An Improved Hybrid Scheduler for WiMAX and its Performance Evaluation

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***Abstract* - IEEE 802.16 based Worldwide interoperability for Microwave Access (WiMAX) provides broadband wireless access with integration of variety of applications such as voice, video and data with different Quality of Service (QoS) requirements. In WiMAX, MAC layer scheduling is an integral part of providing QoS to variety of services. In this paper, a hybrid WiMAX scheduler has been proposed and analytically modeled using Markov chain. The proposed scheduler consists of homogeneous scheduler, Weighted Fair Queuing (WFQ), strict priority and a Round Robin (RR) scheduler. Analytical modeling is carried out to investigate whether the proposed scheduler achieves the design goals namely low complexity, satisfying QoS requirements of a variety of applications, maintaining fairness among all applications. Markovian model balance equations are obtained and solved using matrix multiplication method to derive the performance metrics for comparison, such as throughput, mean queuing delay, and packet loss probability of each traffic and interclass fairness. The analytical results show that the proposed hybrid scheduler satisfies not only the QoS requirements of various applications but improves fairness among services.**

Keywords-WiMAX, Quality of Service (QoS), Scheduling algorithms, Analytical Model.

I. INTRODUCTION

Increased demand for support of triple play services (voice, video and data) and high speed internet access led to the development of Wireless Metropolitan Area Networks (WMAN). WiMAX provides advantages of long range communication and support for QoS at the MAC layer as compared to other access technologies. Various QoS constraints are achieved at MAC layer by differentiation of traffic types through five service classes as defined by the standard: Unsolicited Grant Services (UGS), extended real time Polling Service (ertPS), real time Polling Service (rtPS), non real time polling service (nrtPS) and Best Effort (BE). In WiMAX, Base Station (BS) implements the scheduling for both uplink and downlink connections to allocate slots for channel utilization [1]. Although standard has defined the service classes, scheduling mechanism has not been defined. Scheduler at BS transforms the QoS requirements of Subscriber Stations (SSs) into appropriate number of slots. BS then informs each SS about the scheduling decision through UpLink MAP (ULMAP) and DownLink (DLMAP) messages at the beginning of each frame.

WiMAX schedulers can be broadly classified into homogeneous, hybrid and opportunistic. Homogeneous schedulers are based on legacy scheduling algorithms. Homogeneous schedulers are also known as channel unaware schedulers as they do not take care of channel error, packet loss rates and power level into consideration. They serve as intraclass schedulers. Hybrid scheduler is a combination of legacy schedulers while opportunistic scheduler considers the variability in channel condition [2].

In this paper, an improved hybrid scheduler is proposed and analyzed, for four different applications such as voice, video, data and web traffic. The proposed improved scheduler not only satisfies QoS requirements of real time and non real time applications, but also provides high fairness among all applications as compared to the existing three queue scheduler proposed in the literature [3]. The hybrid scheduler is analyzed using Markovian model and the balance equations obtained from Markovian model are solved using matrix multiplication method to derive the performance metrics for comparison such as throughput, queuing delay and packet loss probability of each traffic and fairness among various applications. The average rate at which packets pass through a scheduler at steady state is termed as throughput. Packet loss probability of a traffic class is the probability that no space is available in the corresponding buffer.

Various studies have focused on analytical modeling of hybrid schedulers. In the field of networking, Markov models have been widely used to model the behavior of communication networks under variable traffic load conditions. In [4], queue decomposition method was proposed which divided the Priority Queuing (PQ) system into a group of Single-Server Single-Queue (SSSQ) to obtain their service capacities. Queue length distributions of individual traffic are investigated through analytical modeling. In this paper, the hybrid scheduler is modeled as a Markov chain and stationary probabilities are obtained using closed loop expressions and matrix geometric method.

In [5], priority queuing traffic is divided into heterogeneous Long Range Dependent (LRD) self similar and Short Range Dependent (SRD) Poisson traffic and is analytically modeled by Priority Qeueing- Generalized Processor Sharing (PQ-GPS) scheduling mechanism. In order to deal with heterogeneous traffic, they extended the Schilder’s theorem and developed the analytical upper and lower bounds of queue length distributions of individual traffic flows. A model based on G/M/1 queuing system is

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proposed in [6] to take into account multiple classes of traffic that exhibit long range dependencies and self similarity among traffic. The authors in [6] developed a Markov chain for non preemptive priority scheduling which is solved to extract a numerical solution for proposed analytical framework. The accuracy of the model is demonstrated by comparing the numerical solution of the analytical modeling to simulation experiments and compared with the actual test bed results.

A discrete time priority queue with two layered general arrival process is analyzed in [7] in which higher priority is given to small fraction of the requests applications that generate large revenues and to applications with small size request. By using probability generating functions, performance measures of the queue such as the moments of the packet delays of both classes are calculated. Through analysis, [8] developed several upper bounds on the queue length distribution of GPS with Long Range Dependent (LRD) traffic, extending the same to packet based GPS. These bounds show that long range dependency and queue length distribution of LRD traffic is not affected by the presence of other sources. A notion of LRD isolation has been introduced in [8] that broadens the range of services offered by GPS system by admitting the traffic of low priority.

A hybrid scheduler based on the integration of PQ and WFQ schedulers is proposed in [3]. Traffic arrival processes are represented by non bursty Poisson process and bursty Markov Modulated Poisson Process (MMPP). The model consists of three separate buffers representing three traffic flows. The strict priority scheduler assigns highest priority to ertPS traffic and the scheduler WFQ schedules the rtPS traffic and nrtPS traffic.

A scheduler for UL and DL is proposed in [9]. Based on the QoS requirements and priority of services classes needed, resources are calculated and granted in terms of number of slots. The calculation of resources depend on bandwidth requirements of each connection and ensuring that it does not exceed maximum requirement of each connection. UL scheduler calculates number of slots needed by taking into account the polling interval while DL scheduler considers packet size for calculation of number of slots needed. Simulation results show that scheduler fulfills delay and throughput requirements of all service classes of WiMAX. An analytical model for performance evaluation of WiMAX networks is developed in [10]. A one dimensional Markov chain is developed which takes into account frame structure, precise slot sharing based scheduling and channel conditions. Closed form expressions are derived for the scheduling policies to satisfy slot fairness and throughput fairness. Opportunistic scheduling is considered to derive the performance metrics.

A mathematical analysis is performed for an uplink scheduling algorithm, named “courteous algorithm” which gives advantage to lower priority traffic class without affecting traffic of higher priority [11]. In this scheme scheduling of nrtPS traffic is improved while satisfying the delay constraints of rtPS traffic. In case maximum packet loss rate has not reached, lower priority traffic is served over higher priority as long as the maximum waiting time of higher priority traffic is not violated. Various performance parameters such as mean waiting time, waiting time for courteous packets, maximum burst size and packet priority are calculated using mathematical model and validated by a simulation. An analytical modeling of MAC protocol of WiMAX network is applied through queuing theory and Markov chain in [12] to analyze average message delays for real time and non real time applications.

The remainder of the paper is organized as follows: Section 2 provides a brief description of proposed hybrid scheduler. The analytical modeling of proposed hybrid scheduler is outlined in Section 3. The results are analyzed and discussed in Section 4. Finally the paper is concluded in Section 5.

II. DESCRIPTION OF PROPOSED HYBRID SCHEDULER

In this section, proposed hybrid scheduling algorithm for the BS and SS in WiMAX system is presented. The main objective of the proposed scheme is to provide QoS to both real time and non real time applications. The scheduler is implemented at the BS for uplink scheduling. Hybrid scheduler, consisting of WFQ, RR and strict priority, combines the advantages of well known scheduler strategies to provide QoS in a communication network [13].

Figure 1 illustrates the proposed hybrid scheduler that provides scheduling among four service classes of WiMAX namely ertPS, rtPS, nrtPS and BE. The incoming traffic is assigned to four separate buffers (Q_1, Q_2, Q_3 and Q_4) and each queue is served in First Come First Serve (FCFS) manner. As the packets of real time traffic such as voice and video, cannot tolerate higher delay they are given higher priority than non real time traffic. ErtPS and rtPS packets are served before nrtPS and BE packets of non real time traffic such as data traffic.

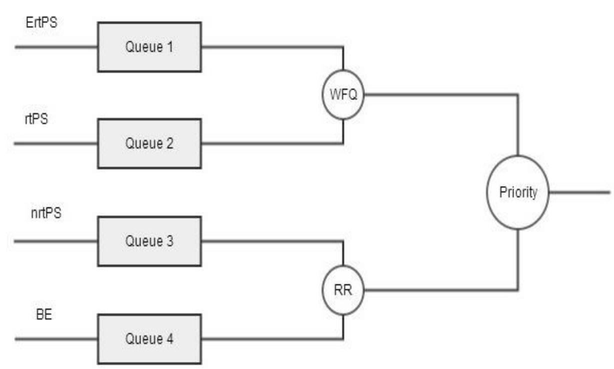

Figure 1: Architecture of proposed hybrid scheduler for providing QoS at MAC layer of WiMAX

The packets of ertPS and rtPS are buffered in queues Q_1 and Q_2 respectively and are served by the scheduler WFQ. Packets of nrtPS and BE traffic are placed in queues Q_3 and Q_4 respectively and are served by the scheduler RR. Queues Q_1 and Q_2 are each assigned a weight representing the maximum number of packets to be served in each round. The weight for queue Q_1 is varied from lowest value of 10% to highest value of 90% for ertPS traffic and simultaneously weight of queue Q_2 for rtPS traffic is varied from 90% to 10%.

III. ANALYTICAL MODELLING OF PROPOSED HYBRID SCHEDULER

The analytical model of the proposed scheme consists of single server multiple queues one for each service class subjected to hybrid scheduling. The system is represented by M/M/1/K queuing with queues (Q_1, Q_2, Q_3 and Q_4) of size K_1, K_2, K_3 and K_4 respectively. The input traffic is a Poisson process and the arrival rate for class c is λ_c. The service time has exponential distribution with service rates μ_1, μ_2, μ_3 and μ_4 and the service capacity of the system is s. The hybrid scheduler is represented by a Markov chain with the state space diagram for the proposed hybrid scheduler diagram shown as in Figure 2. A state P_{mnrs} represents the number of packets m, n, r, s for classes ertPS, rtPS, nrtPS and BE in their respective buffers. A packet added to queue Q_1 changes the state from P_{mnrs} to P_{m+1nrs}. Servicing a packet from queue Q_1 will change the state from P_{mnrs} to P_{m-1nrs}. Similarly the state of each queue changes depending on whether a packet is added to it or serviced from it.

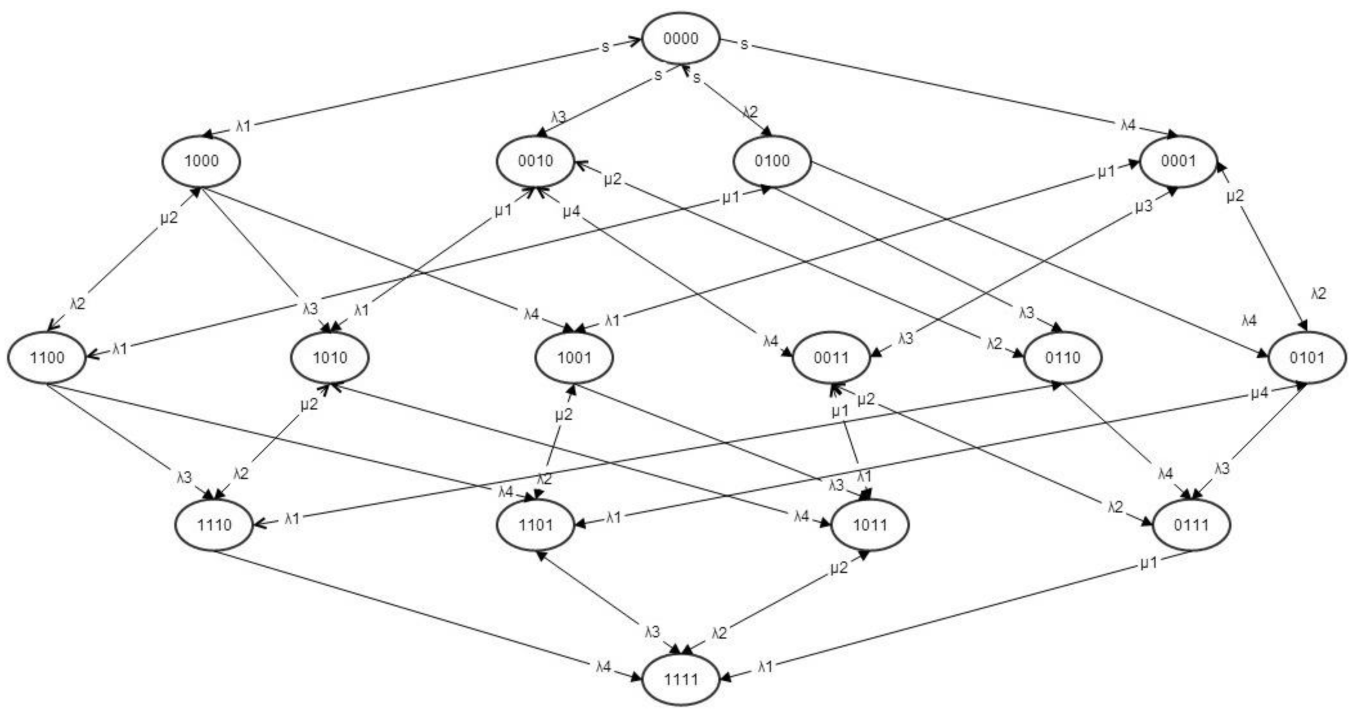

Figure 2: State space diagram for the proposed hybrid scheduler with single buffer queues

Matrix multiplication method approach is used to determine the steady state or limiting state probability of the system. The π matrix represents the steady state probability vector and satisfies equations (1) and (2) [3].

$$\pi Q = 0 \tag{1}$$

$$\pi e = 1 \tag{2}$$

Where e = (1, 1, 1……1)^T is a unit column vector of length $(K_1+1)x(K_2+1)x(K_3+1)x(K_4+1)x1$ and Q is a generator matrix and π is a steady sate probability column vector. The multiplication of these matrices provide balance equations which are further solved to obtain the steady state probabilities.

The probability p_m^c of having m packets of class c (c = 1, 2, 3, 4) in the corresponding buffer can be calculated from joint state probability p_{ijkl} using equations (3) to (6) [3]:

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$$p_m^c = \sum_{l=0}^{K_4}\sum_{k=0}^{K_3}\sum_{j=0}^{K_2} p_{mjkl} \qquad for\ class\ 1 \tag{3}$$

$$p_m^c = \sum_{l=0}^{K_4}\sum_{k=0}^{K_3}\sum_{i=0}^{K_1} p_{imkl}\ \ for\ class\ 2 \tag{4}$$

$$p_m^c = \sum_{l=0}^{K_4}\sum_{j=0}^{K_2}\sum_{i=0}^{K_1} p_{ijml}\ \ for\ class\ 3 \tag{5}$$

$$p_m^c = \sum_{k=0}^{K_3}\sum_{j=0}^{K_2}\sum_{i=0}^{K_1} p_{ijkm}\ \ for\ class\ 4 \tag{6}$$

With the help of the probabilities p_m^c for each class, performance metrics can be calculated from equations (7) to (10). The mean number of packets in the buffer of class c, L^C , is given by equation (7).

$$L^C = \sum_{m=0}^{L_c}[m * p_m^c] \tag{7}$$

Similarly the throughput T^C is given by equation (8).

$$T^C = \lambda_c * \sum_{m=0}^{L_c-1}[p_m^c] \tag{8}$$

The mean queuing delay D^C is given by equation (9).

$$D^C = \frac{L^c}{T^c} \tag{9}$$

The fairness index F is given by equation (10).

$$F = \frac{(\sum_{i=1}^{c} T^i)^2}{C * \sum_{i=1}^{c}(T^i)^2} \tag{10}$$

The steady state balance equations (equations 11-27) are derived from equations (1) and (2).

$$\sum_{i=0}^{n-1}\pi_i = 1 \tag{11}$$

$$-(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)\pi_0 + s\pi_1 + s\pi_2 + s\pi_3 + s\pi_4 = 0 \tag{12}$$

$$\lambda_4\pi_0 - (\lambda_1 + \lambda_3 + \lambda_2 + s)\pi_1 + \mu_1\pi_7 + \mu_3\pi_8 + \mu_2\pi_{10} = 0 \tag{13}$$

$$\lambda_3\pi_0 - (\lambda_2 + \lambda_1 + \lambda_4 + s)\pi_2 + \mu_1\pi_6 + \mu_4\pi_8 + \mu_2\pi_9 = 0 \tag{14}$$

$$\lambda_2\pi_0 - (\lambda_4 + \lambda_3 + \lambda_1 + s)\pi_3 + \mu_4\pi_5 = 0 \tag{15}$$

$$\lambda_1\pi_0 - (\lambda_4 + \lambda_2 + \lambda_3 + s)\pi_4 + \mu_2\pi_5 = 0 \tag{16}$$

$$\lambda_1\pi_3 + \lambda_2\pi_4 - (\lambda_3 + \lambda_4 + \mu_4 + \mu_2)\pi_5 = 0 \tag{17}$$

$$\lambda_1\pi_2 + \lambda_3\pi_4 - (\lambda_2 + \lambda_4 + \mu_1)\pi_6 + \mu_2\pi_{11} = 0 \tag{18}$$

$$\lambda_1\pi_1 + \lambda_4\pi_4 - (\mu_1 + \lambda_2 + \lambda_3)\pi_7 + \mu_2\pi_{12} = 0 \tag{19}$$

$$\lambda_3\pi_1 + \lambda_4\pi_2 - (\mu_4 + \mu_3 + \lambda_2 + \lambda_1)\pi_8 + \mu_1\pi_{13} + \mu_2\pi_{14} = 0 \tag{20}$$

$$\lambda_2\pi_2 + \lambda_3\pi_3 - (\mu_2 + \lambda_1 + \lambda_4)\pi_9 + \mu_1\pi_{11} = 0 \tag{21}$$

$$\lambda_2\pi_1 + \lambda_4\pi_3 - (\mu_2 + \lambda_3 + \lambda_1)\pi_{10} + \mu_1\pi_{12} = 0 \tag{22}$$

$$\lambda_3\pi_5 + \lambda_2\pi_6 + \lambda_1\pi_9 - (\mu_2 + \mu_1 + \lambda_4)\pi_{11} = 0 \tag{23}$$

$$\lambda_4\pi_5 + \lambda_2\pi_7 + \lambda_1\pi_{10} - (\mu_2 + \mu_1 + \lambda_3)\pi_{12} = 0 \tag{24}$$

$$\lambda_4\pi_6 + \lambda_3\pi_7 + \lambda_1\pi_8 - (\mu_1 + \lambda_2)\pi_{13} = 0 \tag{25}$$

$$\lambda_2\pi_8 + \lambda_4\pi_9 + \lambda_3\pi_{10} + \mu_1\pi_{15} - (\mu_2 + \lambda_1)\pi_{14} = 0 \tag{26}$$

$$\lambda_4\pi_{11} + \lambda_3\pi_{12} + \lambda_2\pi_{13} + \lambda_1\pi_{14} - \mu_1\pi_{15} = 0 \tag{27}$$

IV. ANALYSIS OF RESULTS

This section deals with investigation on the impact of weights of traffic flows scheduled by WFQ on the performance metrics: throughput, queuing delay, packet loss probability of each traffic class and fairness. The size of the buffer for queues (Q_1, Q_2, Q_3 and Q_4) is set to be 1 for each queue. The mean service rate s is 10. The service rate for queue 1 increases from 1 to 9 corresponding to increase in weight ratio from 10% to 90%. Simultaneously, the service rate for queue 2 varies from 9 to 1 corresponding to reduction in weight ratio from 90% to 10%. The idea behind varying weights is to find the optimum weight at which the design goals are achieved for proposed hybrid scheduler model Queues Q_3 and Q_4 are scheduled by RR; therefore, both are serviced with same weight.

Class 1 traffic, carried by ertPS service class, represents audio traffic which requires a lower delay, while higher or lower throughput does not affect much the quality of audio traffic. Thus requirement of low delay is mandatory for ertPS. RtPS service class, representing streaming video traffic, also requires a low delay but the requirement is not so stringent. Class 3 traffic, carried by nrtPS, represents the web traffic for which the requirement of high throughput is mandatory and low delay and low throughput is optional. Class 4 traffic, carried by BE, is the data traffic requiring high throughput.

Figure 3 shows the variation of mean queuing delay of each traffic class with respect to variation in weight ratio of WFQ scheduler. The graph shows that the queuing delay of class 1 traffic is reduced with the increase in weight of class 1 traffic since with the increase in weight more packets are serviced from queue and the queue delay is reduced. When the weight of class 1 traffic increases, the weight of class 2 traffic is reduced, causing an increased delay as a smaller number of packets is being serviced. Class 3 and class 4 traffic show a similar behavior as both are scheduled by RR. Figure 4 shows the variation of throughput for each traffic class with respect to variations in the weight ratio of scheduler WFQ. Figure 4 shows that as the weight for class 1 or class 2 traffic is increased, throughput also increases as more number of packets depart from the buffer. Class 4 has the highest arrival rate (λ_4) of 4 while class 3 has arrival rate of 3. Therefore, it is observed that the throughput for class 4 is the highest.

Figure 5 shows the variation of packet loss probability of each traffic class with respect to variation in weight ratio of WFQ scheduler. The figure shows that as the weight of

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class 1 traffic increases, the packet loss probability reduces as mean number of packets in the queue reduces, due to higher service rate. Similar behavior is displayed for class 2 traffic. Class 3 and class 4 traffic have highest packet loss probability as both are given lower priority than class 1 and class 2 traffic. As long as there are packets in class 1 or class 2 traffic buffer queues, lower priority class 3 or class 4 traffic is not served.

Figure 6 shows the variation of fairness with respect to increase in weight ratio of WFQ scheduler. The interclass fairness is the highest for a weight ratio of 9:1. For satisfying low delay requirement of class 1 and class 2 traffic, weight ratio 8:2 can be considered to be optimum as at this weight class 1 traffic has lower delay while class 2 traffic also has lower delay. At a weight ratio of 9:1 class 1 has lowest delay but class 2 has maximum delay verifying that it is not the optimum choice. At a weight ratio of 8:2, class 3 and class 4 have higher throughput than class 1 and class 2. Though they have the highest throughput at a weight ratio of 5: 5, at this ratio, class 1 traffic does not have a lower delay. Therefore, weight ratio of 8:2 satisfies the delay requirement of class 1 and class 2 traffic. It also satisfies the throughput requirement of class 3 and class 4. With respect to interclass fairness, weight ratio 9:1 is optimum as it provides highest fairness but at this weight ratio QoS requirements of all traffic classes are not satisfied. The proposed model not only satisfies QoS requirements of all service classes but also provides high fairness among all the traffic classes with a complexity of O(N) [13].

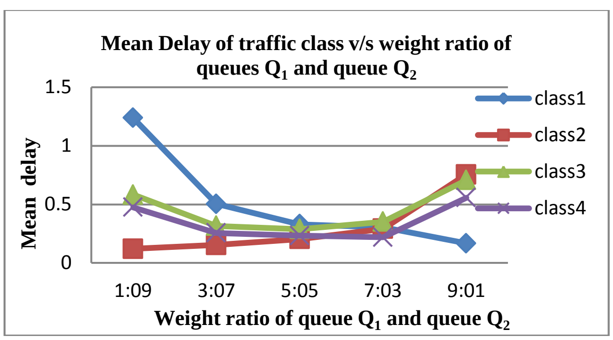

Figure 3: variation of mean Queuing delay for four classes of traffic v/s weight ratio for improved hybrid scheduler

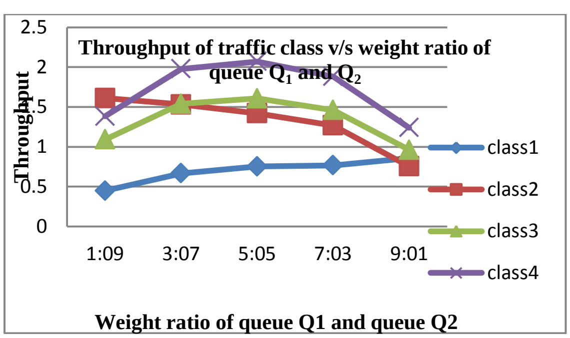

Figure 4: Variation of throughput for four classes of traffic v/s weight ratio for improved hybrid scheduler.

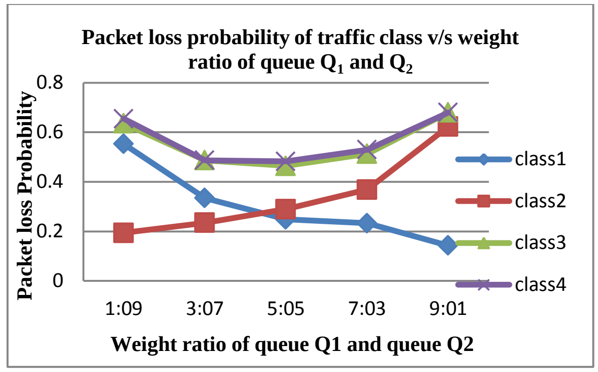

Figure 5: Variation of packet loss probability for four classes of traffic v/s weight ratio for improved hybrid scheduler.

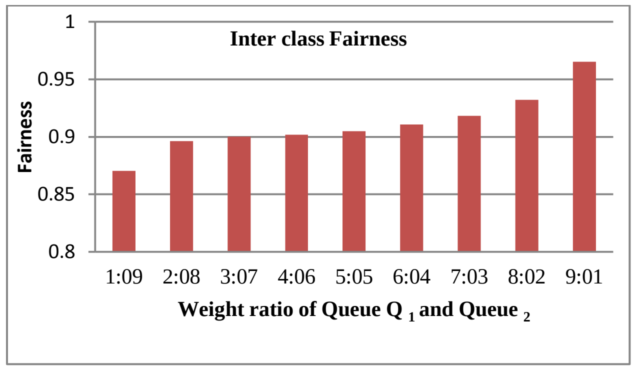

Figure 6: Variation of Interclass fairness v/s weight ratio for improved hybrid scheduler.

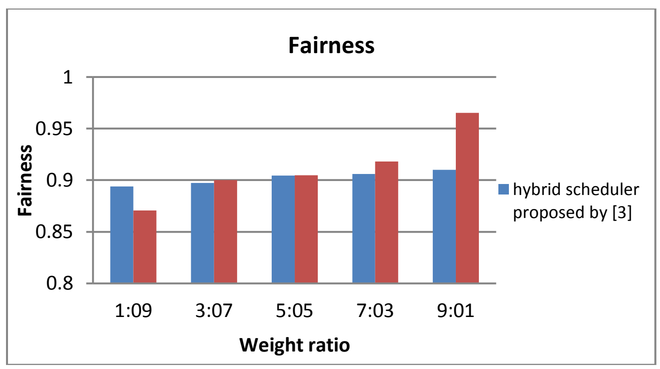

Figure 7: Variation of fairness of proposed improved hybrid scheduler and hybrid scheduler proposed in [3] v/s weight ratio.

Figure 7 shows the variation of fairness of proposed improved hybrid scheduler and the hybrid scheduler proposed in [3] with respect to variation in weight ratio of WFQ scheduler. The figure shows that the proposed improved scheduler provides better fairness at high weight ratio and almost the same fairness at lower weight ratio. Hence the proposed improved scheduler is more fair to all service classes than the scheduler proposed in [3].

Table 1 compares the performance of a three queue hybrid scheduler proposed in [3] (case I) and the four queue improved hybrid scheduler (case II) proposed in this paper. Performance metrics considered for comparison are Packet Loss Probability (PLP) and queuing delay of real time applications served by class 1 and throughput of non real time application served by class 3. The class 1 traffic in case I is provided highest priority while class 1 traffic in case II is scheduled by WFQ. Therefore, the PLP and queuing delay of class 1 for case I are lower as compared to that of class 1 of case II. Class 2 traffic in both cases is served by WFQ. Case II provides lower PLP and queuing delay for lower weight.

The comparison shows that the proposed improved hybrid scheduler satisfies the major objective of fairness among all service classes along with satisfying the QoS requirements of voice, video and data traffic.

TABLE 1: COMPARISON OF PERFORMANCE METRICS OF A HYBRID SCHEDULER PROPOSED IN [3] (CASE I) AND THE IMPROVED HYBRID SCHEDULER PROPOSED IN THIS PAPER (CASE II).

Weight ratio / Performance metric of a class	1:9	3:7	5:5	7:3	9:1
Case- I ,class 1 PLP	0.09	0.08	0.09	0.08	0.08
Case- II, class 1 PLP	0.55	0.33	0.24	0.23	0.14
Case- I, class 1 Delay	0.1	0.09	0.1	0.09	0.11
Case- II,class 1 Delay	1.23	0.50	0.33	0.30	0.16
Case- I, class 2PLP	0.25	0.23	0.22	0.20	0.19
Case- II, class 2 PLP	0.19	0.23	0.29	0.36	0.62
Case- I, class 2 Delay	0.17	0.14	0.14	0.12	0.11
Case- II, class 2 Delay	0.12	0.15	0.20	0.29	0.75
Case- I, class 3 throughput	2.20	2.20	2.12	2.15	2.00
Case- II, class 3 throughput	1.09	1.53	1.60	1.46	0.96

V. CONCLUSION

WiMAX supports deployment of triple play services by providing QoS through scheduling at MAC layer. This paper proposes a WiMAX hybrid scheduler for triple play services. WFQ, RR and strict priority schedulers are integrated in proposed scheduler to perform scheduling. Analysis of the proposed scheduler is carried out using queuing theory and Markov chain for deriving expressions for performance metrics, such as throughput, mean queuing delay, and packet loss probability to investigate the effectiveness of proposed hybrid scheduler in satisfying design goals. Weight ratio is changed to investigate its effect on performance metrics and to discover the optimum weight which satisfies design goals of a scheduler. Proposed scheduler satisfies QoS requirements of a variety of applications and it maintains fairness among all applications at a complexity of O (N). It can be used in non bursty applications where fairness is the main issue along with satisfaction of QoS requirements. The proposed scheduler can provide the flexibility in varying the weights of various traffic classes for achieving better design objective as per the application and requirement.

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