PERFORMANCE EVALUATION OF SCHEDULING SCHEMES FOR FIXED BROADBAND WIRELESS ACCESS SYSTEMS

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Abstract -The IEEE 802.16 broadband wireless access system (BWA) offers the advantage of fast deployment and cost-effective solution to the last-mile wireless connection problem. For mass adoption and large scale deployment of BWA system, it must support Quality of Service (QoS) for real-time and high bandwidth applications. The IEEE 802.16 standard defines the QoS signaling framework and various types of service flows, but the actual QoS mechanisms such as packet scheduling algorithms for these service flows are unspecified in the standard. We evaluate the performance of the various packet scheduling algorithms and also propose an efficient scheduling algorithm based on the transmission opportunity given to each station to support QoS in IEEE 802.16 standard. We show that the proposed scheduler provides improved performance in terms of mean delay and average system throughput compared to the other scheduling schemes through extensive simulations.

Keywords -- QoS, Broadband Wireless Access, IEEE 802.16, Packet Scheduling

I. INTRODUCTION

Fixed Broadband Wireless Access (FBWA) System is defined by the IEEE 802.16 standard. FBWA provides network access to buildings through exterior antennas communicating with central radio base stations. The IEEE standard 802.16-2004 specifies the air interface for FBWA systems supporting multimedia services. The MAC supports a point to multipoint architecture with the optional mesh topology. It is structured to support multiple physical layer(PHY) specifications each suited to a particular operational environment. For operating frequencies of 10-66 GHz, the wirelessMAN-SC based on single carrier modulation is specified. For frequencies below 11 GHz, where the propagation without direct line of sight must be accomodated, the wirelessMAN-OFDM (Orthogonal frequency division multiplexing), the wirelessMAN-OFDMA(Orthogonal frequency division multiplexed access and the wirelessMAN-SCa(using single carrier modulation) are employed .

The MAC of the IEEE 802.16 has three sublayers . The service specific convergence sublayer(CS) provides mapping of external data, received through the CS service access point(SAP), into MAC SDUs received by the MAC Common Part Sublayer(MAC CPS) through the MAC SAP. This includes classifying external network Service Data Units(SDUs) and associating them to the proper MAC service flow and connection identifier(CID). It may also include functions such as payload header suppression. Multiple CS specifications are provided for interfacing with various protocols. The MAC CPS provides the core MAC functionality of system access, bandwidth allocation, connection establishment and maintenance. It receives data from the various CSs, through the MAC SAP and classifies to particular MAC connections. The IEEE 802.16 standard defines the QoS signaling framework and various types of service flows, but the actual QoS mechanisms such as packet scheduling algorithms for these service flows are unspecified in the standard.

A pinwheel approach for the real time scheduling problem has been studied in [2]. Performance evaluations of IEEE 802.16 MAC protocol over various physical layers have been studied in [3]. The multimedia performance of IEEE 802.16 using two types of traffic namely Ethernet packet traffic and constant bit rate traffic, has been evaluated in [4]. The authors assume that traffic arrivals follow a Poisson distribution in [4]. An architecture to support QoS mechanisms for the IEEE 802.16 standard was developed and a weighted fair queueing (WFQ) algorithm was used for evaluation in [5]. The architecture in [5] for subscriber station includes shaper and policer, four different queues, uplink service flow data base, grant allocator, request generator and upstream generator and for the BS includes shaper and policer, four different queues, an uplink scheduler and a downlink scheduler

In this paper, we evaluate the IEEE 802.16 MAC protocol performance under different scheduling schemes, namely First in First out (FIFO), Earliest Due Date (EDD), Preemptive Earliest Due Date (PEDD) on the uplink, grant allocator and Round Robin (RR) scheduler on the downlink. A modified scheduling algorithm namely TXOP based scheduler for the IEEE 802.16 system on the uplink and the downlink has also been proposed and the performance has been evaluated.

The rest of the paper is organized as follows, Section II provides an overview of the QoS related features of the IEEE 802.16 standard. The various scheduling schemes used in performance evaluation are discussed in Section III. Section IV provides necessary simulation setup developed for performance evaluation. Section V provides results and discussion. Finally we finish up with the conclusions drawn and future work that can be carried out in Section VI.

II QoS FEATURES OF IEEE 802.16

The IEEE 802.16 standard for fixed BWA systems supports metropolitan area network architecture. It assumes a point-to-multipoint topology with a base station (BS) and several Subscriber Stations (SSs). BS controls and manages the entire system and SSs perform as interface between end users and the BS. This standard defines a connection-oriented MAC protocol that supports multiple physical layer specifications. The physical layer air interface is optimized for bands from 10 to 66 GHz. The downlink channel on which data flow is directed from BS to SSs uses TDM scheme and the uplink channel in opposite direction applies TDMA scheme [6]. The IEEE 802.16 standard defines four types of service flows, each with different QoS requirements as given below [1]

- Unsolicited Grant Service (UGS): The UGS is designed to support real-time service flows that generate fixed size data packets on a periodic basis, such as T1, E1 and Voice over IP without silence suppression. This service receives fixed size unsolicited data grants (transmission opportunities) on a periodic basis. Therefore, it eliminates the overhead and latency of requiring the SS to send requests for data grant.
- Real Time Polling Service (rtPS): The rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as MPEG video. This service offers periodic unicast request opportunities, which meet the flows real-time needs.
- Non-Real Time Polling Service (nrtPS): This service is introduced for non-real-time flows which require variable size data grants on a regular basis, such as high bandwidth FTP. This service offers unicast polls on a periodic basis, but using more spaced intervals than rtPS. This ensures that the flow receives request opportunities even during network congestion.
- Best Effort Service (BE): This service is for best effort traffic such as HTTP. There is no QoS guarantee.

The IEEE 802.16 standard defines several ways for SSs to request bandwidth, combining the determinism of unicast polling with the responsiveness of contention-based requests and the efficiency of unsolicited bandwidth. The BS is allowed to allocate bandwidth in the following two modes;
(i) Grant Per Connection (GPC), in which bandwidth is assigned to each connection, and (ii) Grant Per Subscriber Station (GPSS), in which an SS requests for transmission opportunities for all of its connections and re-distributes the bandwidth among them. The latter is more suitable when there exists many connections per terminal and it is mandatory for systems using the 10-66 GHz PHY specification [1],[2].

III SCHEDULING SCHEMES

Scheduler is used to schedule the incoming traffic to its destination depending upon the QoS requirements of the service and the resource available. Scheduler should be designed to meet QoS requirements such as throughput, latency, delay-jitter, packet loss ratio of each service and to efficiently utilize the BW and avoid starvation of low priority service. Proper design of scheduler is important to maintain the QoS requirements of the service. Schedulers such as First in First out (FIFO), Earliest Due Date (EDD), preemptive Earliest Due Date (PEDD), Round Robin (RR) schedulers and TXOP based scheduler are considered for the analysis purpose. BS downlink scheduler and SS uplink scheduler use FIFO, EDD, PEDD and TXOP based scheduler. RR and TXOP based scheduler (with slight modification from BS downlink scheduler) are used in the BS uplink scheduler modules.

- First in First out (FIFO) scheduler is one of the simplest scheduling algorithms. In the FIFO scheme, packets are served in the order in which they arrive. FIFO does not protect well behaved sources against ill-behaved ones. A single source sending packets at a sufficiently high speed can capture a high fraction of the bandwidth of the outgoing line.
- Earliest Due Date (EDD) scheduler serves the packets in the order of the deadline set for each packet. EDD scheduler provides the delay and the throughput guarantees under the light loading condition. It provides fair treatment to all services.

- Preemptive Earliest Due Date (PEDD) scheduler works similar to the EDD, but the difference is that when BW available is not enough for a service, the scheduler checks for other services which fit the remaining BW and allocates. In this case, the waiting time decreases and the throughput increases for the low BW service compared to EDD scheduler.
- Round Robin (RR) scheduler provides fair treatment to all types of services and it is a type of preemptive scheduler. All the SSs are served in round robin manner. In case an SS does not need BW then, next SS is provided the opportunity.
- In the TXOP Based Scheduler, BW allocation is made considering the tolerable delay limits of each service. Design procedures for the scheduler used at BS downlink and uplink are discussed below.

III A) BS DOWNLINK SCHEDULER

TXOP based scheduler operates on the basis of number of packets to be transmitted by each service under strict scheduling. The BW allocated for different services is calculated depending upon delay and packet size. Maximum number of transmission opportunities (TXOPs) per service (Ai) is calculated as follows,

$$A_i = \frac{\sum_{j=1}^{3} \frac{T_j}{u_j}}{\frac{T_i}{u_i}}$$

where, Ti represents packet tolerable delay limits of service i and u_i represents packet holding time of the service i.

Once the maximum number of transmission opportunities per service Ai is calculated, the same numbers of packets are scheduled per service and repeated in a cyclic order. Unused slots dedicated for a service are utilized by other services in demand.

III B) BS UPLINK SCHEDULER

Amount of BW share per SS per service is calculated as follows.

$$BWS_{ij} = \frac{BWR_{ij}}{\sum_{l=1}^{n} BWR_{ij}}$$

where BWRij represents BW requirement for i th station j th service type made at the BS. Number of transmission opportunities (TXOPs) per SS per connection TA_{ij} is given by

$$TA_{ij} = \begin{cases} BWS_{ij} * 10 & \text{, if } BWS_{ij} * 10 * \text{packet size} <= BWR_{ij} \\ BWR_{ij} & \text{, if } BWS_{ij} * 10 * \text{packet size} > BWR_{ij} \\ 1 & \text{, if } 0 < BWS_{ij} <= 1 \end{cases}$$

Once TA_{ij} is calculated for the current BW requirement of the SSs and it is allocated in the subsequent frames to the requested SSs. TA_{ij} is recalculated after the previously calculated allocations are granted. Ai is taken as the limiting value for the maximum number of transmission opportunities to be granted per service per cycle.

IV SYSTEM MODEL

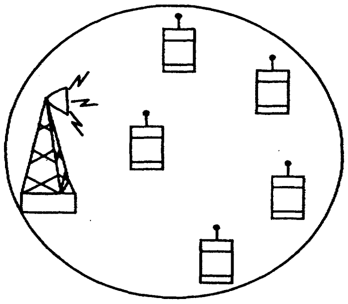

Figure 1. System Model

The performance of the scheduling schemes, applied to the IEEE 802.16 both on the uplink and on the downlink is evaluated through extensive simulations. A system consisting of one base station and five subscriber stations as shown in Figure 1 is considered. The positions of the subscriber stations are assumed to be independent and identically distributed. QoS architecture for the BS and the SS are considered as in [6]. Each SS and BS is assumed to have four types of services, namely the UGS, rtPS, nrtPS and BE. There are a total of four queues per SS and a single server to process packets arriving at different queues. Scheduling is done both at the BS and SS.

Traffic model considered is shown in Table 1. The following assumptions are made for the evaluation.

- SSs and BS are assumed to have four types of service.
- Call arrivals follow Poisson distribution and inter arrival times are exponentially distributed.

- Infinite size queues with the different waiting time threshold for the different traffic types are assumed.
- Upstream and downstream traffic are assumed to be similar.
- Self correcting nature of request/grant protocol requires that SSs shall periodically use aggregate bandwidth request.
- Aggregate bandwidth request interval is 40ms and incremental request is through piggybacking.

Service	Arrival Rate (Kbps)	Latency (ms)	Packet size (bytes)	Packet Interval (ms)	Traffic Load (Mbps)
UGS (eg.Voice)	64	20	160	20	1
rtPS (eg.Video)	64 640 1500	50	240	2.6	12
nrtPS (eg.Audio)	320	100	120	3	2-14
BE (eg.Email)	192	400	120	5	2-14

Table 1. Traffic Model

Simulation model considered are as shown in Table 2. Latency assumed is within the limits as defined in [7] Traffic load assumed as in [5] for the purpose of comparison. Performance evaluation is done considering two scenarios. (1) Assuming all SS with equal priority and. (2) Randomly selected two SS having increased rate of high priority traffic. The average system throughput, mean delay and link utilization are taken as the metrics for the evaluation of scheduler performance.

V. RESULTS AND DISCUSSION

Figure 2, Figure 3 and Figure 4 present the Average system throughput plot as function of the traffic load for the rtPS, nrtPS and BE services respectively.

Cell Radius	1 Km
Duplexing Schemes	TDD
Ratio of uplink slot to downlink in TDD	50%
Number of slots per frame	5000
Number of subscriber station	5
Downstream data transmission rate	20 Mbps
Aggregate upstream data transmission rate	20 Mbps
Initial backoff parameter	3 (window size = 8)
Maximum backoff parameter	10(window size = 1024)
Length of simulation run	10 seconds

Table 2 Simulation Model

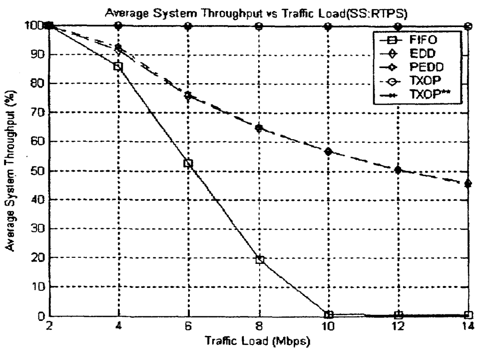

Figure 2. (rtPS) Average System Throughput vs Traffic Load (Scenario 1)

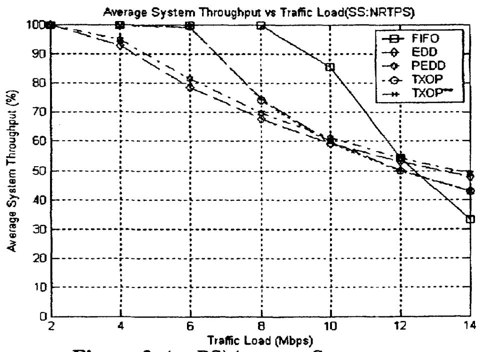

Figure 3. (nrtPS)Average System Throughput vs Traffic Load (Scenario 1)

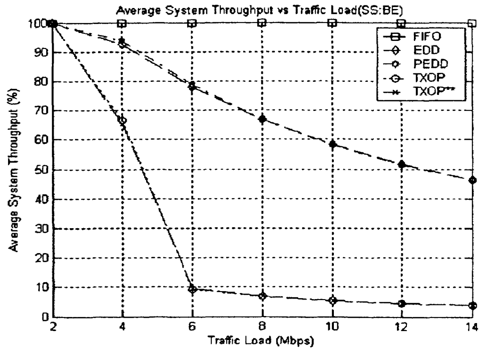

Figure 4. (BE)Average System Throughpput vs Traffic Load (Scenario 1)

From Figure. 2, it is observed that the FIFO scheduler's average system throughput decreases, because as the load increases waiting time increases. Since rtPS has minimum waiting time (20ms), average system throughput decreases with increase in load. For EDD and PEDD schedulers average system throughput decreases as the load increases, because scheduling is based on min (maximum wait time – delay suffered) i.e. due date. Therefore the average system throughput is proportional to the percentage of load contributed by the rtPS service to the system. TXOP scheduler's rtPS

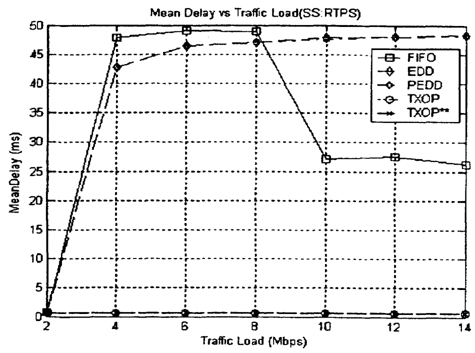

Figure 5. (rtPS) Mean Delay vs Traffic Load (Scenario 1)

average system throughput is maintained at 100% at all loading conditions, because transmission opportunity provided is inversely proportional to the waiting time threshold ratio, therefore the rtPS that has minimum waiting time limit (20ms) obtains maximum transmission opportunity. The above stated reasons hold good for the Figures 3 and 4 which is the average system throughput plot of BE and nrtPS respectively.

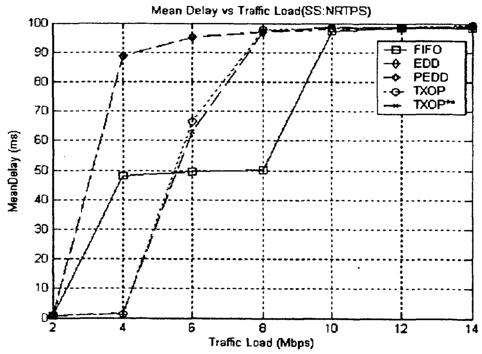

Figure 6. (nrtPS)Mean Delay vs Traffic Load (Scenario 1)

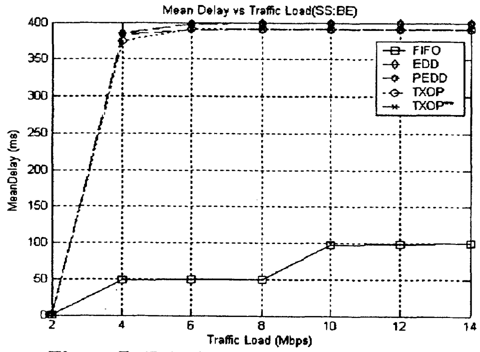

Figure 7. (BE)Mean Delay vs Traffic Load (Scenario 1)

Figures 5, 6 and 7 present the mean delay plot as function of the traffic load for the rtPS, nrtPS and BE services respectively. From Figure 5, it is observed that the FIFO scheduler's mean delay initially reaches waiting time limit and later decreases, because for loads <8Mbps, this service contributes >43% of total load, obtains maximum transmission opportunity and hence mean delay is near to waiting time limit. For loads >8Mbps, this service contributes <43% of total load, obtains lesser transmission opportunity and hence mean delay decreases. For EDD and PEDD schedulers the mean delay rises to waiting time limit, because as load increases, waiting time increases and hence transmission opportunity is provided to the call nearer to the waiting time threshold. TXOP scheduler has minimum mean delay, because it obtains maximum transmission opportunity which is inversely proportional to the waiting time limit (rtPS has 20ms). It is observed that the mean delay increases as the load increases for nrtPS and BE services from Figure.6 and Figure.7 respectively.

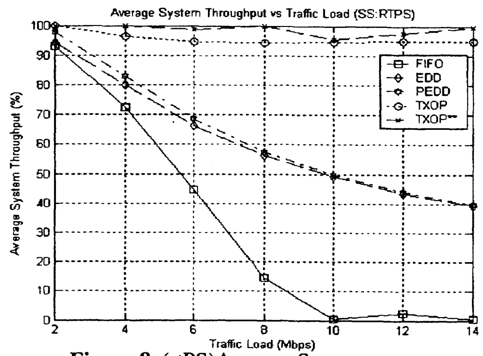

Figure 8. (rtPS)Average System Throughput vs Traffic Load (Scenario 2)

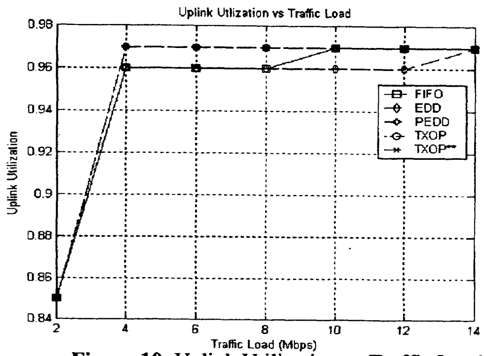

Figure 10. Uplink Utilization vs Traffic Load

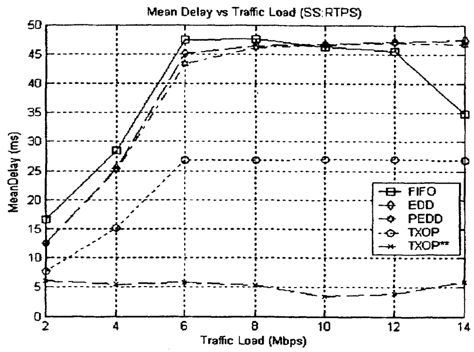

Figure 9. (rtPS)Mean Delay vs Traffic Load (Scenario 2)

Figure 8 and Figure 9 show the plots of rtPS average system throughput and mean delay as function of traffic load for scenario 2. From Figure 8 it is observed that the average system throughput performance of EDD, PEDD and FIFO schedulers remain the same. TXOP scheduler performance degrades compared to Figure. 2, because Round Robin scheduler in the BS uplink does not have the mechanism to differentiate high priority SSs. TXOP** scheduler performance almost similar to Figure. 2, because TXOP scheduler in the BS uplink provides grants according to the proportional BW requirement of SSs. From Figure. 9, it is observed that there is a shift in mean delay initially compared to Figure 5, because of increase traffic flow of rtPS traffic flow rate. It is been observed that EDD, PEDD and FIFO scheduler performance remains almost similar to Figure. 5. RR scheduler treats all SSs equally hence mean delay increases and settles around 27ms. TXOP** scheduler has minimum mean delay (5ms) since it has mechanism to differentiate at the BS uplink scheduler among SSs traffic priorities.

Fig. 10 presents uplink utilization as function of traffic load. It is observed that the performance of TXOP and TXOP** scheduler is better up to 10Mbps load and later the utilization of all schedulers are similar, because TXOP and TXOP** scheduler operation is based on the QoS requirement for delay. Most of the results obtained are not presented here due to space constraints, though we have presented and discussed the important results.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, performance of the various schedulers were evaluated for the fixed broadband wireless access systems using IEEE 802.16 standard. In has been observed that the FIFO scheduling algorithm provides high throughput and minimum delay depending upon demand and delay threshold. EDD and PEDD scheduling algorithms provide fairness in proportion to the percentage of load contributed by the class of service. RR scheduling (BS uplink scheduler) algorithm performance is better under scenario 1, but its performance is degraded under scenario 2. TXOP scheduler performance is better for the delay critical and high BW services (i.e. rtPS) and certain amount of fairness has been provided for the other services (i.e. nrtPS and BE). TXOP** scheduling algorithm performance is similar and better under both the scenarios compared to all other scheduling algorithm considered.

Understanding the IEEE 802.16 MAC protocol behavior for the various QoS mechanisms defined, different queuing algorithms and different types of services is important. Modeling the system will provide the complete behavior of the system. System can be modeled using multi dimensional Markov chain. Another interesting modeling technique is the Game Theory approach.

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