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# Dynamic Weight based Fair Resource Allocation In IEEE 802.16 Broadband Wireless Access Networks

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## ABSTRACT

The IEEE 802.16 Broadband Wireless Access(BWA) system offers a cost-effective solution to the last-mile wireless connection problem. Optimal scheduling mechanisms and resource allocation strategies are required to provide the necessary QoS guarantees to the multimedia traffic in BWA systems while utilizing the resources as efficiently as possible. In this paper, we propose a utility based fractional knapsack framework for bandwidth allocation in IEEE 802.16e broadband wireless networks with multiple classes of traffic flows. The proposed mechanism also includes dynamic weight adjustment to provide fairness among different competing traffic classes by prioritizing traffic depending on the load conditions and QoS requirements. We study the system performance in terms of normalized throughput and mean delay for each traffic class. From the results we find that the proposed mechanism improves throughput and decreases mean delay for varying traffic load compared to well-known allocation strategies.

## General Terms

Broadband communication, Bandwidth allocation, Fractional knapsack framework

## Keywords

IEEE 802.16, utility, dynamic weight assignment, Quality of Service, resource allocation

## 1. INTRODUCTION

IEEE 802.16 WiMAXsystem aims at providing high-speed internet access and multimedia services through wireless medium provides low cost all IP solutions for scalable networks with voice, data and video services. The main advantages are fast deployment, ability to reach crowded or rural areas without the use of costly wired infrastructure and the ability to support Quality of Service (QoS) required for different real time applications in wireless networks[1], [2]. Data rates of 32-130 Mbps can be achieved depending on the channel bandwidth and modulation techniques used. Multiple types of traffic flows (data, voice and video) are supported. Each flow requires a certain minimum bandwidth to achieve its quality-of-service (QoS). Bandwidth should be allocated so that all flows share the available capacity in compliance with the fairness criteria. The increased flow of traffic belonging to any QoS class increases its bandwidth requirement. Hence, it is essential to change the bandwidth allocation policy dynamically based on instantaneous traffic load. Several allocation mechanisms, such as max-min fairness, proportional fairness and static priority based allocation have been studied [3].

Resource allocation in wireless networks has been a key issue dealt with considerable depth in the literature [4]– [9]. In Abdel Karim et al [4]have presented the analytical study results of resource allocation for a number of video streams. Also, a simple ARIMA model (SAM) has been suggested to represent video generators for WiMAX networks. Sarabjot Singh et al [5]have proposed a joint Call Admission Control (CAC) and Bandwidth Allocation (BA) for an IEEE 802.16 based WiMAX system. The presented schemes aim to provide QoS support along with a fair resource allocation algorithm for nrtPS traffic. Two strategies for CAC namely Conservative and Non-Conservative have been proposed. Conservative CAC guarantees the QoS requirements for all classes of traffic but is more restrictive and less efficient than the Non-Conservative CAC.

P. Satish Kumar et al [6]have presented a resource allocation method that maximizes the argotic weighted-sum rate of a multiuser Mobile WiMAX while satisfying user's specific minimum rate demand and system fairness requirement for a given power budget. Though this is originally a nonlinear optimization problem, the problem can be reformulated as a Lagrangian dual problem. From this, a method has been proposed to efficiently solve the problemof resource allocation. Ravi Kokku et al [7]have presented that channel variations that are induced by user activity should be separated from those induced by network deployments and accounted-for differently by a MAC scheduler to be beneficial to both users and network operators.

LiminPeng et al [8]have addressed the problem of resource allocation with the goal of providing fairness access to wireless channel for all the nodes as well as high network throughput in IEEE 802.16 mesh networks. Node’s unsatisfactory index and throughput function is first defined. Further, a multi-objective programming formulation is proposed for optimizing network performance. Accordingly, a dynamic programming based resource allocation and scheduling algorithm is presented to provide an optimal resource allocation to achieve fairness among different nodes as well as high network throughput in IEEE 802.16 mesh networks. Anderson Rissato et al [9]have proposed a QoS control approach to guarantee the quality level of sessions crossing Worldwide Interoperability for Microwave Access (WiMAX) systems, independently of the QoS model or bandwidth capacity supported by neighbor networks. The proposed scheme is based on the coordination of resource allocation, QoS mapping and adaptation mechanisms, which allow the dynamic quality level control of sessions over heterogeneous environments.

In this paper, we propose a utility based resource allocation mechanism for WiMAX radio access networks based on the

IEEE 802.16e, with dynamic weight adjustment that takes into account varying traffic load conditions. We model the resource allocation problem as a variant of fractional knapsack. The proposed dynamic weight assignment mechanism allocates bandwidthby taking into account

- Traffic load in each traffic class and
- Priority of traffic class.

We compare the performance of the proposed scheme with that of other well-known allocation strategies [3].Results show that when higher priority traffic load increases, average throughput is enhanced by 16 % and mean delay reduced by about 33%.When lower priority load increases, averagethroughput increases by 10% and the mean delay decreases by 16%.

The rest of the paper is organized as follows. Section 2 provides an overview of IEEE 802.16 MAC protocol. The system model is presented in Section 3. Section 4 presents the utility based resource allocation with dynamic weight assignment mechanism.Section 5 presents the results andconclusions are drawn in Section 6.

## 2. OVERVIEW OF IEEE 802.16e MAC

The IEEE 802.16e radio access network consists of the subscriber stations (SS) and the base station (BS). The system typically uses orthogonal frequency division duplexing (OFDMA) with time division duplexing (TDD). The medium access control (MAC) frame consists of the uplink and downlink sub-frames. The duration of these sub-frames is dynamically determined by the BS. Each sub-frame consists of several slots for data transmission. The allocation information for each SS (i.e., slots and sub-carriers assigned to each SS) is contained in the DL-MAP and UL-MAP messages in the downlink sub-frame. The MAC protocols are connection oriented and employ strict admission control. To establish a new connection, SS sends a connection request message, DSA-REQ, containing traffic type and QoS specifications. The connection is accepted and bandwidth is allocated if there are sufficient resources are available. Bandwidth allocation is performed by the BS throughappropriate scheduling mechanisms. The allocation of bandwidth by the BS can be based on grant per subscriber station (GPSS) or grant per connection (GPC) mode. In GPSS mode,the SS obtains aggregate bandwidth for all of its individual flow and in turn reallocates the bandwidth to each individual flow. In GPC mode, the bandwidth allocation is made on per flow basis.

The IEEE 802.16 defines the following traffic flow types that should be treated appropriately by the MAC protocol.

1) Unsolicited Grant Service (UGS): Real-time traffic that generates fixed-size data packets on a periodic basis such as ATM frame relay and constant bit rate (CBR) VoIP fall in this category. These applications require fixed bandwidth allocation.
2) Real-time polling service (rtPS): This category includes real-time traffic flows that generate variable size data packets on a periodic basis, such as variable bit rate (VBR) VoIP and MPEG video. These applications have specific bandwidth requirements as well as constraints on the maximum delay that can be tolerated.
3) Non-real time polling service (nrtPS): nrtPStraffics include non-real time traffic flows that require variable size bandwidth grants on a regular basis, such as FTP and HTTP. These applications are insensitive to delay and require minimum bandwidth allocation.
4) Best effort (BE): BE traffic flows such as e-mail typically do not have strict requirements.

The rtPS, nrtPS and BE traffic flows have varying bandwidth requirements and hence bandwidth assignment for these traffic classes is performed dynamically. Since UGS is allocated fixed and reserved bandwidth, it does not require dynamic reassignment of bandwidth.

## 3. SYSTEM MODEL

A system consisting of single BS and n SSs is considered. The system model is presented in Figure 1. Each SS is associated with *N*queues,each corresponding to the different traffic types for which resources have to be allocated dynamically. Each SS sends a DSA-REQ message containing the required QoS for the traffic class. The BS checks if the required QoS can be supported and sends an appropriate DSA-RSP message indicating the allocated resources. The BS assigns bandwidth to each connectionof the GPC SS or aggregate bandwidth to the GPSS SS, which in turn re-allocates the bandwidth to the traffic flows incident on it.

The following assumptions are made in our analysis.

- There are N traffic classes in the system that request bandwidth
- The $j^{th}$ class requires a bandwidth $b_j$.
- Total available bandwidth in the system is $BW_T$.
- Each traffic class is associated with weight $w_i$, $i = 1,2,..,N$

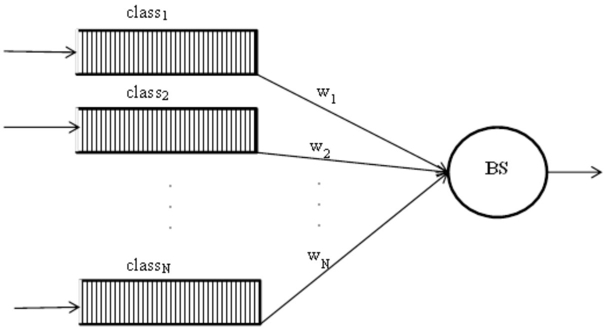

**Figure 1 : System model**

## 4. DYNAMIC BANDWIDTH ALLOCATION

In this section, we formulate the utility based resource allocation problem and present the dynamic weight assignment mechanism to provide fairness among the competing traffic classes.

### 4.1 Utility based resource allocation

According tothe theory of micro economics [18], utility indicates user satisfaction.For network applications user satisfaction is usually a monotonically increasing concave function of bandwidth allocated [11]. The optimal means to formulate utility functions is through extensive subjective surveys, in which users are asked to judge the performance under a wide range of network conditions. A detailed description of such subjective studies can be obtained in [12]. From the study in [12], it was found that logarithmic curves trace the actual survey results most closely.

Here, we consider logarithmic utility function, since it is often used to represent elastic traffic [11],[12]. The utility function for the j^th^traffic classis

$$U_j(x_j) = w_j\, log\left(\frac{x_j}{b_j}+1\right) \; where\; x_j \in [0, b_j], \tag{1}$$

where $w_j$, is a dynamic weight assigned to each traffic class to ensure fairness. This weight changes according to traffic load conditions of the traffic class to which flow *i* belongs to and the QoS requirement of traffic class as will be explainedin detail inSection 4.2.

Since, the objective is to maximize the overall system utility; the resource allocation problem can be formulated as the following optimization problem [17],

$$max\left(\sum_{j=1}^{N} w_j\, log\left(\frac{x_j}{b_j}+1\right)\right) \tag{2}$$

subject to the constraints

$$\sum_{j=1}^{N} x_j \le BW_T \tag{3}$$

$$x_j \in [0, b_j] \tag{4}$$

where$BW_T$ represents the total bandwidth available and N indicates the number of traffic classes.

We formulate the above optimization problem as a variant of fractional knapsack. The fractional knapsack problem can be stated as follows[19]. There are *n* items available. For *i = 1,2,...,n*, item *i* has a weight $g_i > 0$ and worth $v_i > 0$. Let $x_i$ represent the fraction of each item selected.Item *i* contributes to value $x_i v_i$ and weight $x_i g_i$. The objective is to fill the knapsack with selected items such that the value is maximized and weight does not exceed the capacity G of knapsack, i.e., solve the optimization problem,

$$max \sum_{i=1}^{n} x_i v_i \tag{5}$$

subject to

$$\sum_{i=1}^{n} x_i g_i \le G \tag{6}$$

In the resource allocation problem, $b_i$, corresponds to weight of the fraction knapsack problem, $x_i$, corresponds to fraction of item selected. $x_i = b_i$implies that traffic class$_i$is allocated all the requested resource and when $x_i < b_i$ , only a fraction of the requested resource is allocated.In traditional fractional knapsack problems, values and weights are independent. Hence, we consider the values per unit weight to select the items. For bandwidth allocation problem considered here the value depends on the weight. The corresponding measure is the derivative of the value with respect to weight, i.e., $v_i = \frac{\partial U_j}{\partial x_j} = \frac{w_i}{x_i + b_i}$.

**Theorem 1**: The optimal solution should satisfy the relation$x_i = b_i \;\forall\; i \;or\; \sum_{i=1}^{n} x_i = BW_T$.

**Proof:**

Consider a feasible solution, $\tilde{x} = \{\tilde{x}_1, \tilde{x}_2, \ldots, \tilde{x}_n\}$ such that $\sum_{i=1}^{n} \tilde{x}_i < BW_T \;\forall\; i$and$x_j < b_j \; for\; some\; j$. Let $\varphi \triangleq BW_T - \sum_{i=1}^{n} \tilde{x}_i$. Note that $\varphi > 0$. Consider a new solution $x^* = \{x_1^*, x_2^*, \ldots, x_n^*\}$ such that $x_i^* = \min\left(b_i, \tilde{x}_i + \frac{\varphi}{n}\right) \;\forall\; i$. Note that $\sum_{i=1}^{n} x_i^* = BW_T$or $x_i^* = b_i, \forall\, i$.Also note that$x_i^* > \tilde{x}_i, \forall\, i$. Since utility function in (1) is an increasing function,

$$\sum_{i=1}^{n} w_i \log\left(\frac{\tilde{x}_i}{b_i}+1\right) < \sum_{i=1}^{n} w_i \log\left(\frac{x_i^*}{b_i}+1\right) \tag{7}$$

Hence ,$\tilde{x}_i$ is not an optimal solution.

Theorem 1 is applied to develop the algorithm for optimal resource allocation. The algorithm for resource allocation can be stated in Algorithm 1, where *n* is the total number of traffic classes,$v_i$ indicates the value associated with each traffic class. $b_i$ , $x_i$represent the required and allocated bandwidth for traffic class$_i$.Initially $v_i$ *and* $b_i$are sorted in ascending order.

**Algorithm 1:** allocate_resource $(n, v_i, b_i, x_i, BW_T)$

```
1.  for i = 1 to ndo
2.      $x_i = 0$                    /* Initialize solution */
3.  end for
4.  $K = BW_T$.
5.  If$\sum_{i=1}^{n} b_i < K$return$x_i = b_i$     /* No competition */
6.  for i = 1 to ndo                       /* Allocate */
7.      if$b_i > K$then
8.          exit;
9.      end if
10.     $x_i = 1$                    /* Required resource allocated*/
11.     $K = K - b_i$
12. end for
13. if$i < n$then
14.     $x_i = K/b_i$      /*Fractionalresource allocated*/
15. end if
```

Note that Steps 5, 10 and 14 of Algorithm 1 follow from Theorem 1. The complexity of the *for loop* that allocates resource is $O(n)$. Including the time for sort, the complexity of the algorithm is $O(n \log n)$.

## 4.2 Dynamic Weight Assignment

Different traffic classes have varying bandwidth requirement depending on the traffic load.Based on the stringent nature of the QoS requirements, traffic classes are classified into higher and lower priority traffic classes. As observed in Section IV, A, each traffic flow is assigned a weight, $w_i$depending on the type of traffic it belongs to. The weight assigned to different traffic classes should take into account i) QoS requirement and ii) queue length (which depends on load conditions) of the traffic class. If the weights to the different traffic classes are assigned statically, then it could lead to starvation of resources for lower priority traffic classes. As an example, consider the scenario when weights are assigned statically and there is an increase in the lower priority traffic load. Since static weight assignment leads to a larger bandwidth allocation for higher priority traffic. As a result, the queue length of lower priority traffic increases which results in large delay for lower priority traffic classes. It is noted that although lower priority traffic class does not pose any requirement; starvation of resources could result in loss of performance. Static allocation of weights results in loss of fairness among the traffic classes. Hence, it is required to make the weight adaptive with respect to the queue length.

Let $\rho_i$represent the traffic load of traffic class$_i$given by $\rho_i = \frac{\lambda_i}{\mu_i}$ where, $\lambda_i$ is the arrival rate for traffic class$_i$and $\frac{1}{\mu_i}$ is the service time for traffic class$_i$[13]. The following conditions hold

- $0 < \rho_i < 1, \forall\, i = 1,2,\ldots,N$.
- $\sum_{i=1}^{N} \rho_i < 1$
- $\sum_{i=1}^{N} w_i = 1$
- class$_1$has the highest priority followed by class$_2$, …, class$_N$.

The first two conditions ensure stability of the queues and the last condition is a normalization condition. In order to account for the relationship between weight and traffic load, we introduce a term, sensitivity, which represents the change in weight of a given traffic class with respect to change in load of other traffic classes.

Let $\alpha$ be the sensitivity of class$_i$ to the variations in the traffic load of classes with higher priority compared to $i$. Note that$\alpha \in (0, \infty)$. $\alpha \to 1$ indicates no sensitivity and $\alpha \to \infty$ indicates maximum sensitivity.Hence $\alpha \to 1$ when $\sum_{j=1}^{i-1} \rho_j \to 0$ and $\alpha \to \infty$ when $\sum_{j=1}^{i-1} \rho_j \to 1$ . An expression that satisfies the above condition is

$$\alpha_i = \frac{1}{1 - \sum_{j=1}^{i-1} \rho_j} \tag{8}$$

Weights assigned to traffic classes need to satisfy the following properties.

- Weight has to be an increasing function of the corresponding traffic load.
- The weight of lower priority traffic class has to decrease with increase in higher priority traffic load.
- Under equal traffic load conditions, the weight of higher priority class has to be greater than that of lower priority class.
- When lower priority traffic load is greater than higher priority traffic load, higher weight is assigned to the lower priority traffic class. This avoids starvation for the lower priority traffic class and hence ensures fairness.

Based on the properties discussed above, we formulate the weight of a traffic class as

$$w_i = \left(1 - \sum_{j=1}^{i-1} w_j\right) {\rho_i}^{\alpha_i} \tag{9}$$

Further, we normalize the weight assigned as

$$w_{iNorm} = \frac{w_i}{\sum_{i=1}^{N} w_i} \tag{10}$$

such that the relation $\sum_{i=1}^{N} w_{iNorm} = 1$ is satisfied. In the following sections of the paper we represent $w_{iNorm}$ as $w_i$.
The following theorems discuss the behavior of the weight allocation mechanism under different load conditions.

**Theorem 2**: Under equal traffic load conditions weight of higher priority traffic class is greater than lower priority traffic class. $i.e., when\, \rho_1 = \rho_2 = \cdots = \rho_N,\ w_1 > w_2 > \cdots > w_N$

**Proof:** Let $\rho_1 = \rho_2 = \cdots = \rho_N = \rho$. From (9) , we have, $w_{N-1} = \left(1 - \sum_{j=1}^{N-2} w_j\right)\rho^{\alpha_{N-1}}$ ; $w_N = \left(1 - \sum_{j=1}^{N-1} w_j\right)\rho^{\alpha_N}$. From (8), $\alpha_{N-1} < \alpha_N$.Hence, for $\rho < 1$, we have $w_{N-1} > w_N$.

**Remarks:** The above condition enables the mechanism to maintain QoS requirements of the system.

**Theorem 3:** For a higher load of lower priority class, corresponding higher weight is assigned to the traffic class.
i.e., when $\rho_N > \cdots > \rho_2 > \rho_1, w_N > \cdots > w_2 > w_1$.

**Proof :**Let$\rho_N = k\rho_{N-1}$. From (9) we have,

$w_{N-1} = \left(1 - \sum_{j=1}^{N-2} w_j\right)\rho_{N-1}^{\alpha_{N-1}}, w_N = \left(1 - \sum_{j=1}^{N-1} w_j\right)k^{\alpha_N}\rho_{N-1}^{\alpha_N}$.

For $k > 1\ and\ \alpha_N \geq 1\ we\ have\ w_N > w_{N-1}$, since $\alpha_{N-1} < \alpha_N$.

**Remarks:** When lower priority traffic class has higher load compared to higher priority traffic class, correspondingly higher weight is assigned to it. Though a lower weight is assigned to higher priority class, it does not degrade the overall system performance since the bandwidth requirement is comparatively less. This property brings fairness in the proposed weight allocation mechanism.

## 5. RESULTS AND DISCUSSION

To simulate the proposed scheme, network simulator (NS2) [10] is used. The proposed scheme has been implemented over IEEE 802.16 MAC protocol. In the simulation, clients (SS) and the base station (BS) are deployed in a 1000 meter x 1000 meter region for 50 seconds simulation time. All nodes have the same transmission range of 250 meters. There are six uplink traffics from SS to BS. The simulation settings and parameters are summarized inTable 1. VBR traffic represents rtPS, nrtPS traffic class and FTP represents BE traffic class.

**Table 1.Simulation Settings**

| | |
|---|---|
| Area Size | 1000 X 1000 |
| Mac | 802.16 |
| Clients | 10 |
| Radio Range | 250m |
| Simulation Time | 50 sec |
| Routing Protocol | DSDV |
| Traffic Source | VBR, FTP |
| Physical Layer | OFDM |
| Packet Size | 1500 bytes |
| Frame Duration | 0.005 |
| Transmission Rate | 250Kb,500Kb,750Kb, 1000Kb |
| No. of Flows | 1,2,3,4,5,6 |

Figure 2shows a comparison of mean delay for increase in VBR traffic load. It is observed that as traffic load increases, there is increase in mean delay. The rate of increase is minimal with the proposed mechanism. From Figure 2 we observe that for a traffic load of 0.9, mean delay for proposed mechanism is 0.03 ms, 0.13ms for proportional fairness and 0.95 ms for static priority. This implies a decrease in mean delay by 33% compared to proportional fairness mechanism and by two orders of magnitude compared to static priority allocation.

Figure 3shows the mean delay experienced by nrtPS traffic class with increase in nrtPS traffic load. As expected, the mean delay increases as traffic load increases. But, the increase is less pronounced for proposed mechanism because of the dynamic weight assigned to the three traffic classes. nrtPS is assigned a higher weight, which results in an increased resource allocation for this traffic class. As the traffic load increases, the corresponding bandwidth requirement increases. Since, the weight assigned also adapts itself accordingly,rate of increase in mean delay decreases. Since nrtPS traffic class is assigned second priority, these packets suffer additional delay in static priority mechanism.

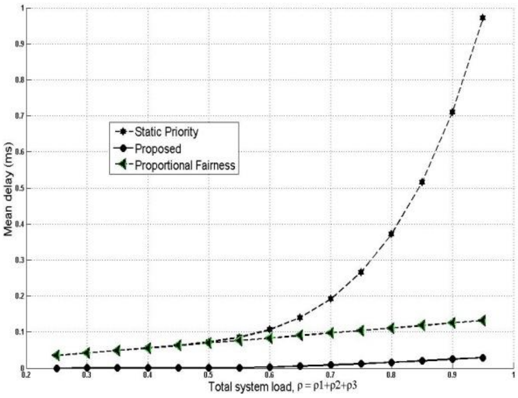

**Figure 2: rtPS mean delay**

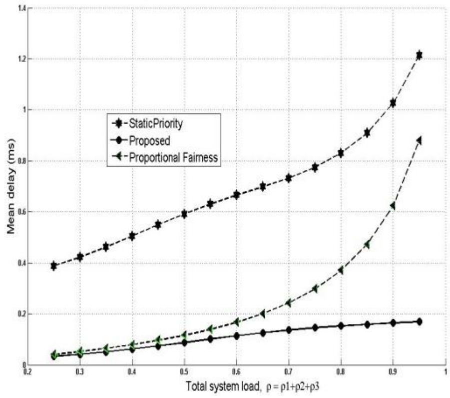

**Figure 3 : nrtPS mean delay**

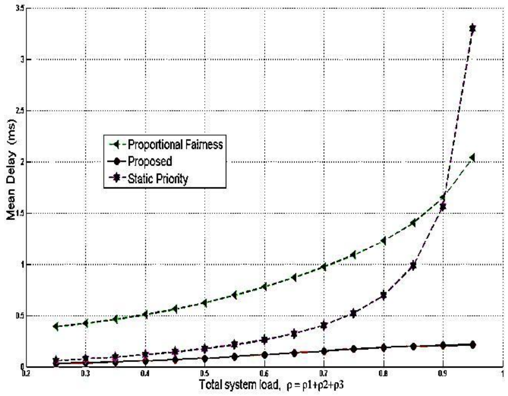

**Figure 4 : BE Mean delay**

Figure 4shows the mean delay of BE traffic class with increase in BE traffic load. For lower traffic loads we find that static priority has lower mean delay compared to proportional fairness mechanism. The reason is proportional fairness mechanism does not take queue length into account for bandwidth allocation. Hence, a portion of the bandwidth allocated to higher priority classes is not fully utilized and lower priority traffic class is not allocated enough resource. Hence, in proportional fairness mechanism wastage of resources occurs at lower loads, whereas resource starvation occurs in static priority mechanism. From the results, we observe that the above problems are considerably eliminated in the proposed mechanism and hence improvement in mean delay is obtained

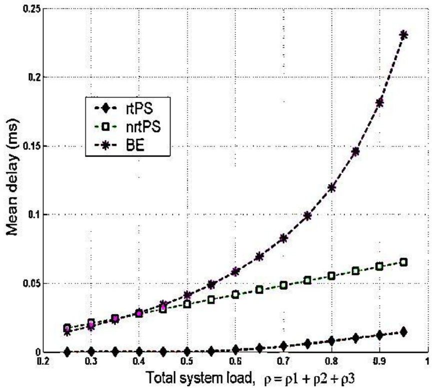

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**Figure 5 : Comparison of mean delay of rtPS, nrtPS and BE**

Figure 5shows the delay curves of rtPS ,nrtPS and BE traffic classes . We find that the proposed mechanism does not affect the performance of higher priority traffic classes even when a higher weight is assigned to lower priority traffic class. Also, the rate of increase in mean delay for higher traffic classes is very much less because of dynamic weight assignment.

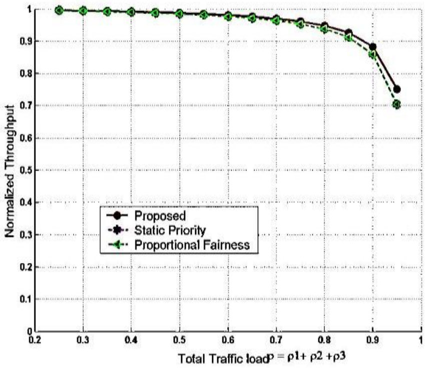

**Figure 6 : rtPS Normalized System Throughput**

In Figure 6, we compare the normalized throughput of rtPS traffic class for the three different mechanisms. We find that the performance of static priority and proportional fairness is almost similar and slight improvement is observed in the proposed mechanism at higher traffic loads. Similar results are observed for nrtPS traffic classes also.

# 6. CONCLUSION

We have proposed a utility based resource allocation mechanism with dynamic weight assignment for fair resource allocation in IEEE 802.16e based WiMAX radio access networks. We formulated a mechanism to dynamically adjust the weights assigned to different traffic classes based on QoS requirement and instantaneous queue length. Performance of the proposed utility based mechanism is compared with static priority, proportional fair allocation mechanisms. It has been observed that the proposed mechanism enhances the aggregate system utility, decreases mean delay and increases throughput.

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