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Measuring inter-class fairness in wireless networks using a fuzzy approach

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Abstract: Fairness of allocation in wireless networks is an important network performance parameter that defines the quality of service. With the advent of 4G mobile communication technology and the continuous increase in the number of network users each with different requirements, measuring fairness as a utility function proves to be an efficient technique. The utility function proposed in this paper measures fairness as a relative degree of satisfaction with respect to the quality of service requirements of different users of the network. Fuzzy logic is used to model the behaviour of the proposed utility function. The authors also propose a novel biphasic growth curve that defines fairness at both user level and system level. The behaviour of fairness is simulated for users belonging to traffic classes supported by the fourth generation Long Term Evolution network.

Keywords: Communication system traffic, 4G mobile communication, quality of service, wireless networks, fuzzy systems

1. Introduction

The Long Term Evolution (LTE) network released under the Third Generation Partnership Project (3GPP) is considered to be an evolution of the traditional Universal Mobile Telecommunication System (UMTS) era. The resource scheduler plays an important role when it comes to providing fairness of allocation and Quality of Service (QoS) satisfaction to a wide variety of users. The function of a resource scheduler is to provide fair share of the wireless network resource to each user in order to satisfy their QoS requirements to the largest possible extent. Various resource allocation algorithms (RAAs) have been defined in literature for LTE networks and can be found in [5]. For measuring fairness of resource allocation made to its users, these RAAs make use of 'fairness measures'. The most widely used fairness measures are the Jain's fairness index [6], entropy [7], max-min fairness [8] and proportional fairness [9]. Jain's index and entropy classified as quantitative methods are capable of providing a numerical value to fairness but they cannot measure relative QoS satisfaction. The qualitative methods i.e. proportional fairness and max-min fairness, cannot quantify fairness, can only ensure fairness if the specified conditions are satisfied.

Another class of measures known as utility functions [10] captures fairness as a relative degree of satisfaction of all the users. The most widely used approach for measuring inter-class fairness is the utility function. To measure inter-class fairness, the proposed model considers the traffic classes of the LTE network. As the number of mobile network users is increasing rapidly with each user imposing different QoS constraints on the network, a great amount of research is dedicated to design fairness measurement techniques that consider inter-class fairness. This paper exploits the utility function approach to design the proposed model for measuring fairness. There are two characteristics associated with wireless networks i.e. dynamic nature of radio channel and uncertainty of channel quality which make it difficult to interpret the obtained utility value in terms of fairness. To deal with this, the proposed model is based on fuzzy logic which can very well capture the dynamism and uncertainty of the radio channel conditions. There is quite an insufficient amount of literature available on use of fuzzy logic for measuring fairness in wireless networks. .. The proposed model is simulated on MATLAB. The simulation results reveal a novel characteristic curve termed as '*biphasic growth curve*' that defines fairness at both user level and system level. This novel curve is aimed at improving the efficiency of network performance measurement techniques.

The remaining paper is organized into five sections. Related work on fairness of allocation is discussed in section two. Design of the proposed model and its components is given in section three. Simulation and performance analysis of the proposed model is described in section four. The work is concluded in section five.

Table 1. QoS Classes in 4G LTE Network

QCI	Service type	Priority	Packet delay budget	Packet error loss rate	Supported service type examples
1	GBR	2	100ms	10^{-2}	Conversational voice
2	GBR	4	150ms	10^{-3}	Conversational video (live streaming)
3	GBR	3	50ms	10^{-3}	Real time gaming, V2X messages
4	GBR	5	300ms	10^{-6}	Non-Conversational video (buffered streaming)
65	GBR	0.7	75ms	10^{-2}	Mission Critical user plane Push To Talk voice
66	GBR	2	100ms	10^{-2}	Non-mission-critical user plane PTT voice
75	GBR	2.5	50ms	10^{-2}	Vehicle to everything (V2X) messages
5	non-GBR	1	100ms	10^{-6}	IMS signaling
6	non-GBR	6	300ms	10^{-6}	Video (buffered streaming) TCP-based
7	non-GBR	7	100ms	10^{-3}	Voice, Video (live streaming), interactive gaming
8	non-GBR	8	300ms	10^{-6}	Video (buffered streaming) TCP-based
9	non-GBR	9	300ms	10^{-6}	Video, TCP-based. Typically used as default bearer
69	non-GBR	0.5	60ms	10^{-6}	Mission critical delay sensitive signaling (e.g., MC-PTT signaling)
70	non-GBR	5.5	200ms	10^{-6}	Mission critical data (example services are the same as QCI 6/8/9)
79	non-GBR	6.5	50ms	10^{-2}	V2X messages

2. Related Work

Wireless networks such as 4G LTE are designed to support a large number of users each belonging to different traffic classes. The different traffic classes and their specifications can be found in the technical specifications by the Third Generation Partnership Project (3GPP) [1] and [2] and are summarized in Table 1. The services are classified as guaranteed bit rate (GBR) and non- guaranteed bit rate (non-GBR) in the table. Each of the supported services is identified using a QoS class identifier (QCI) value. For satisfying the QoS requirements of diverse users, the resource allocation algorithms (RAAs) must fairly allocate the wireless network resource among these users. The popularly used algorithms are maximum throughput (MT), proportional fair (PF), modified largest weighted delay first (MLWDF), exponential PF (EXP-PF), exponential rule (EXP RULE), log rule (LOG RULE) and frame level scheduler (FLS).Table 2 summarizes the popularly used RAAs. These RAAs quantify fairness as an index that helps in identifying the algorithm most suitable for a user type under given network conditions as shown in [5].

The Jain's Fairness Index in [6] defines fairness in terms of *equality of allocation* i.e. it quantifies how far the allocation is from equality. The index is computed as shown in eq. (1).

Table 2. Resource Allocation Algorithms in 4G LTE Networks

Resource allocation algorithm	Network parameters considered					QoS class serviced
	Head of line delay	Past average throughput	Instantaneous data rate	Spectral efficiency	Packet drop probability	
MT				✓		non-GBR
PF			✓	✓		non-GBR
MLWDF	✓	✓	✓	✓	✓	GBR
EXP-PF	✓	✓	✓		✓	GBR
EXP RULE	✓			✓	✓	GBR
LOG RULE	✓			✓	✓	GBR
FLS	✓	✓	✓	✓	✓	GBR

$$F(X) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n.\sum_{i=1}^{n} x_i^2};\ x_i \geq 0 \qquad (1)$$

Where x_i represents the amount of resource allocated to a user *i* and *n* is the total number of users. Jain's index shows that an individual's fairness can be defined by a bell-shaped curve indicating that fairness index increases with allocation until it reaches a maximum value of 1. Any further allocation to the user results in discrimination to other user(s). Another method of quantifying fairness known as Entropy is defined in [7]. This measure has properties similar to Jain's index and is computed as shown in eq. (2).

$$H(\mathbf{P}) = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (2)$$

Where p_i is the proportion of resource allocated to user *i*. Similar to Jain's index, entropy is bounded between 0 and 1. These quantitative fairness measures require complete information of allocation and do not identify unfairly treated individuals. The qualitative fairness measures on the other hand ensure that an allocation is completely fair if it satisfies the conditions imposed by the measures. One of such popular measures is the max-min fairness [8] which is achieved if an individual's allocation cannot be increased further without decreasing another individual's allocation which is already less than the others. Similarly min-max fairness is achieved if an individual's allocation cannot be decreased further without increasing another individual's allocation which is already the required amount. In a multi resource environment, the allocation of a resource to the users is said to be proportionally fair [9] if it is bounded by the finite capacity of the resource and allocation of any other proportion of the resource to a user is not possible.

There is another class of fairness measures that define fairness as a relative degree of satisfaction for users of all traffic classes. These are known as utility functions. The generalized representation of utility functions is given in [10] and is written as in eq. (3).

$$U(x,\varepsilon) = \begin{cases} (1-\varepsilon)^{-1} x^{1-\varepsilon} & if\ \varepsilon \neq 1 \\ \log x & if\ \varepsilon = 1 \end{cases} \qquad (3)$$

Which denotes rate maximization when ε=0, proportional fairness when ε=1, minimum potential delay when ε=2 and max-min fairness when$\varepsilon \rightarrow \infty$. Another form of the utility function is the α-utility function [11]. Under the α-fairness, the system throughput, efficiency and Jain's fairness index have been redefined in [12].

3. Design of the Proposed Model

The proposed model measures both inter-class fairness and intra-class fairness of allocation. The model has been named as fuzzy logic based utility function (FLBUF) and is shown in Fig. 1. The FLBUF model is a two inputs and two outputs system. The inputs to the system are categorized into *Input class 1* and *Input class2*. This classification is based on the 3GPP specified QoS classes for 4G LTE. The *Input class 1* comprises of QoS parameters for GBR type of users and the *Input class 2* comprises of QoS parameters for non-GBR type of users. These parameters have been adopted from the utility function defined in [15]. QoS parameters belonging to *Input class 1* are v which is a function of the packet delay (in milliseconds) and the packet error loss (ratio of packets transmitted and received) and V_M denoting the QoS parameter budget specifications. QoS parameters belonging to *Input class 2* are r which is the data rate (in Mbps) and R_M denoting the QoS parameter budget specifications. The fuzzy controller of the proposed FLBUF model transforms the QoS parameters of *Input class 1* and *Input class 2* of the proposed model from crisp values to fuzzy values.

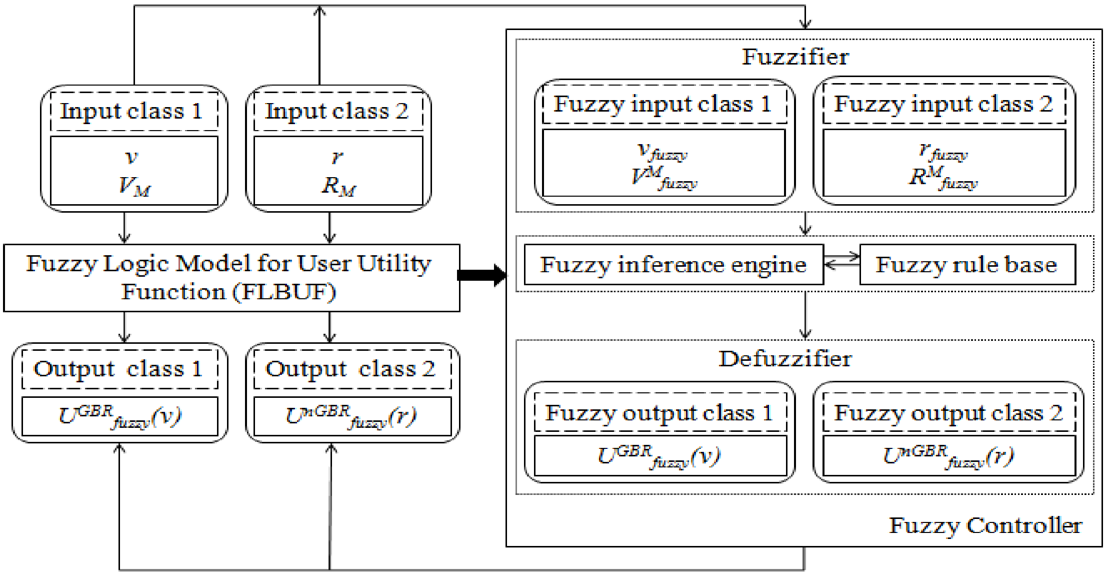

Figure 1. The proposed fuzzy logic based utility function model.

As the observed behaviour of fairness resembles the Gaussian function, the process of fuzzification of QoS parameters utilizes the Gaussian membership function 'GMF'. The GMF is a bell shaped curve that defines the membership of the input variable with respect to a fuzzy data set. The Input membership function for the proposed FLBUF model is shown in Fig. 2(a). The output of the system is categorized into *Output class 1* represented by $U^{GBR}{}_{fuzzy}(v)$ that defines the utility function for GBR users *Output class 2* represented by $U^{nGBR}{}_{fuzzy}(r)$for non-GBR users. The output variables of the fuzzy controller are also defined by a GMF (see Fig. 2(b)) that give a relative degree of QoS satisfaction for all users. The fuzzy sets for input variables v, V_M, r and R_M are defined by three membership values (MVs): Low (L), Medium (M) and High (H).

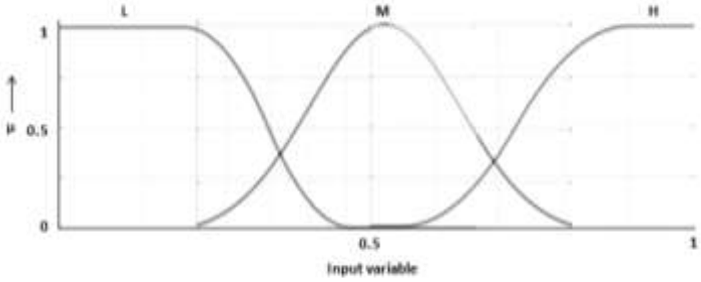

Figure 2(a). Input membership function for the proposed FLBUF model

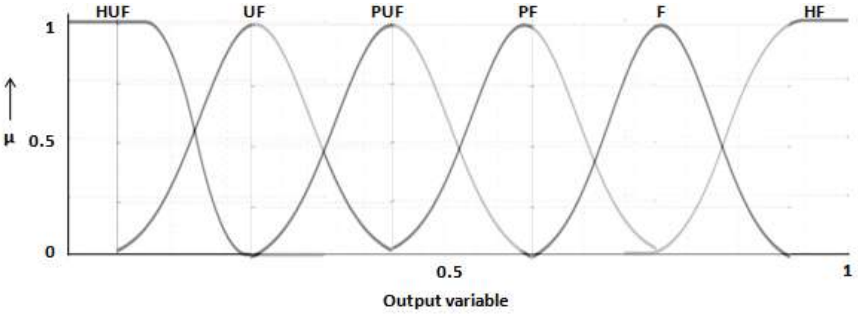

Figure 2(b). Output membership function for the proposed FLBUF model

v_{fuzzy} = {L, M, H}; V^{M}_{fuzzy} = {L, M, H}; r_{fuzzy} = {L, M, H}; R^{M}_{fuzzy} = {L, M, H}

The fuzzy sets for output variables $U^{GBR}_{fuzzy}(v)$ and $U^{nGBR}_{fuzzy}(r)$ are defined by six MVs: Highly Unsatisfied (HUS), Unsatisfied (US), Partially Unsatisfied (PUS), Partially Satisfied (PS), Satisfied (S), and Highly Satisfied (HS). The set representations are shown below.

$U^{GBR}_{fuzzy}(v)$ = {HUS, US, PUS, PS, S, HS}; $U^{nGBR}_{fuzzy}(r)$ = {HUS, US, PUS, PS, S, HS}

The rule base for the proposed fuzzy logic system is shown in Table 3 and explained below.

Rule base for *Input class 1*:

(1) If v_{fuzzy} is *L* and V^{M}_{fuzzy} is *L* Then $U^{GBR}_{fuzzy}(v)$ is *HS*
(2) If v_{fuzzy} is *L* and V^{M}_{fuzzy} is *M* Then $U^{GBR}_{fuzzy}(v)$ is *HS*
(3) If v_{fuzzy} is *L* and V^{M}_{fuzzy} is *H* Then $U^{GBR}_{fuzzy}(v)$ is *HS*
(4) If v_{fuzzy} is *M* and V^{M}_{fuzzy} is *L* Then $U^{GBR}_{fuzzy}(v)$ is *PUS*
(5) If v_{fuzzy} is *M* and V^{M}_{fuzzy} is *M* Then $U^{GBR}_{fuzzy}(v)$ is *PS*
(6) If v_{fuzzy} is *M* and V^{M}_{fuzzy} is *H* Then $U^{GBR}_{fuzzy}(v)$ is *S*
(7) If v_{fuzzy} is *H* and V^{M}_{fuzzy} is *L* Then $U^{GBR}_{fuzzy}(v)$ is *HUS*
(8) If v_{fuzzy} is *H* and V^{M}_{fuzzy} is *M* Then $U^{GBR}_{fuzzy}(v)$ is *PUS*
(9) If v_{fuzzy} is *H* and V^{M}_{fuzzy} is *H* Then $U^{GBR}_{fuzzy}(v)$ is *PS*

Rules (1), (4) and (7) measure the degree of QoS satisfaction $U^{GBR}_{fuzzy}(v)$ for real-time users with strict QoS requirements i.e. low values of V^{M}_{fuzzy}. Users with lower values of v_{fuzzy} observe more fairness ($U^{GBR}_{fuzzy}(v)$ =HS) as compared to those with high v_{fuzzy} values ($U^{GBR}_{fuzzy}(v)$ =HUS). For users with less strict QoS requirements ($V^{M}_{fuzzy}=M$), the degree of satisfaction is more as shown in rules (2), (5) and (8). For users with non-strict QoS requirements ($V^{M}_{fuzzy}=H$), the degree of QoS satisfaction is always high given by *HS*, *S* and *PS* respectively for low, medium and high values of v_{fuzzy} (rules (3), (6) and (9)).

Rule base for *Input class 2* is:

(1) If r_{fuzzy} is *L* and R^{M}_{fuzzy} is *L* Then $U^{nGBR}_{fuzzy}(r)$ is *PS*
(2) If r_{fuzzy} is *L* and R^{M}_{fuzzy} is *M* Then $U^{nGBR}_{fuzzy}(r)$ is *PUS*
(3) If r_{fuzzy} is *L* and R^{M}_{fuzzy} is *H* Then $U^{nGBR}_{fuzzy}(r)$ is *HUS*
(4) If r_{fuzzy} is *M* and R^{M}_{fuzzy} is *L* Then $U^{nGBR}_{fuzzy}(r)$ is *S*
(5) If r_{fuzzy} is *M* and R^{M}_{fuzzy} is *M* Then $U^{nGBR}_{fuzzy}(r)$ is *PS*
(6) If r_{fuzzy} is *M* and R^{M}_{fuzzy} is *H* Then $U^{nGBR}_{fuzzy}(r)$ is *PUS*
(7) If r_{fuzzy} is *H* and R^{M}_{fuzzy} is *L* Then $U^{nGBR}_{fuzzy}(r)$ is *HS*
(8) If r_{fuzzy} is *H* and R^{M}_{fuzzy} is *M* Then $U^{nGBR}_{fuzzy}(r)$ is *HS*
(9) If r_{fuzzy} is *H* and R^{M}_{fuzzy} is *H* Then $U^{nGBR}_{fuzzy}(r)$ is *HS*

Rules (1), (4) and (7) measure the degree of QoS satisfaction $U^{nGBR}_{fuzzy}(r)$ for best effort users with non-strict QoS requirements i.e. low values of R^{M}_{fuzzy}. For such users, fairness increases with the observed value of

r_{fuzzy}. As the strictness of QoS requirement increases ($R^M_{fuzzy} = M$), low degree of satisfaction is observed for lower values of observed r_{fuzzy} as seen in rules (2), (5) and (8). Users with more strict QoS requirements ($R^M_{fuzzy} = H$), observe even lower degrees of satisfaction as r_{fuzzy} decreases (rules (3), (6) and (9)).

3.1 Measuring fairness with the proposed model

To measure the fairness of allocation for users of the same class, the fuzzy rule base of either of the two classes is used. This ***Intra-class fairness*** considers the QoS parameters associated with the particular class only and hence cannot give a degree of QoS satisfaction relative to all the types of users. To measure the ***Inter-class fairness***, fuzzy rule base for both the classes are used. The QoS parameters of both GBR and non-GBR classes are considered and a relative degree of satisfaction is measured.

3.1.1 Measuring inter-class fairness

Case I: The observed data-rate is low

Rules for '*Output class 1*' (GBR) fairness relative to observed delay and associated PLR ('v_{fuzzy}' in Table 3):
-If v_{fuzzy} is *L* then the GBR user is *PS*
-If v_{fuzzy} is *M* then the GBR user is *PUS*
-If v_{fuzzy} is *H* then the GBR user is *HUS*

For small values of observed data-rate the degree of satisfaction of GBR users decreases as the value of observed v_{fuzzy} increases.

Rules for '*Output class 2*' fairness (non-GBR) relative to the available data-rate:
-If R^M_{fuzzy} is *L* then the non-GBR user is *S*
-If R^M_{fuzzy} is *M* then the non-GBR user is *PUS*
-If R^M_{fuzzy} is *H* then the non-GBR user is *HUS*

For small values of observed data-rate the degree of satisfaction of non-GBR users varies between satisfied (S) if the available data-rate is low and high dissatisfaction (HUS) for large values of the available data-rate.

Case II: The observed data-rate is medium

Rules for '*Output class 1*':
-If v_{fuzzy} is *L* then the GBR user is *S*
-If v_{fuzzy} is *M* then the GBR user is *PUS*
-If v_{fuzzy} is *H* then the GBR user is *HUS*

The degree of satisfaction of GBR users in this case shows a slight increase for low values of v_{fuzzy} as compared to 'case I' scenario where observed data-rate is low.

Rules for '*Output class 2*':
-If R^M_{fuzzy} is *L* then the non-GBR user is *S*
-If R^M_{fuzzy} is *M* then the non-GBR user is *PS*
-If R^M_{fuzzy} is *H* then the non-GBR user is *PUS*

The degree of satisfaction of non-GBR users also shows a slight increase compared to 'case I' scenario.

Case III: The observed data-rate is high

Rules for '*Output class 1*':
-If v_{fuzzy} is *L* then the GBR user is *HS*
-If v_{fuzzy} is *M* then the GBR user is *PUS*
-If v_{fuzzy} is *H* then the GBR user is *US*

For large values of observed data-rate the degree of satisfaction of GBR users varies between high satisfaction (HS), for low values of observed delay, and dissatisfaction (US) for large values of observed delay.

Table 3. Measuring fairness with the proposed FLBUF model

QoS parameters for defined classes				Fairness			
Input class 2		Input class 1		Inter-class		Intra-class	
r_{fuzzy}	R^M_{fuzzy}	v_{fuzzy}	V^M_{fuzzy}	$U^{GBR}_{fuzzy}(v)$	$U^{nGBR}_{fuzzy}(r)$	$U^{GBR}_{fuzzy}(v)$	$U^{nGBR}_{fuzzy}(r)$
L	L	L	L	PS	PS	HS	PS
L	L	L	M			HS	PS
L	L	L	H			HS	PS
L	M	M	L	PUS	PUS	PUS	PUS
L	M	M	M			PS	PUS
L	M	M	H			S	PUS
L	H	H	L	HUS	HUS	HUS	HUS
L	H	H	M			US	HUS
L	H	H	H			PS	HUS
M	L	L	L	S	S	HS	S
M	L	L	M			HS	S
M	L	L	H			HS	S
M	M	M	L	PUS	PS	PUS	PS
M	M	M	M			PS	PS
M	M	M	H			S	PS
M	H	H	L	HUS	PUS	HUS	PUS
M	H	H	M			US	PUS
M	H	H	H			PS	PUS
H	L	L	L	HS	HS	HS	HS
H	L	L	M			HS	HS
H	L	L	H			HS	HS
H	M	M	L	PUS	HS	PUS	HS
H	M	M	M			PS	HS
H	M	M	H			S	HS
H	H	H	L	US	HS	HUS	HS
H	H	H	M			US	HS
H	H	H	H			PS	HS

Rules for '*Output class 2*':

-If R^M_{fuzzy} is *L* then the non-GBR user is *HS*

-If R^M_{fuzzy} is *M* then the non-GBR user is *HS*
-If R^M_{fuzzy} is *H* then the non-GBR user is *HS*
For large values of observed data-rate the degree of satisfaction of non-GBR users is high (HS) for any values of the available data-rate.

4 Discussion of Simulation Results

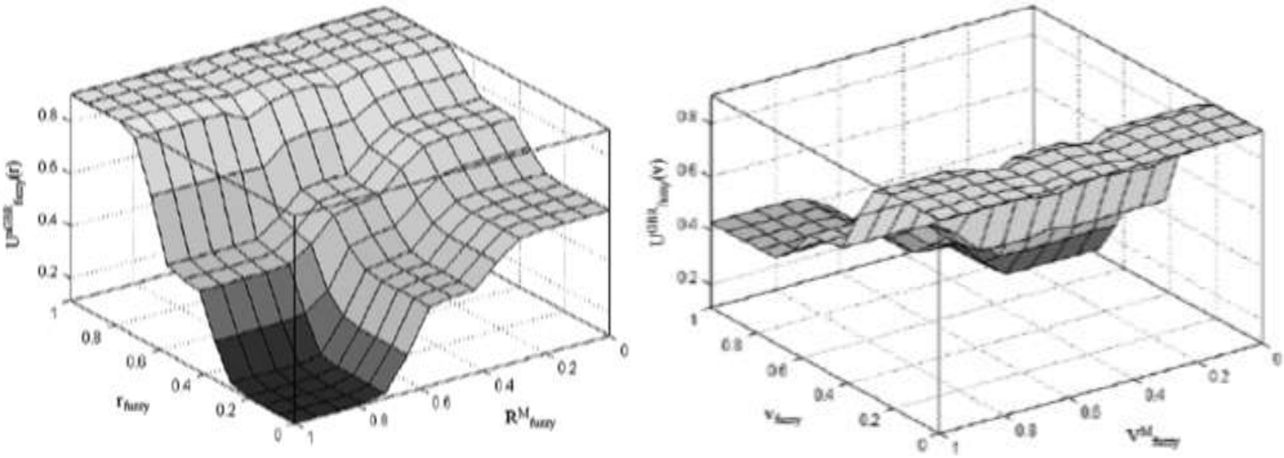

Figure 3. Proposed FLBUF model measuring fairness for
(a). non-GBR users **(b).**GBR user

The proposed FLBUF model has been simulated in Matlab. Because of its intuitiveness and widespread acceptance, the fuzzy controller of the proposed model uses mamdani type inference system. For measuring fairness of allocation, the proposed model generates a utility function based on the QoS parameters of the respective classes. The relative degree of satisfaction as observed by non-GBR users is simulated (see Fig. 3a) as a function of observed data rate and the maximum allowable budget observed. For GBR users the simulation (see Fig. 3b) is a function of maximum allowable delay (and PLR). Defuzzified simulation values of Table 4 show that for non-GBR user's low values of QoS parameter budget (maximum available data rate) and low to medium ranged observed QoS parameter values (throughput) result in high degree of satisfaction. For high values of the observed QoS parameter, the degree of satisfaction is always high. Defuzzified simulation values of Table 5 show that for GBR users low ranged values of the observed QoS parameter (delay and PLR) result in a high degree of satisfaction. For medium and high values of observed QoS parameter, the degree of satisfaction increases with increase in the budget value of the QoS parameter (maximum allowable delay and PLR).

The behaviour curve of *degree of satisfaction* as analyzed by the proposed FLBUF model for *non-GBR* and *GBR* users of an *LTE network* is shown in Fig. 4(a) and 4(b) respectively. The authors propose that such a *biphasic growth curve* (*BGC*) in *wireless networks* can be used to represent the degree of QoS satisfaction, i.e. *fairness* for different types of users. These BGC curves comprise of three different *phases* each representing the trend of fairness observed. The first phase is the *user utility region* that defines fairness as observed by an individual user. The second phase is the *stationary phase* which explains that the fairness remains constant for some duration after a sudden increase or decrease in value. The third phase is the *network utility region* that defines system fairness.

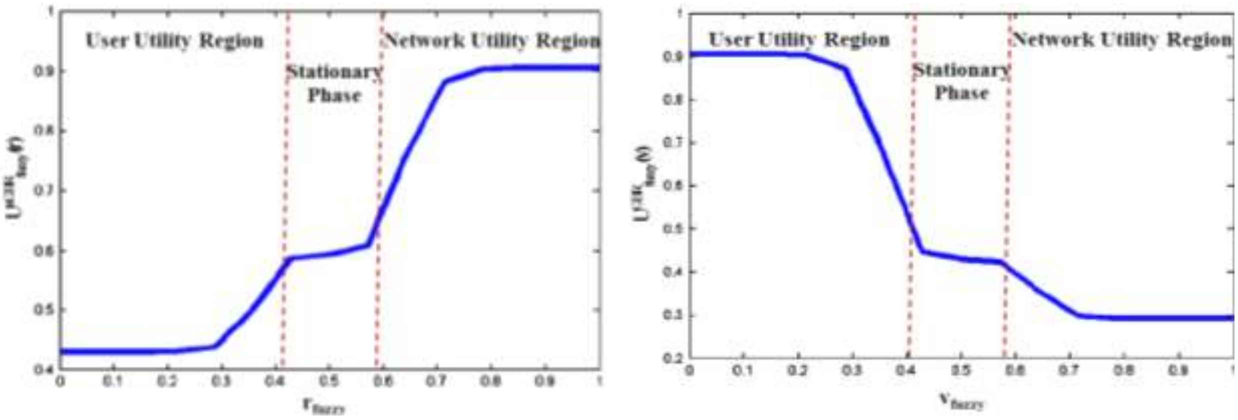

Figure 4. The proposed BGC curve for
(a). non-GBR users **(b).** GBR users

Table 4. Defuzzified simulation values for non-GBR users

r_{fuzzy} = L			r_{fuzzy} = M			r_{fuzzy} = H		
R^M_{fuzzy}	r_{fuzzy}	$U^{nGBR}_{fuzzy}(r)$	R^M_{fuzzy}	r_{fuzzy}	$U^{nGBR}_{fuzzy}(r)$	R^M_{fuzzy}	r_{fuzzy}	$U^{nGBR}_{fuzzy}(r)$
L - 0.20	0.12	PS - 0.59	L - 0.12	0.45	S - 0.75	L - 0.12	0.74	HS - 0.898
M - 0.45	0.25	PUS - 0.43	M - 0.59	0.57	PS - 0.59	M - 0.57	0.84	HS - 0.897
H - 0.74	0.35	HUS - 0.24	H - 0.84	0.66	PUS - 0.48	H - 0.98	0.96	HS - 0.905

Table 5. Defuzzified simulation values for GBR users

v_{fuzzy} = L			v_{fuzzy} = M			v_{fuzzy} = H		
V^M_{fuzzy}	v_{fuzzy}	$U^{GBR}_{fuzzy}(v)$	V^M_{fuzzy}	v_{fuzzy}	$U^{GBR}_{fuzzy}(v)$	V^M_{fuzzy}	v_{fuzzy}	$U^{GBR}_{fuzzy}(v)$
L - 0.20	0.12	HS - 0.905	L - 0.12	0.45	PUS - 0.39	L - 0.12	0.74	HUS - 0.12
M - 0.45	0.25	HS - 0.894	M - 0.59	0.57	PS - 0.44	M - 0.57	0.84	PUS - 0.30
H - 0.74	0.35	HS - 0.773	H - 0.84	0.66	S - 0.49	H - 0.98	0.96	PS - 0.429

Fig. 4(a) shows the BGC curve for best effort users. The first phase shows that for small values of observed throughput r_{fuzzy}, there is insignificant change in fairness $U^{nGBR}_{fuzzy}(r)$. For significantly large values of throughput r_{fuzzy} a sudden increase in fairness is observed which remains constant for any further insignificant increase in r_{fuzzy} in the stationary phase. With increase in number of users experiencing large degrees of satisfaction, the system fairness tends to increase in similar fashion (third phase). Fig. 4(b) shows the BGC curve for real-time users classified as GBR users by the network specifications. The first phase shows that for small values of observed QoS parameter v_{fuzzy}, there is insignificant change in fairness $U^{GBR}_{fuzzy}(v)$. For significantly large values of v_{fuzzy} representing large delay and PLR, a sudden decrease in fairness is observed which remains constant for any further insignificant increase in v_{fuzzy} as shown by the stationary phase. With increase in number of users experiencing small degrees of satisfaction, the system fairness tends to decrease in similar fashion as is shown by the third phase.

5. Conclusion

The authors propose a novel method (FLBUF model) for measuring fairness of allocation in wireless networks based on utility function that is capable of measuring inter-class fairness of allocation. Also proposed in this work is the biphasic growth curve which depicts the behaviour of fairness as observed by both GBR and non-GBR users. The FLBUF model in general is a more descriptive framework that is aimed at improving the network performance with the help of the extensive analysis of fairness parameter for different types of users. The proposed method has been designed to measure fairness specifically for 4G LTE networks. However, this model can be adopted for other networks as well which might require certain modifications as per the network traffic class specifications. In this work, the use of fuzzy logic controller has been proposed to model fairness and QoS as possible range of values so that it may be well adapted to real time wireless networks.

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