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Bandwidth Optimization, Recycling In IEEE 802.16 Networks by Using Call Admission Control & Scheduler

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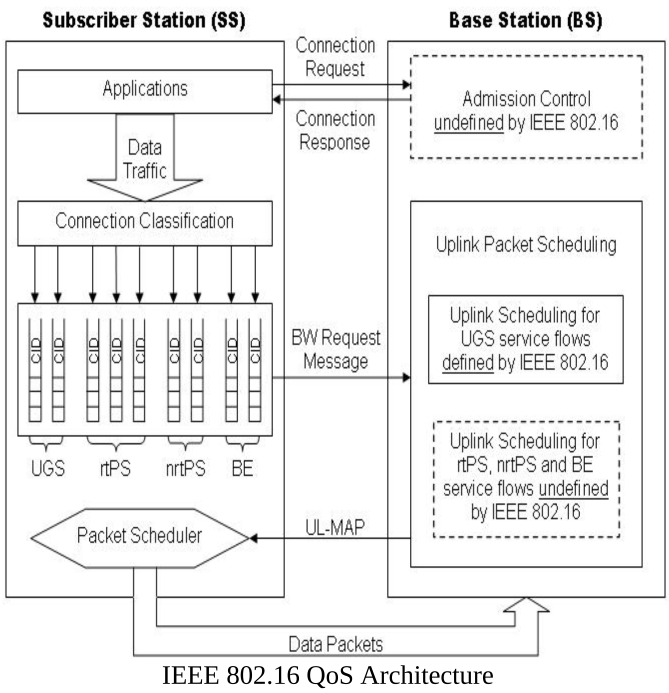
Abstract-**The IEEE 802.16 Working Group and was designed to support the bandwidth demanding applications with quality of service (QoS). Bandwidth is reserved for each application to ensure the QoS. For variable bit rate (VBR) applications, however, it is difficult for the subscriber station (SS) to predict the amount of incoming data. It is developing a standard for broadband wireless access in Metropolitan Area Networks (MAN) known as WiMAX. One of the features of the MAC layer, in this standard, is that it is designed to provide differentiated servicing for traffic with multimedia requirements. To ensure the QoS guaranteed services, the SS may reserve more bandwidth than its demand. As a result, the reserved bandwidth may not be fully utilized all the time. Based on these assumptions, and considering that the standard previous work specify a priority based scheduling algorithm, a new scheduler with call admission control was proposed based on Latency-Rate (LR) server theory and with system characteristics as specified by the system standard using the Wireless MAN-OFDM (Orthogonal Frequency Division Multiplexing) air interface. The proposed scheduling algorithm calculates the time frame (TF) in order to maximize the number of stations allocated in the system while managing the delay required for each user and is to allow other SS to utilize the unused bandwidth when it is available. Properties of this proposal have been investigated theoretically and through simulations. A set of simulations is presented with both Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic, and performance comparisons are made between cases with different delays and different TFs. The results show that an upper bound on the delay can be achieved for a large range of network loads, with bandwidth optimization and recycling of unused bandwidth on average.**

Keywords— **IEEE 802.16, scheduling algorithm; delay bound; optimization; Call Admission Control (CAC).**

INTRODUCTION

The IEEE 802.16 standard also known by the name of its vendor interoperability organization, WiMAX. The PHY and MAC layers of 802.16 are described in detail with regards to their QoS aspects. And the relations and interactions of these QoS mechanisms are described to give an understanding of how QoS can be achieved over 802.16. The deployment of high-speed Internet access is often cited as a challenge for the second decade of this century. Known as broadband Internet, it is effective in reducing physical barriers to the transmission of knowledge, as well as transaction costs, and is fundamental in fostering competitiveness. However, wired access to broadband Internet has a very high cost and is sometimes unfeasible, since the investment needed to deploy cabling throughout a region often outweigh the service provider's financial gains. One of the possible solutions in reducing the costs of deploying broadband access in areas where such infrastructure is not present is to use wireless technologies, which require no cabling and reduce both implementation time and cost. This was one of the motivations behind the development by the IEEE (Institute of Electrical and Electronics Engineers) of a new standard for wireless access, called 802.16, also known as Worldwide Interoperability for Microwave Access (WiMAX). It is an emerging technology for next generation wireless networks which supports a large number of users, both mobile and nomadic (fixed), distributed across a wide geographic area. Motivated by the growing need for ubiquitous high-speed access, wireless technology is an option to provide a cost-effective solution that may be deployed quickly and easily, providing high bandwidth connectivity in the last mile.



IEEE 802.16 QoS Architecture

However, despite the many advantages of wireless access networks, such as low deployment and maintenance costs, ease of configuration and device mobility, there are challenges that must be overcome in order to further advance the widespread use of this type of network. To achieve this purpose, the IEEE 802.16 standard introduces of a set of mechanisms, such as service classes and several coding and modulation schemes that adapt themselves according to channel conditions. However, the standard leaves open certain issues related to network resource management and scheduling algorithms.

QoS Service Class	Description
Unsolicited Grant Service (UGS)	Supports CBR services, such as T1/E1 emulation and VoIP without silence suppression
Real-Time Polling Service (rtPS)	Supports real-time services with variable size data on a periodic basis, such as MPEG and VoIP with silence suppression
Non-Real-Time Polling Service (nrtPS)	Supports non-real-time services that require variable size data grant bursts on a regular basis, such as FTP
Best Effort (BE)	For applications that do not require QoS, such as web surfing

IEEE 802.16 QoS Service Classes

This paper presents a new scheduler with admission control of connections to a WiMAX Base Station (BS). We developed an analytical model based on Latency-Rate (LR) server theory [3], from which an ideal frame size, called Time Frame (TF), was estimated, with guaranteed delays for each user. At the same time, the number of stations allocated in the system is maximized. In this procedure, framing overhead generated by the MAC (Medium Access Control) and PHY (Physical) layers was considered when calculating the duration of each time slot. After developing this model, a set of simulations is presented for constant bit rate (CBR) and variable bit rate (VBR) streams, with performance comparisons between situations with different delays and different TFs and accurately identify the portion of unused bandwidth and provides a method to recycle the unused bandwidth. It can improve the utilization of bandwidth while keeping the same QoS guaranteed services and introducing no extra delay. The Worldwide Interoperability for Microwave Access(WiMAX), based on IEEE 802.16 standard standards [1] [2], is designed to facilitate services with high transmission rates for data and multimedia applications in metropolitan areas. The physical (PHY) and medium access control (MAC) layers of WiMAX have been specified in the IEEE 802.16 standard. Many advanced communication technologies such as Orthogonal Frequency- Division Multiple Access (OFDMA) and multiple-input and multiple-output (MIMO) are embraced in the standards. Supported by these modern technologies,WiMAX is able to provide a large service coverage, high data rates and QoS guaranteed services. Because of these features, WiMAX is considered as a promising alternative for last mile broadband wireless access (BWA). In order to provide QoS guaranteed services, the subscriber station (SS) is required to reserve the necessary bandwidth from the base station (BS) before any data transmissions. In order to serve variable bit rate (VBR) applications, the SS tends to keep the reserved bandwidth to maintain the QoS guaranteed services. Thus, the amount of reserved bandwidth transmitted data may be more than the amount of transmitted data and may not be fully utilized all the time. Although the amount of reserved bandwidth is adjustable via making bandwidth requests (BRs), the adjusted bandwidth is applied as early as to the next coming frame. The unused bandwidth in the current frame has no chance to be utilized. Moreover, it is very challenging to adjust the amount of reserved bandwidth precisely. The SS may be exposed to the risk of degrading the QoS requirements of applications due to the insufficient amount of reserved bandwidth. To improve the bandwidth utilization while maintaining the same QoS guaranteed services, our research objective is twofold: 1) the existing bandwidth reservation is not changed to maintain the same QoS guaranteed services. 2) our research work focuses on increasing the bandwidth utilization by utilizing the unused bandwidth. We propose a scheme, named *Bandwidth Recycling*, which recycles the unused bandwidth while keeping the same QoS guaranteed services without introducing extra delay. The general concept behind our scheme is to allow other SSs to utilize the unused bandwidth left by the current transmitting SS. Since the unused bandwidth is not supposed to occur regularly, our scheme allows SSs with non-real time applications, which have more flexibility of delay requirements, to recycle the unused bandwidth. Consequently, the unused bandwidth in the *current* frame can be utilized. It is different from the bandwidth adjustment in which the adjusted bandwidth is enforced as early as in the next coming frame. Moreover, the unused bandwidth is likely to be released temporarily (i.e., only in the current frame) and the existing bandwidth reservation does not change. Therefore, our scheme improves the overall throughput while providing the same QoS guaranteed services.

According to the IEEE 802.16 standard, SSs scheduled on the uplink (UL) map should have transmission opportunities in the current frame. Those SSs are called transmission SSs (TSs) in this paper. The main idea of the proposed scheme is to allow the BS to schedule a backup SS for each TS. The backup SS is assigned to standby for any opportunities to recycle the unused bandwidth of its corresponding TS. We call the backup SS as the complementary station (CS). In the IEEE 802.16 standard BRs are made in per-connection basis. However, the BS allocates bandwidth in per-SS basis. It gives the SS flexibility to allocate the granted bandwidth to each connection locally. Therefore, the unused bandwidth is defined as the granted bandwidth which is still available after serving all connections running on the SS. In our scheme, when a TS has unused bandwidth, it should transmit a message, called releasing message (RM), to inform its corresponding CS to recycle the unused bandwidth. However, because of the variety of geographical distance between TS and CS and the transmission power of the TS, the CS may not receive the RM. In this case, the benefit of our scheme may be reduced. In this research, we investigate the probability that the CS receives a RM successfully.

BACKGROUND WORK

Since the standard only provides signaling mechanisms and no specific scheduling and admission control algorithms, some scheduling algorithms have been proposed to provide QoS (Quality of Service) for WiMAX. However, many of these solutions only address the implementation or addition of a new QoS architecture to the IEEE 802.16 standard. A scheduling algorithm decides the next packet to be served on the waiting list and is one of the mechanisms responsible for distributing bandwidth among several streams. Regarding data traffic, it was observed that the overhead due to the physical transmission of preambles increases with the number of stations. A polling-based MAC protocol is presented along with an analytical model to evaluate its performance. Due to development of closed-form analytical expressions for cases in which stations are polled at the beginning or at the end of uplink sub frames. It is not possible to know how the model may be developed for delay guarantees.

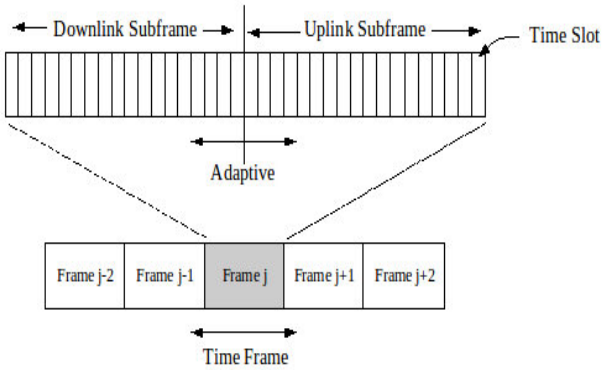


FIG.1 IEEE 802.16 FRAME STRUCTURE

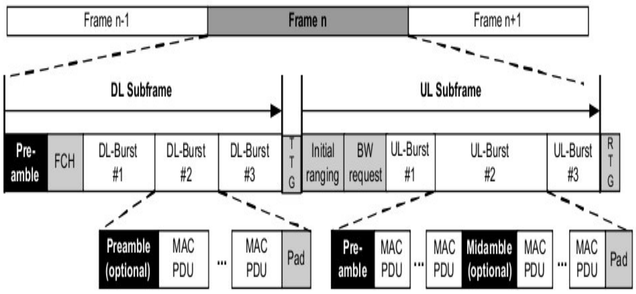


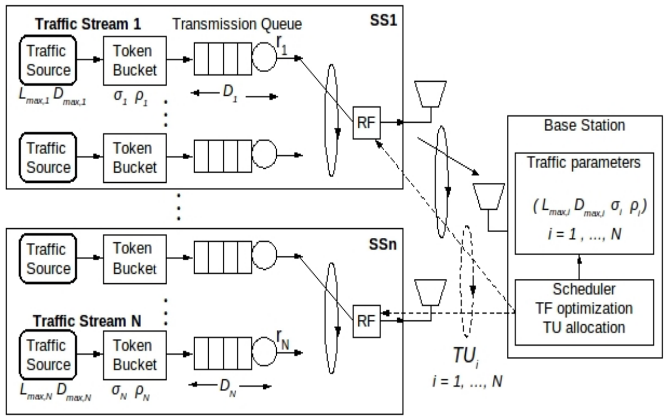
FIG2.OFDM FRAME STRUCTURE WITH TDD

A well-established architecture for QoS in the IEEE 802.16 MAC layer. The subject of this work is the component responsible for allocating uplink bandwidth to each SS, although the decision is taken based on the following aspects: bandwidth required by each SS for uplink data transmission, periodic bandwidth needs for UGS flows in SSs and bandwidth required for making requests for additional bandwidth. Considering the limitations exposed above, these works form the basis of a generic architecture, which can be extended and specialized. However, in these studies, the focus is in achieving QoS guarantees, with no concerns for maximizing the number of allocated users in the network. This paper presents a scheduler with admission control of connections to the WiMAX BS. We developed an analytical model based on Latency-Rate (LR) server theory from which an ideal frame size called Time Frame (TF) was estimated, with guaranteed delays for each user and maximization of the number of allocated stations in the system. A set of simulations is presented with CBR and VBR streams and performance comparisons are made for different delays and different TFs. The results show that an upper bound on the delay may be achieved for a large range of network loads with bandwidth optimization.

ANALYSIS OF THE ANALYTICAL MODEL
SYSTEM DESCRIPTION

Section A

Figure 3 illustrates a wireless network operating the newly proposed scheduler with call admission control, which is based on a modified LR scheduler and uses the tokenbucket algorithm. The basic approach consists on the token bucket limiting input traffic and the LR scheduler providing rate allocation for each user. Then, if the rate allocated by the LR scheduler is larger than the token bucket rate, the maximum delay may be calculated.



The behavior of an LR scheduler is determined by two parameters for each session θ_i: latency θ_i and allocated rate r_i. The latency θ_i of the scheduler may be seen as the worst-case delay and depends on network resource allocation parameters. In the new scheduler with call admission control, the latency θ_i is a TF period, which is the time needed to transmit a maximum-size packet and separation gaps (TTG and RTG) of DL and UL sub frames. In the new scheduler, considering the delay for transmitting the first packet, the θ_I latency θ_i of is given by θ_i.

$$\theta_i = T_{TTG} + T_{RTG} + T_{DL} + T_{UL} + \frac{L_{MAX,i}}{R}$$

where TTTG and TRTG are DL and UL subframes gaps durations, TDL and TUL are the DL and UL subframesduration, Lmax;i is the maximum packet size and R is the outgoing link capacity.

Now, we show how the allocated rate r_i for each session i may be determined, and how to optimize TF in order to increase the number of connections accommodated with Call Admission Control (CAC).

Section B

The main idea of the proposed scheme is to allow the BS to pre-assign a CS for each TS at the beginning of a frame. The CS waits for the possible opportunities to recycle the unused bandwidth of its corresponding TS in this frame. The CS information scheduled by the BS is resided in a list, called complementary list (CL). The CL includes the mapping relation between each pair of pre-assigned CS and TS. Each CS is mapped to at least one TS. The CL is broadcasted followed by the UL map. To reach the backward compatibility, a broadcast CID (B-CID) is attached in front of the CL. Moreover, a stuff byte value (SBV) is transmitted followed by the B-CID to distinguish the CL from other broadcast DL transmission intervals. The

UL map including burst profiles and offsets of each TS is received by all SSs within the network. Thus, if a SS is on both UL map and CL, the necessary. Information (e.g., burst profile) residing in the CL may be reduced to the mapping information between the CS and its corresponding TS.

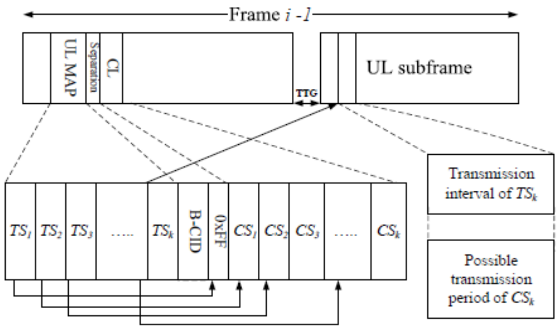
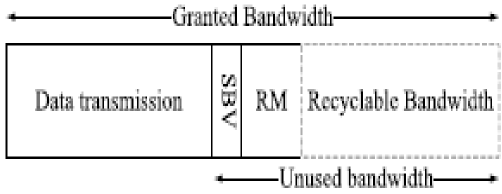


Fig:4 The mapping relation between Css and Tss in a MAC Frame

The BS only specifies the burst profiles for the SSs which are only scheduled on the CL. For example, as shown in Fig. *CSj* is scheduled as the corresponding CS of *TSj* , where 1 ≤ *j* ≤ k. When *TSj* has unused bandwidth, it performs our protocol introduced in Section 4.1. If *CSj* receives the message sent from *TSj* , it starts to transmit data by using the agreed burst profile. The burst profile of a CS is resided on either the UL map if the CS is also scheduled on the UL map or the CL if the CS is only scheduled on CL. Our proposed scheme is presented into two parts: the protocol and the scheduling algorithm. The protocol describes how the TS identifies the unused bandwidth and informs recycling opportunities to its corresponding CS. The scheduling algorithm helps the BS to schedule a CS for each TS.

Protocol

According to the IEEE 802.16 standard, the allocated space within a data burst that is unused should be initialized to a known state. Each unused byte should be set as a padding value (i.e., 0xFF), called stuffed byte value (SBV). If the size of the unused region is at least the size of a MAC header, the entire unused region is initialized as a MAC PDU. The padding CID is used in the CID field of the MAC PDU header. In this research, we intend to recycle the unused space for data transmissions. Instead of padding all portion of the unused bandwidth in our scheme, a TS with unused bandwidth transmits only a SBV and a RM. The SBV is used to inform the BS that no more data are coming from the TS. On the other hand, the RM comprises a generic MAC PDU with no payload. The mapping information between CL and UL map is based on the basic CID of each SS. The CID field in RM should be filled by the basic CID of the TS. Since there is an agreement of modulation for transmissions between TS and BS, the SBV can be transmit ted via this agreed modulation. However, there are no agreed modulations between TS and CS. Moreover, the transmission coverage of the RM should be as large as possible in order to maximize the probability that the RM is able to be received successfully by the CS.To maximize the transmission coverage of the RM, one possible solution is to increase the transmission power of the TS while transmitting the RM. However, the power may be a critical resource for the TS and should not be increased dramatically. Therefore, under the circumstance of without increasing the transmission power of the TS, the RM should be transmitted via BPSK which has the largest coverage among all modulations supported in theIEEE 802.16 standard.



Scheduling Algorithm

Assume *Q* represents the set of SSs serving non-real time connections (i.e., nrtPS or BE connections) and *T* is the set of TSs. Due to the feature of TDD that the UL and DL operations can not be performed simultaneously, we can not schedule the SS which UL transmission interval is overlapped with the target TS. For any TS, *St*, let *Ot* be the set of SSs which UL transmission interval overlaps with that of *St* in *Q*. Thus, the possible corresponding CS of *St* must be in *Q−Ot*. All SSs in *Q−Ot* are considered as candidates of the CS for *St*. A scheduling algorithm, called *Priority-based Scheduling Algorithm* (PSA), shown in Algorithm 1 is used to schedule a SS with the highest priority as the CS. The priority of each candidate is decided based on the scheduling factor (SF) defined as the ratio of the current requested bandwidth (CR) to the current granted bandwidth (CG). The SS with higher SF has more demand on the bandwidth. Thus, we give the higher priority to those SSs. The highest priority is given to the SSs with zero CG. Non-real time connections include nrtPS and BE connections. The nrtPS connections should have higher priority than the BE connections because of the QoS requirements. The priority of candidates of CSs is concluded from high to low as: nrtPS with zero CG, BE with zero CG, nrtPS with non-zero CG and BE with non-zero CG. If there are more than one SS with the highest priority, we select one with the largest CR as the CS in order to decrease the probability of overflow.

ANALYSIS

The percentage of potentially unused bandwidth occupied in the reserved bandwidth is critical for the potential performance gain of our scheme. We investigate this percentage on VBR traffics which is popularly used today. Additionally, in our scheme, each TS should transmit a RM to inform its corresponding CS when it has unused bandwidth. However, the transmission range of the TS may not be able to cover the corresponding CS. It depends on the location and the transmission power of the TS. It is possible that the unused bandwidth cannot be recycled because the CS does not receive the RM. Therefore, the benefit of our scheme is reduced. In this section, we analyze mathematically the probability of a CS to receive a RM successfully. Obviously, this probability affects the bandwidth recycling rate (BBR). BBR stands for the percentage of the unused bandwidth which is recycled. Moreover, the performance analysis is presented in terms of throughput gain (TG). At the end, we evaluate the performance of our scheme under different traffic load. All analytical results are validated by the simulation.

Algorithm: Scheduling Algorithm
Input: T is the set of TSs scheduled on the UL map.
Q is the set of SSs running non-real time applications.
TF is the optimal time frame dynamically alloted.
Output: Schedule CSs for all TSs in T by considering TF.
For
i =1 to //T//in *TF* do
a. *St ← TSi.*
b. *Qt ← Q−Ot: In optimal time frame.*
c. Calculate the SF for each SS in *Qt*.
d. **If** Any SS € *Qt* has zero granted bandwidth,
If Any SSs have nrtPS traffics and zero granted bandwidth, Choose one running nrtPS traffics with the largest CR in optimal frame.
else
Choose one with the largest CR.
else
Choose one with largest SF and CR.
e. Schedule the SS as the corresponding CS of *St* in optimal time frame.
End For.

Calculation of Optimal Time Frame

All PHY and MAC layer parameters used in simulation are summarized in Table I.

QoS Parameter Set	Description
ProvisionedQoSParamSet	A set of external QoS parameters provided to the MAC, for example by the network management system
AdmittedQoSParamSet	A set of QoS parameters for which the BS and possibly the SS are reserving resources, since the associated service flows have been admitted by the BS
ActiveQoSParamSet	A set of QoS parameters that reflect the actual service being provided to the associated service flow

IEEE 802.16 QoS Parameter Sets

Table I
PHY and MAC parameters

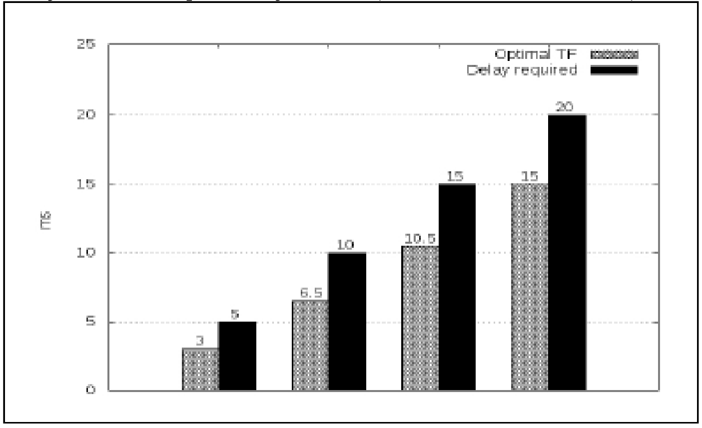
PARAMETER	VALUE
Bandwidth	20MHz
OFDM Symbol Duration	13,89 μs
Delay	5 / 10 / 15 and 20 ms
Δ (Initial Ranging and BW Request) $\rightarrow$ 9 OFDM Symbols	125,10 μs
TTG + RTG $\rightarrow$ 1 OFDM Symbol	13,89 μs
UL Subframe (preamble + pad) $\rightarrow$ 10% OFDM Symbol	1,39 μs
Physical Rate	70 Mbps
DL Subframe	1% TF

Performance of the new scheduler with call admission control is evaluated as the delay requested by the user and assigned stations. Station allocation results, in the system with an optimal TF, limited by the delay requested by the user, are described in sequence. The first step is define token bucket parameters, which are estimated in accordance with the characteristics of incoming traffic and are listed on Table II.

Table II
Token bucket parameters

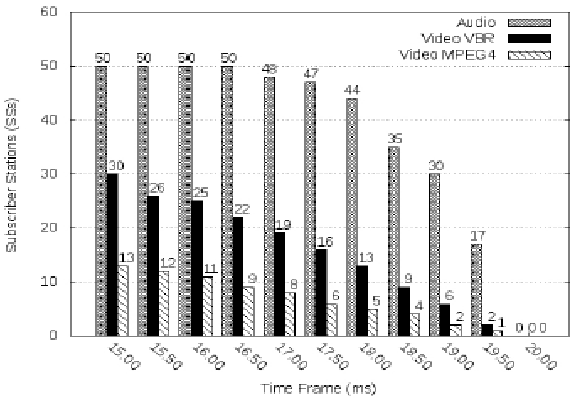
	Audio	VBR video	MPEG4 video
Token Size (bits)	3000	18000	10000
Token Rate (kb/s)	64	500	4100

Thus, the optimal TF value is estimated according to the PHY and MAC layer's parameters (see Table I), token bucket parameters (see Table II), required maximum allowable delay, physical rate and maximum package size. The graph in Figure 7 shows the optimal TF value, for four delay values required by users (5, 10, 15 and 20 ms).



Optimal TF

Next, we show the number of SSs assigned to each traffic type. As an example, Figure 8 show that when the user-requested delay is of 20 ms, an optimal TF of 15 ms is calculated and 50 users can be allocated for audio traffic, or 30 users for VBR video traffic, or 13 users for the MPEG4 video traffic.



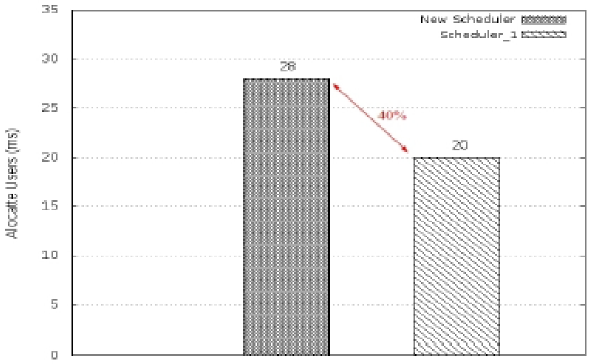
Comparison with other Schedulers

The new scheduler with call admission control, here called New Scheduler, was compared to those of [9], here called Scheduler1, and here called Scheduler2. The comparison was accomplished through the ability to allocate users in a particular time frame (TF). Table IV shows the parameters used for comparisons. In the graph of Figure 10, we compare the New Scheduler with the Scheduler_1. A maximum delay of 0.12 ms was requested by the user, and the duration of each frame (TF) was set at 5 ms. Other parameters are listed in Table.

Parameters used for comparisons

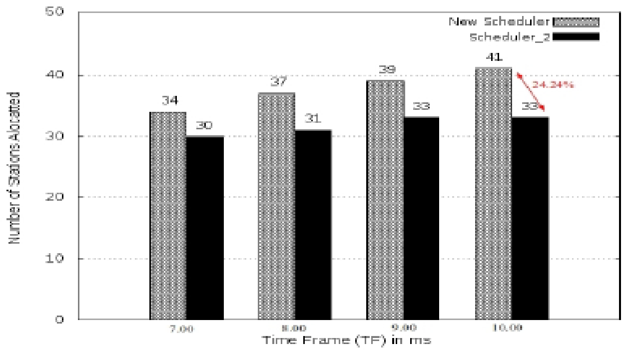
PARAMETER	*Scheduler_1*	*Scheduler_2*
Bandwidth	$20\ MHz$	$20\ MHz$
OFDM symbol duration	$13.89\ \mu s$	$13.89\ \mu s$
Time Frame (TF)	$5\ ms$	$10\ ms$
Delay Requested by the user	$0.12\ ms$	$20\ ms$
Maximum Data Rate	$70\ Mbps$	$70\ Mbps$
Traffic type	Audio	Audio

In comparison, the New Scheduler allocates 28 users in each frame, while the Scheduler_1, allocates 20 users. Thus, the New Scheduler presents a gain in performance of 40% when compared with the Scheduler_1. In the graph of Figure 11, we compare the New Scheduler with the Scheduler_2. A maximum delay of 20 ms was requested by the user, and the duration of each frame (TF) was set at 10 ms. Other parameters are listed in Table.



Comparison allocation of user with scheduler-1

The comparison was extended by also considering frame duration values of 7.00 ms, 8.00 ms and 9.00 ms to demonstrate the efficiency of the New Scheduler. For a TF of 10 ms, the New Scheduler allocates 41 users in each frame, while the Scheduler_2 allocates only 33 users. This represents 24.24% better performance for the New Scheduler. Similarly, the New Scheduler also allocates more users per frame in comparison with the Scheduler_2 for all other frame duration values.



Comparison allocation of user with scheduler-2

CONCLUSION

This work has presented the design and evaluation of a new scheduler with call admission control for IEEE 802.16 fixed networks, that guarantees different maximum delays for traffic types with different QoS requisites and optimizes bandwidth usage. Variable bit rate applications generate data in variant rates. It is very challenging for SSs to predict the amount of arriving data precisely. Although the existing method allows the SS to adjust the reserved bandwidth via bandwidth requests in each frame, it cannot avoid the risk of failing to satisfy the QoS requirements. Moreover, the unused bandwidth occurs in the current frame cannot be utilized by the existing bandwidth adjustment since the adjusted amount of bandwidth can be applied as early as in the next coming frame. Our research does not change the existing bandwidth reservation to ensure that the same QoS guaranteed services are provided. We proposed *bandwidth recycling* to recycle the unused bandwidth once it occurs. It allows the BS to schedule a complementary station for each transmission stations. Each complementary station monitors the entire UL transmission interval of its corresponding TS and standby for any opportunities to recycle the unused bandwidth. Besides the naive priority-based scheduling algorithm, three additional algorithms have been proposed to improve the recycling effectiveness. Our mathematical and simulation results confirm that our scheme can not only improve the throughput but also reduce the delay with negligible overhead and satisfy the QoS requirements. Firstly, we developed an analytical model to calculate an optimal TF, which allows an optimal number of SSs to be allocated and guarantees the maximum delay required by the user. Then, a simulator was developed to analyze the behavior of the proposed system. To validate the model, we have presented the main results obtained from the analysis of different scenarios. Simulations were performed to evaluate the performance of this model, demonstrating that an optimal TF was obtained along with a guaranteed maximum delay, according to the delay requested by the user. Thus, the results have shown that the new scheduler with call admission control successfully limits the maximum delay and maximizes the number of SSs in a simulated environment.

SUMMARY

There are a number of concerns over broadband wireless access, such as packet loss and atmospheric interference, but these problems can be mitigated with QoS. The 802.16 MAC is connection-oriented and provides Service Flows, each assigned a QoS service class. 802.16 also uses Dynamic Service Establishment and a Two-Phase Activation Model for QoS provisioning. The 802.16 PHY layer includes OFDM, FEC and Adaptive Modulation to improve QoS performance. And Adaptive Burst Profiles allow the modulation and coding schemes to be adaptively adjusted according to link conditions. The 802.16 standard is a grant-based protocol, which provides centralized control and low overhead, as opposed to a contention-based protocol such as 802.11 that relies on acknowledgements. And 802.16 has the power and range to provide the “last mile” in voice services, at a lower cost than 3G. 802.16 research is hot now as people are trying to build the standard and improve its performance. And, QoS over 802.16 may be the key to getting wider acceptance of broadband wireless access for voice and multimedia services.

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