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LAN Performance Ratings Using Fuzzy Set Theory

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----------ABSTRACT----------
A single dimension cannot quantify or properly express the performance of a LAN. It is very difficult to interpret LAN metrics without knowing what application (users) are involved. LAN performance measurement metrics are resource usages, processing delays, throughput, availability, fairness of measured data, and communigram. LAN policies need to be frequently updated based on feedbacks from implementation of previous policies. These feedbacks are always stated in the form of ordinal ratings, e.g. "high speed", "average performance", "good condition". The Different people can describe different values to these ordinal ratings without a clear-cut reason or scientific basis. There is need for a way or means to transform vague ordinal ratings to more appreciable and precise numerical estimates. The paper transforms the ordinal performance ratings of some LAN performance strategies to numerical ratings using Fuzzy Set Theory.

Keywords: Fuzzy Set Theory, LAN Performance, Performance Strategies, Transformation.

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1. Introduction

The performances of the LAN metrics are always measured in ordinal ratings such as, very good, average, poor, low or high [1]. 1) The resource usage: the processor, memory, transmission medium and peripheral devices all contribute to the processing of a user measures how much of their respective capacities are used and how much reserved capacity remains. 2) Processing delays: network delays can be viewed as a combination of delays due to hardware and software processing and this total processing delay is the only meaningful performance metric. 3) Throughput: the number of bytes transmitted per unit of time is a function of message volume and message size. 4) Availability: Most LAN measurement tools are only able to measure availability because delay measurement may add several orders of magnitude to the measurement tool complexity. 5) Fairness of measured data: an hourly average measured data rate may not reveal any performance bottlenecks, which a one second recording rate might reveal. 6) Communigram: the traffic volume used to quantify the traffic between communication partners is greatly affected by the measured and reported intervals. These all measurement metric ratings are ordinal and are subject to ambiguity. This means that these ratings have some elements of uncertainty, ambiguity or fuzziness.

When humans are the basis for an analysis, there must be a way to assign some rational value to intuitive assessments of individual elements of a fuzzy set. There is need to translate from human fuzziness to numbers that can be used by a computer.

Lofti A Zadeh introduced Fuzzy Set Theory (FST) in the early 1960's as a means of modeling the uncertainty, vagueness, and imprecision of human natural language. It was built on the basis that as the complexity of a system increases, it becomes more difficult and eventually impossible to make a precise statement about its behavior, eventually arriving at a point of complexity where the fuzzy logic method born in humans is the only way to get at the problem.

[2] described *Fuzzy Set Theory (FT)* as the extension of classical set theory. The basic idea is that the membership of a value to a set cannot only assume the two values "yes" or "no", but can be expressed by gradual membership function within a range from zero to normally "1" in case of full membership degree. Membership function can assume several forms, and in practice triangular or trapezium forms are often used (Figure 1).

2. Problem Defined

The resource usage, processing delays, throughput, availability, fairness of measured data, and communigram, are imprecise or fuzzy. The LAN performance strategies are: (1) Resource usage, (2) Processing delays, (3) Throughput, (4) Availability, (5) Fairness of measured data, and (6) Communigram.

The ratings are in rough (imprecise, inexact or fuzzy) ranges, reflecting the variability in how each strategy could be implemented and the uncertainties involved in projecting the impacts of the strategies. For a meaningful numerical research, as stated in the introduction, these ordinal ratings need to be transformed to numerical ratings and this forms the thrust of the paper. That is, to transform opinion held by human beings,

which would be "fuzzy" (e.g. low, mid-high performance) to being very precise (e.g. 15%, 80% performance), that is not "fuzzy" using fuzzy set theory [3], [4].

3. Theoretical Foundations

A fuzzy system is a system whose variable(s) range over states that are approximate. The fuzzy set is usually an interval of real number and the associated variables are linguistic variable such as “most likely”, “about”, etc. [4]. Appropriate quantization, whose coarseness reflects the limited measurement resolution, is inevitable whenever a variable represents a real-world attribute. Fuzzy logic consists of Fuzzy Operators such as “IF/THEN rules”, “AND, OR, and NOT” called the *Zadeh operators* [5].

The Membership Function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system. There are different memberships functions associated with each input and output response. Some features of different membership functions are: SHAPE - triangular is common, but bell, trapezoidal, haversine and, exponential have been used also; HEIGHT or magnitude (usually normalized to 1); WIDTH (of the base of function); SHOULDERING; CENTER points (centre of the member and OVERLAP (Figure 1) [6].

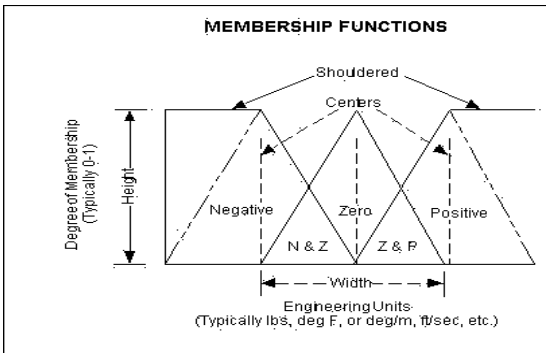

Fig. 1 Triangular membership function

The degree of fuzziness of a system analysis rule can vary between being very precise, that is not "fuzzy", to being based on an opinion held by a human, which would be "fuzzy." Being fuzzy or not fuzzy, therefore, has to do with the degree of precision of a system analysis rule.

The Degree of Membership (DOM) is the placement in the transition from 0 to 1 of conditions within a fuzzy set. The degree of membership is determined by plugging the selected input parameter into the horizontal axis and projecting vertically to the upper boundary of the Membership function(s) [7]. Fuzzy Variable includes words like red, blue, good and sweet are fuzzy and can have many shades and tints. A Fuzzy Algorithm is a procedure, usually a computer program, made up of statements relating linguistic variables. A Fuzzy Logic Control System- measures an input against a given situation and the system takes action automatically.

4. Methodology

The relative effectiveness of these LAN performance strategies is summarizes as shown in Table 1 in terms of four basic transportation policy objectives or criteria: (1) Effectiveness, (2) Economic Efficiency, (3) Economic Equity and (4) Immediate Access flexibility. In the table, LAN performs between ***medium to high*** on practical congestion reduction effectiveness, ***high*** in terms of economic efficiency, ***medium to high*** on economic equity for the poor and ***medium to high*** on immediate access flexibility.

5. Notations

Effec.	Effectiveness
Eco.Eff.	Economic Efficiency
Eco Equity	Economic Equity
Imm.	Immediate
Flex.	Flexibility
m	medium
h	high
l	low
min	Minimun
Max	Maximum
Avg	Average
Perf	Performance

Table 1: LAN performance strategies ratings

Multi-objective Evaluation of LAN Strategies				
	Ratings on Objectives (high = best)			
LAN performance strategies	Effec (P)	Eco. Eff. (N)	Eco. Equity (Q)	Imm. Access flex. (X)
Resource Usage (a)	m-h	h	m-h	m-h
Processing delays (b)	m-h	m-h	m-h	m-h
Throughput (c)	l-m	l-m	m	h
Availability (d)	l-m	l	m	h
Fairness of Measured data (e)	l-m	l	m	m
Communigram (f)	l-m	l	m	l-m

6.Fuzzy Variables

In the paper, the adjectives describing the fuzzy variables and the range of performance are shown in Table 2. The Range of Performance for the individual fuzzy variables is substituted in Table 1 to obtain Table 3.

Table 2**:** Fuzzy Variables and their ranges.

Fuzzy Variables	**Range of Performance %**
High	75 – 100
Med-High	55 - 80
Med (Medium)	35 - 60
Low-Med	15 - 40
Low	0 - 20

Table 3**:** Fuzzy Range of Performance for the individual fuzzy variables.

Multi-objective Evaluation of LAN Strategies				
	Ratings on Policy Objectives (high = best)			
LAN performance strategies	**Effec. (P)**	**Eco.Eff. (N)**	**Eco.** Equity **(Q)**	**Imm. Access** Flex. **(X)**
Resource Usage (a)	55 - 80	75 – 100	55 - 80	55 - 80
Processing delays (b)	55 - 80	55 - 80	55 - 80	55 - 80
Throughput (c)	15 - 40	15 - 40	35 - 60	75 – 100
Availability (d)	15 - 40	0 - 20	35 - 60	75 – 100
Fairness of measured data (e)	15 - 40	0 - 20	35 - 60	35 - 60
Communigram (f)	15 - 40	0 - 20	35 - 60	15 - 40

7.Fuzzy Mapping

The fuzzy variables in Table 1, were transformed to numerical ratings using *Fuzzy Set Theory* as shown in Figures 2–6.

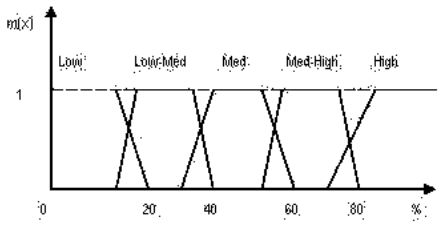

Fig. 2: Trapezoidal membership function

8.Aggregation of Fuzzy Scores

Using Figure 3, for each LAN strategy (LS) *i* and each criterion (CRIT) *j*,

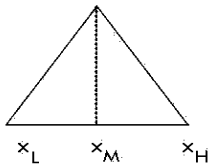

Fig. 3: Aggregation of Fuzzy Scores.

$i = 1, 2, 3, ..., 7.$ and $j = 1, 2, 3, 4.$

For CRIT (j) when LS(i, j) = x_L THEN LSPER (i, j) = L

For CRIT (j) when LS(i, j) = x_M THEN LSPER (i, j) = M

For CRIT (j) when LS(i, j) = x_H THEN LSPER (i, j) = H

Where, CRIT (j) ≡ Criterion j (j = 1, 2, 3, 4)

LS (i, j) ≡ LAN performance Strategy i under Criterion j
LSPER(i, j) ≡ LAN Performance Strategy i under Criterion j Performance:

$$\text{LSSCORE(i)} = \sum_{j} \frac{\text{LS(i, j)}}{4} \qquad (1)$$

9. Membership Functions of the Fuzzy Sets

Using Aggregation methods for the fuzzy sets to reduce it to a triangular shape for the membership function, overlapping adjacent fuzzy sets were considered with the membership values shown in Figure 4.

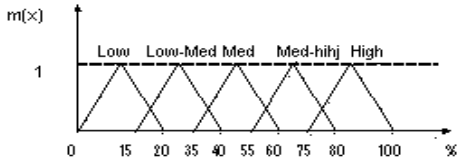

Fig. 4**:** Derived Triangular membership function

For the strategies and their performances, the membership functions shown in Figure 5 of the fuzzy sets were assigned.

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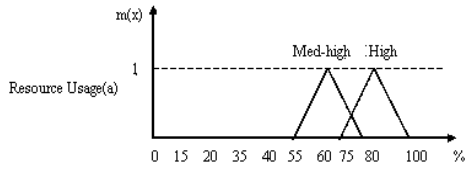
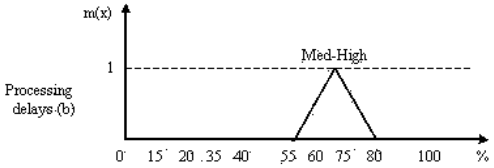
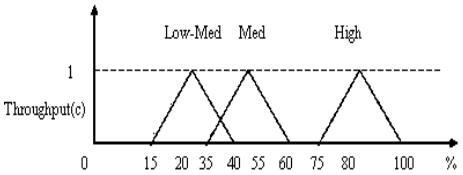


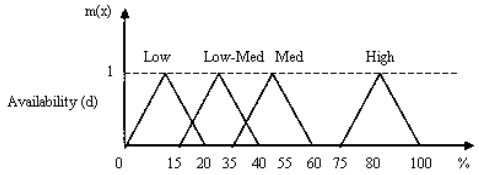
Criteria: (P, Q, X = med-high; N = high)



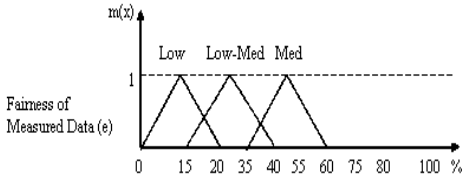
Criteria: (P, N, Q, X = med-high)



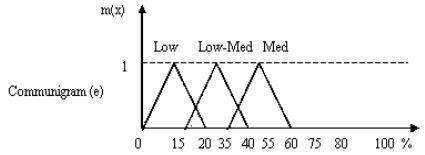
Criteria: (P, N = low-med; Q = med; X = high)



Criteria: (P = low-med; N = low; Q = med; X = high)



Criteria: (P = low-med; N = low; Q, X = med)



Criteria: (P, X = low-med; N= low; Q = med).

Fig. 5: Derived triangular membership functions for the

The ranges in figure 4 and figure 5 were aggregated to singletons. For the average performance of all the strategies, we have the fuzzy scaled rating as shown in figure 6.

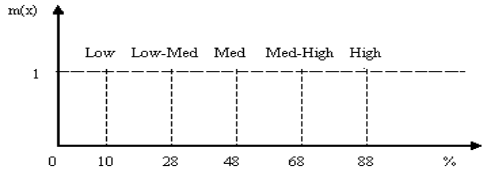


Fig. 6: Singleton aggregation of the ratings in table 1.

From Figs. 2–6, the Membership Values assigned to each set of Universe of Discourse can be tabulated as shown in Table 4.

Table 4**:** Fuzzy performance ratings of Membership Values assigned to each set of Universe of Discourse.

LAN Performance Strategies	**Criteria**							
	Effectiveness		**Economic Efficiency**		**Economic Equity**		**Immediate Access flexibility**	
Resource usage (a)	**med-high**		**high**		**med-high**		**med-high**	
	X	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
	55	0	75	0	55	0	55	0
	68	1	88	1	68	1	68	1
	80	0	100	0	80	0	80	0
Processing delays (b)	**med-high**		**med-high**		**med-high**		**Med-high**	
	X	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
	55	0	55	0	55	0	55	0
	68	1	68	1	68	1	68	1
	80	0	80	0	80	0	80	0
Throughpt	**low-med**		**low-med**		**med**		**high**	
	X	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
	15	0	15	0	35	0	75	0
	28	1	28	1	48	1	88	1
	40	0	40	0	60	0	100	0

	low-med		low		med		High	
	X	Y	X	Y	X	Y	X	Y
Availability (d)	15	0	0	0	35	0	75	0
	28	1	10	1	48	1	88	1
	40	0	20	0	60	0	100	0
	low-med		**low**		**med**		**Med**	
Fairness of measured data (e)	**X**	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
	15	0	0	0	35	0	35	0
	28	1	10	1	48	1	48	1
	40	0	20	0	60	0	60	0
	low-med		**low**		**med**		**Low-med**	
Communigram (f)	**X**	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
	15	0	0	0	35	0	15	0
	28	1	10	1	48	1	28	1
	40	0	20	0	60	0	40	0

10.Results

From the above figure 3, it is shown that x_L, x_M and x_H are referred to as the Minimum performance, Average performance and Maximum Performance. Using equation (1), we can calculate the Average Scores of different LAN performance strategies for all the four criteria in respect of x_L referring to as the Minimum Performance (as shown in Table 5), in respect of x_M referring to as the Average Performance (as shown in Table 6), and in respect of x_H referring to as the Maximum performance (as shown in Table 7).

Table 5:Numerical transformation of LAN Strategies for Minimum Performance using fuzzy set theory.

Multi-objective Evaluation of LAN Strategies					
	Ratings on Policy Objectives (high = best)				
LAN performance strategies	**Effec (P)**	**EcoEff. (N)**	**Eco.** Equity **(Q)**	**Imm. ccess** Flex. **(X)**	**Avg. Score**
Resource Usage (a)	55	75	55	55	60
Processing delays (b)	55	55	55	55	55
Throughput (c)	15	15	35	75	35
Availability (d)	15	0	35	75	31
Fairness of measured data (e)	15	0	35	35	21
Communigram (f)	15	0	35	15	16

Table 6: Numerical transformation of LAN Strategies for Medium Performance using fuzzy set theory.

Multi-objective Evaluation of LAN Strategies					
	Ratings on Policy Objectives (high = best)				
LAN performance strategies	**Effec (P)**	**Eco Eff. (N)**	**Eco.** Equity **(Q)**	**Imm. Access** Flex. **(X)**	**Avg. Score**
Resource Usage (a)	68	88	68	68	73
Processing delays (b)	68	68	68	68	68
Throughput (c)	28	28	48	88	48
Availability (d)	28	10	48	88	44
Fairness of measured data (e)	28	10	48	48	34
Communigram (f)	28	10	48	28	29

Table 7: Numerical transformation of LAN Strategies for Maximum Performance using fuzzy set theory.

Multi-objective Evaluation of LAN Strategies					
	Ratings on Policy Objectives (high = best)				
LAN performance strategies	**Effec (P)**	**Eco Eff. (N)**	**Eco.** Equity **(Q)**	**Imm. Access** Flex. **(X)**	**Avg. Score**
Resource Usage (a)	80	100	80	80	85
Processing delays (b)	80	80	80	80	80
Throughput (c)	40	40	60	100	60

Availability (d)	40	20	60	100	55
Fairness of measured data (e)	40	20	60	60	45
Communigram (f)	40	20	60	40	40

Table 8: Comparison between the ordinal fuzzy ratings and the transformed ratings on various criteria of LAN performance.

Ordinal perf (Fuzzy Ratings)	LAN Strategies	Min Perf	Avg Perf	Max Perf
m-h	Resource usage	55	68	80
m-h	Processing delays	55	68	80
m-h	Throughput	15	28	40

Similarly, for other fuzzy ratings of different LAN criteria their comparisons can be found out.
Hence, their performances ratings can be shown such as $x_L < x_M < x_H$.

11. Conclusion

Fuzzy logic was used to transform ordinal LAN performance ratings that are imprecise and fuzzy in nature to precise and defuzzified numerical ratings used in the analysis of performance ratings of different Local area network performance strategies. The Technique used is the only way for solving any highly complex problem.

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