia service.

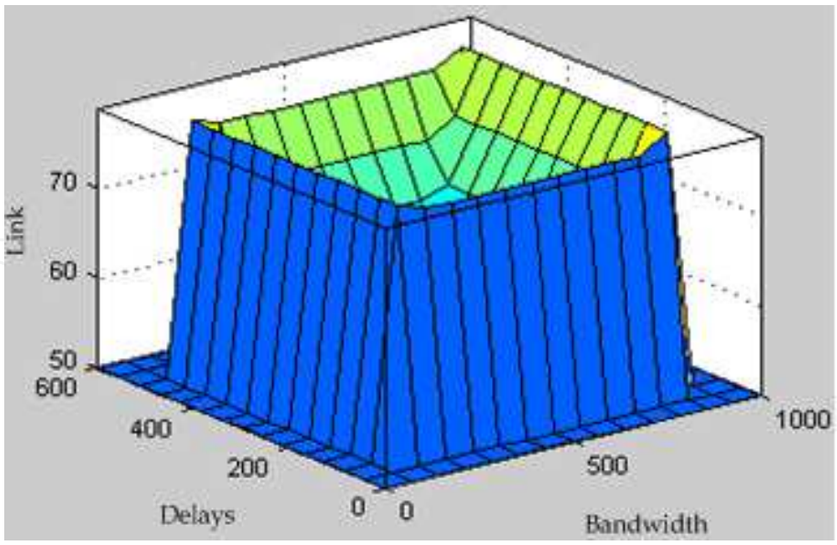
While, 3 D surface viewer for 3 main defuzzification methods will look like below:



a) COG method



b) MOM method



c) LOM method

Fig. 17. Surface viewer for rule 5 when it is used: a) COG, b) MOM and c) LOM

From the above examples can be clearly seen that COG defuzzification method gives better result in aspect of link utilization. This can be seen with surface viewer and rule viewer as presented in the above examples using different rules.

14. Conclusion

In the past, routing problem in communication networks was relatively simple. The applications have used a modest percentage of bandwidth and no one of those applications had QoS requirements. However, the existing routing protocols should be improved or replaced with algorithms that meet different QoS requirements. Thus, it is necessary to present an architecture that supports new services in Internet and guarantees QoS for multimedia applications.

In this chapter we introduced the MPLS technology as a multiple solution for a lot of current problems faced by Internet today. By a wide support for QoS and traffic engineering capability, MPLS is establishing itself as a standard of the next generation's network. In MPLS network, some problems can occur during multimedia service transmission, therefore it is a good idea to design some control mechanisms for solving such problems. As a result of the complex nature of control mechanisms, in this chapter we used intelligent controlled techniques. One of the intelligent controlled techniques that we analyzed here is Fuzzy Logic Controller, a technique that is based on fuzzy logic. We have shown that fuzzy logic approach is suitable for QoS routing analysis in MPLS network. In this chapter we used main metrics of MPLS network acting in the input of FLC and we found the most appropriate defuzzification method for finding better crisp values in the aspect of link utilization in MPLS network. Also, we have shown that the most important part of FLC is defuzzifier, which converts fuzzy values into crisp values. In this chapter we explained the

methods that are used mostly for defuzzification, that are: COGM MOM and LOM. The performance comparison offered by three methods we have described through examples by surface viewer in 3D. Through these analyses using Matlab's toolbox we have shown that COG method gives better results in all analyzed cases.

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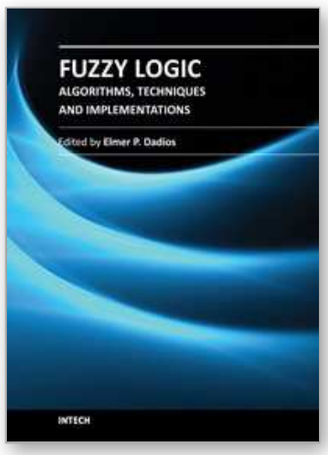
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