Fairness and Performance Evaluation of Fuzzy-Based Resource Allocator for IEEE 802.16 Networks

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Abstract Intensification of mobile devices has triggered use of applications over the web. These applications even put scheduler performance of broadband wireless systems like WiMAX to test. The role of schedulers in such networks had become very challenging, and only adaptive schedulers can survive to fit in user's demands. This paper has evaluated working of dynamic fuzzy-based scheduler used for bandwidth allocation. The scheduler is implemented as component of the base station and works to grant bandwidth to traffic classes after analysis of their traffic share and quality of service parameters. The performance of proposed method is justified by drawing comparisons with established practices.

Keywords Fuzzy scheduler · WiMAX · IEEE 802.16 · QoS

1 Introduction

IEEE 802.16 is one of recent broadband wireless access standards for MANs, commercially popularized by WiMAX Forum with name of Worldwide Interoperability for Microwave Access (WiMAX) [1, 2]. WiMAX has been standardized to cater to needs of ever-growing number of applications on the web. The increase in number of these applications has been manifold because of popularity of smartphones from 122 million to 968 million in 2013 (stastica.com-2014). Resource distribution in such environments is always tedious task as pressure exerted by these multimedia-rich applications is much significant. The presence of real-time applications always tries to overpower resources of low priority non-real-time classes.

Bandwidth allocation mechanism in WiMAX has not been standardized by IEEE, and vendors can opt for any specific implementation according to their requirements. Quality of service is supported by implementing five scheduling

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services or traffic classes, namely unsolicited grant service (UGS), real-time polling service (rtPS), non-real-time polling service (nrtPS), extended real-time polling service (ertPS) and best effort (BE). The quality of service levels for these traffic classes maps to requirements of various user applications. The classifier sends incoming traffic to one of these classes, and bandwidth is allocated by schedulers according to implemented algorithm.

WiMAX implements a request-grant allocation mechanism scheme in which subscribers (SS) registered with the base station (BS) request bandwidth, and BS allocates these resources according to available channel conditions and requested bandwidth. The time gap between resource request and allocation can be a bottleneck in maintaining effectual QoS levels as during this period more admitted real-time applications can account for resources of non-real-time traffic classes. Role of scheduling structure and allocation policy gets much crucial in such circumstances and demands a ploy that shall be fair, intelligent and adaptive so that the performance of scheduling classes do not deteriorate. Design of such intelligent scheduling structure is only possible if most recent information from SS is incorporated into decision-making process. The most current state of traffic shall be made available to scheduler, and decisions regarding allocations shall be made accordingly. In this paper, authors have evaluated the performance of an adaptive method that utilizes fuzzy logic principles. The proposed system evaluates three qualities of service parameters from incoming traffic, and required number of slots are calculated according to these values. The performance analysis has been done by comparing the proposed method against established algorithms for four parameters of throughput, delay jitter and fairness. The paper is organized as follows: Sect. 2 summarizes latest studies in this field followed by formulation of problem. Section 3 introduces the proposed method followed by results and discussion in next section. Conclusion and future directions of work are provided in the last section.

2 Related Work

Use of fuzzy logic for resource allocation in WiMAX has found a limited number of studies in the literature, recently. It is one of hottest research areas, and few of these studies explored by authors can be found at [3–10]. Bchini et al. [11] and Simon et al. [3] used fuzzy logic concepts in designing handover algorithms. An intelligent call admission and control system for different traffic classes of WiMAX has been proposed by Shuaibu et al. [4]. Sadri et al. [5] implemented an interclass scheduler for 802.16 networks on basis of latency for real-time applications and throughput for non-real-time applications. Mohammed et al. [6] had implemented an adaptive version of DRR algorithm on basis of priorities of different service classes, latency and throughput requirements. Similar studies were also given by Hedayati et al. [7], Hwang et al. [8], Seo et al. [9] and Akashdeep and Kahlon [10].

The above-mentioned studies try to use fuzzy logic principles aiming to satisfy latency and throughput requirements of traffic classes. These do not consider request grant allocation mechanism used by WiMAX for bandwidth allocation which can lead to starvation of non-real-time flows. The proposed approach finds instantaneous information from various subscribers and makes allocation decisions accordingly. The approach calculates share of traffic in queues of real and non-real traffic together with latency and throughput requirements when system is up and running. The system then works to find an appropriate value for queue weight using fuzzy logic principles. This weight is utilized further for allocating bandwidth to queues of real and non-real traffic. Comparisons with reputable approaches are provided at end in order to justify the performance of proposed approach. Fairness of the system has also been explored and is found to be sufficiently good.

3 Proposed System

The standard resource allocation process for WiMAX consists of different subscribers requesting resources from the base station. The base station after evaluation of all requests and available resources makes the decision for slot allocation. This static process of allocation has been made adaptive by implementing fuzzy-based scheduler that makes decisions as per latest information available at various SS. The structure utilizes the latest information available at SS, senses changes in incoming traffic and modifies the allocation policy accordingly in order to satisfy requirements of both real as well as non-real-time classes. The proposed fuzzy system works on three input parameters: share of real-time and non-real-time traffic data, throughput requirements for non-real-time traffic and latency requirement for real-time traffic. The framework works adaptively by updating weights of queues serving these traffic classes. Fuzzy system has been implemented to automate weighted fair queuing (WFQ) algorithm for resource allocation on basis of parameters extracted from incoming bandwidth request packets and amount of traffic accumulated in queues of various SS. The output of the fuzzy system is weight for real-time traffic which is utilized to allocate slots to queues. Figure 1

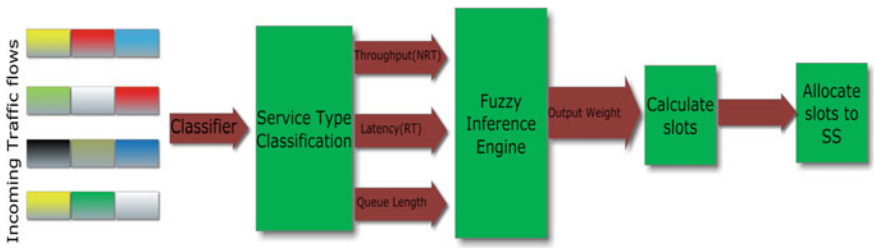

Fig. 1 Model of fuzzy logic-based resource allocator

shows the adopted methodology. The input and output variables have been defined with help of different linguistic levels. For latency and weight, we had defined five linguistic levels, whereas traffic share and throughput is measured on basis of three levels. This makes rules base to be used consisting of 45 different rules. The rules have been framed considering variable traffic patterns and nature of our variables. The dynamics of variables have been taken as ranging from (0) to +(1).

The allocation starts by assigning an initial weight to all flows (i) using Eq. (1)

$$w_i = \frac{R_{\min(i)}}{\sum_{i=0}^{n} R_{\min(i)}} \quad (1)$$

where $R_{\min(i)}$ is the minimum reserved rate for flow (i).

On receiving any bandwidth request from subscriber, the base station calls fuzzy inference system. The fuzzy system reads values of latency, throughput and queue length; performs fuzzification of these values against membership functions defined for these variables and applies the inference mechanism using fuzzy rule base. A final crisp value is generated after de-fuzzification using the centre of gravity method. This crisp-generated value is taken as weight for real-time traffic, and weight for non-real-time traffic is calculated using this generated value. Bandwidth to real and non-real-time traffic is allocated using these two weights according to Eqs. (2) and (3), respectively.

$$B_{\text{real}} = S_i \times \left(\frac{w_i}{\sum_{i=1}^{n} w_i} \right) \times \left(\frac{\text{Frame Duration}}{\text{Maximum Latency}} \right) \quad (2)$$

$$B_{\text{non-real}} = S_i \times \left(\frac{(w_j)}{\sum_{j=1}^{n} w_j} \right) \quad (3)$$

where S_i is the number of slots requested for that flow, w_i and w_j are weighted for real and non-real-time traffic queues. The overall performance of network has increased, and over all fairness and fairness towards non-real-time classes have also improved.

4 Results and Performance Evaluation

A simulating environment consisting of base station and multiple subscribers was set-up for performance evaluations. The simulating environment has one base station with increasing number of subscribers transmitting traffic according to five service classes of WiMAX. The subscribers transmit traffic for ertPS at rate of 10 frames/s, nrtPS traffic at 512 kbps with polling interval of 1s and web (BE) traffic. UGS class has an interval of 0.001 s. The requirement for rtPS has been taken as lower than 150 ms with all connections specifying their minimum and maximum requirements. Experiments are conducted to evaluate the performance of proposed system against established approaches such as EDF (Extended deadline first), WFQ (weighted fair queuing) and WRR (weighted round robin) with concerns to parameters delay, throughput, jitter and fairness.

Figure 2 shows a plot of throughput and shows that system improves considerably in throughput. The fuzzy-based approach was quick to respond to requirements of real-time applications and provided allocation to non-real-time traffic in case requirement from real-time traffic are not rigid. This ability of fuzzy scheduler makes a positive impact on overall throughput value. Figure 3 plots average jitter for fuzzy system against other algorithms. The performance of all algorithms is similar till the number of subscribers is limited as resources are sufficient. The jitter variations are considerable as subscribers are increased further beyond 60. The proposed fuzzy system was successful in keeping jitter variations to minimum possible level.

Figure 4 indicates that proposed system was able to keep delay within permissible limits. This is because fuzzy-based system assigns major chunk of bandwidth to those connection which has comparatively smaller latency values. The fuzzy system is dynamic in nature, whereas other algorithms provide static allocations. The delay gets stable after subscribers reach about 105 which indicates system is able to meet requirements of all traffic classes, and weights are almost stable at this point.

One more experiment to verify the fairness of fuzzy-based approach was conducted in which fairness of different algorithms measured using Jain's Fairness Index was calculated and compared. Three service classes of rtPS, nrtPS and BE were considered for evaluation for reasons that these classes do not get dedicated allocations. Figures 5, 6 and 7 show plot of fairness observed by rtPS, nrtPS and BE classes, respectively. Figure 5 shows that out of all algorithms, EDF is more fair towards rtPS when number of connections are limited. Fairness deteriorates with increase in number of UGS and ertPS connections. The performance of WFQ and WRR is almost constant but shows a decline with increasing number of real-time

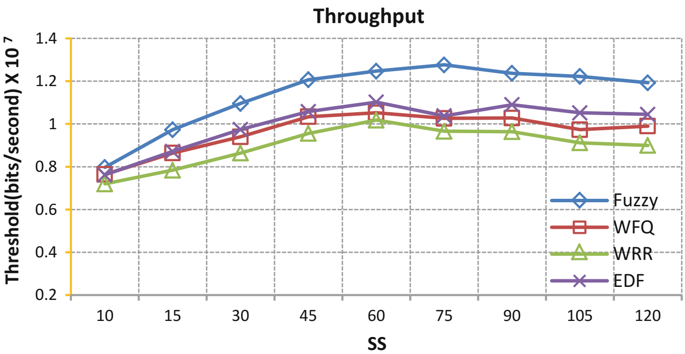

Fig. 2 Performance evaluation for throughput

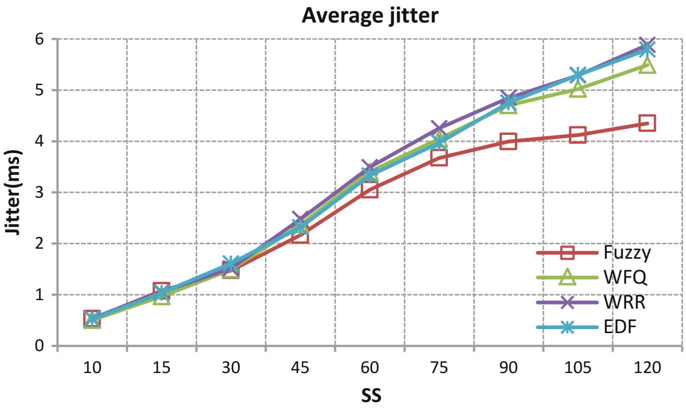

Fig. 3 Performance evaluation for jitter

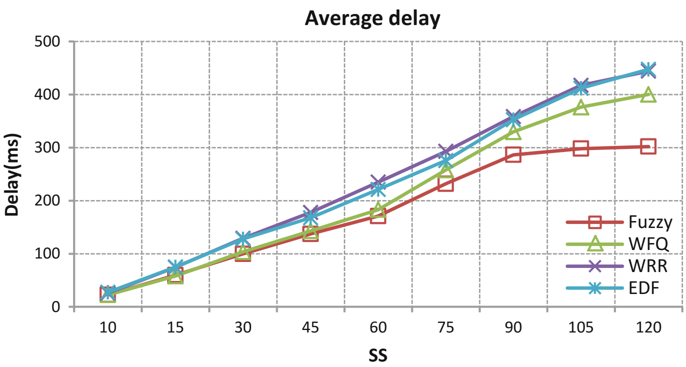

Fig. 4 Performance evaluation for delay

connections. WRR and WFQ are fairer but shows decline in fairness at relatively larger number of real-time connections.

Figures 6 and 7 suggest that proposed method is more inclined in fairness towards non-real-time traffic classes of nrtPS and BE. This may be because allocation to these classes is governed by relative variations in incoming traffic, and fuzzy scheduler increases amount of allocations whenever traffic from these classes tends to increase beyond a limit. This is a major reason for avoiding starvation of these classes, whereas other algorithms fail to adopt this policy, and therefore, the performance of these classes in other algorithms declines. Figure 7 shows that all algorithms have same values for limited amount of traffic but decrease substantially once traffic is increased. Out of all algorithms, WFQ and WRR provide relatively more fair level of performance to BE class. The performance of proposed method is also competitive.

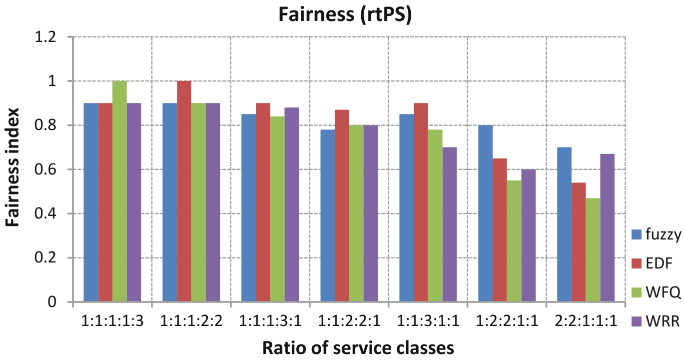

Fig. 5 Fairness comparison for rtPS

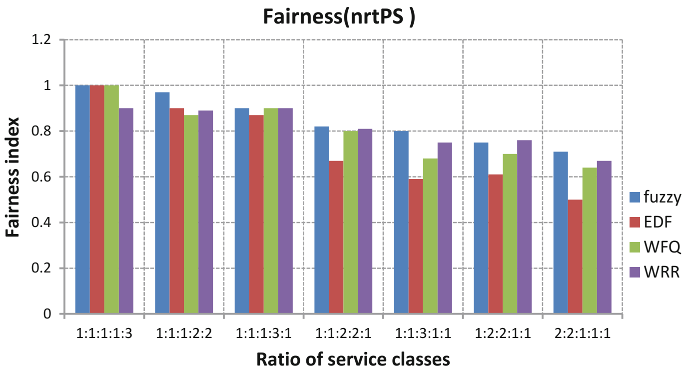

Fig. 6 Fairness comparison for nrtPS

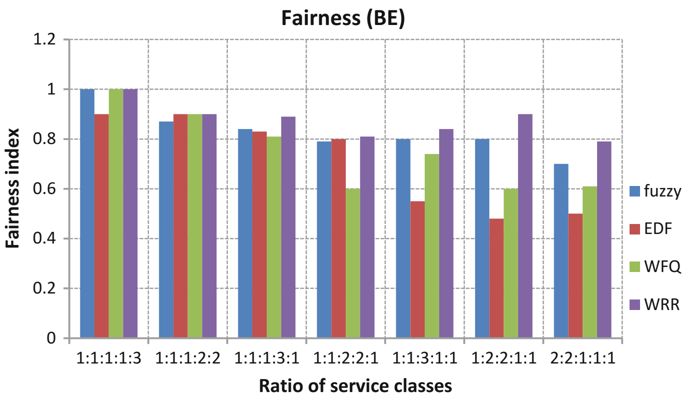

Fig. 7 BE fairness comparison

5 Conclusion

The above study has provided an evaluation of fuzzy logic-based resource allocator to be used in WiMAX networks in terms of different parameters. The approach is implemented to work adaptively using fuzzy logic vagueness. Decisions regarding resource allocation have been implemented using variables that are extracted at simulation time from incoming traffic. Use of fuzzy logic to implement an adaptive system has increased throughput of network. The delay and jitter variations of various service classes have been minimized, and low-prior non-real-time classes are not starved as system takes care of these flows on basis of their share. The approach was also tested for fairness, and results of the study are quite promising.

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