Bandwidth Calculation in IEEE 802.16 Networks

Roop Singh Takur, E.Ramkumar

Abstract- IEEE 802.16 standard 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. To ensure the QoS guaranteed services, the SS may calculate more bandwidth. In this paper, we propose a scheme, named Bandwidth Calculation, to calculate the bandwidth without changing the existing unused calculates bandwidth. The idea of the proposed scheme is to allow other SSs to calculate the bandwidth when it is available. Thus, the system through put can be improved while maintaining the same QoS guaranteed services. Mathematical analysis and simulation are used to evaluate the proposed scheme..Simulation and analysis results confirm that the proposed scheme can calculate on average. By analyzing factors affecting the calculating performance, scheduling algorithms are proposed to improve the overall throughput. The simulation results show that our proposed algorithm improves the overall throughput by 40% in a steady network.

Keywords: WiMAX, IEEE 802.16, Bandwidth Calculation.

I. INTRODUCTION

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 inmetropolitan 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 calculate all the time. Although the amount of calculating bandwidth is adjustable The SS may be exposed to the risk of degrading the QoS requirements of applications due to the insufficient amount of calculating bandwidth. To improve the bandwidth calculation while maintaining the same QoS guaranteed services, our research objective is twofold: 1) the existing bandwidth calculation is not changed to maintain the same QoS guaranteed services. 2) our research work focuses on increasing the bandwidth calculation by utilizing the unused calculating bandwidth. We propose a scheme, named Bandwidth Calculating, which recycles the calculating bandwidth while keeping the same QoS guaranteed services without introducing extra delay. The general concept behind our scheme is to allow other SSs to calculate the unused bandwidth left by the current transmitting SS. Since the calculating bandwidth is not supposed to occur regularly, our scheme allows SSs with non-real time applications ,which have more flexibility of delay requirements, to calculate the unused bandwidth. Consequently, the unused bandwidth in the current frame can be calculated. It is different from the bandwidth adjustment in which the adjusted bandwidth is enforced as early as in the next coming frame. Moreover, the calculated bandwidth is likely to be released temporarily (i.e., only in the current frame)and the existing bandwidth calculation 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 calculate the unused bandwidth of its corresponding TS. We call the backup SS as the complementary station (CS). In theIEEE 802.16 standard, BRs are made in per-connection basis. However, theBS 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 calculate 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. Our theoretical analysis shows that this probability is least 42%, which is confirmed by our simulation. By further investigating the factors that affect the effectiveness of our scheme, two factors are concluded: 1) the CS cannot receive the RM. 2) the CS does not have non-real time data to transmit while receiving a RM. To mitigate those factors, additional scheduling algorithms are proposed. Our simulation results show that the proposed algorithm further improve the average throughput by 40% in a steady network (i.e., 15 to 75second in our simulation). The rest of this paper is organized as follows. In Section 2, we provide the background information of IEEE 802.16. Motivation and related works are presented in Section 3. The proposed scheme is presented in Section4. The analysis of the proposed scheme and simulation results are placed in Section 5 and

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Section 6. In Section 7, three additional scheduling algorithms are proposed to enhance the performance of the proposed scheme. The simulation results of each scheduling algorithm are shown in Section 8. At the end, the conclusion is given in Section 9. Various attributes of web forum discussions and the firm's stock behavior.

II. BACK GROUND ANALYSIS

The IEEE 802.16 standard specifies three types of transmission mediums supported as the physical layer (PHY): single channel (SC), Orthogonal frequency-division multiplexing (OFDM) and Orthogonal Frequency-Division Multiple Access (OFDMA). We assume OFDMA as the PHY in our analytical model since it is employed to support mobility in IEEE 802.16e standard and the scheme working in OFDMA should also work in others. There are four types of modulations supported by OFDMA: BPSK, QPSK, 16-QAM and 64-QAM. This paper is focused on the point-to-multipoint (PMP) mode in which the SS is not allowed to communicate with any other SSs but the BS directly. Based on the transmission direction, the transmissions between BS and SSs are classified into downlink (DL) and uplink (UL) transmissions. The former are the transmissions from the BS to SSs. Conversely, the latter are the transmissions in the opposite direction. There are two transmission modes: Time Division Duplex (TDD) and Frequency Division Duplex (FDD) supported in IEEE 802.16. Both UL and DL transmissions cannot be operated simultaneously in TDD mode but in FDD mode. In this paper, our scheme is focused on the TDD mode. In WiMAX, the BS is responsible for scheduling both UL and DL transmissions. All scheduling behavior is expressed in a MAC frame. The structure of a MAC frame defined in IEEE 802.16 standard contains two parts: UL and DL sub frame. The UL sub frame is for UL transmissions. Similarly, the DL sub frame is for DL transmissions. In IEEE 802.16 networks, the SS is coordinated by the BS. All coordinating information including burst profiles and offsets is in the DL and UL maps, which are broadcasted at the beginning of a MAC frame.The IEEE 802.16 network is connection-oriented. It gives the advantage of having better control over network resource to provide QoS guaranteed services. In order to support wide variety of applications, the IEEE 802.16 standard classifies traffic into five scheduling classes: Unsolicited Grant Service (UGS), Real Time Polling Service (rtPS), Non-real Time Polling Service (nrtPS), Best Effort (BE) and Extended Real Time Polling Service (ertPS). Each application is classified into one of the scheduling classes and establishes a connection with the BS based on its scheduling class. The BS assigns a connection ID (CID) to each connection. The bandwidth calculation is made based on the CID via sending a BR. When receiving a BR, the BS can either grant or reject the BR depending on its available resources and scheduling policies. There are two types of BRs defined in the IEEE 802.16 standard: incremental and aggregate BRs. The former allow the SS to indicate the extra bandwidth required for a connection. Thus, the amount of bandwidth calculation can be only increased via incremental BRs. On the other hand, the SS specifies the current state of queue for the particular connection via a aggregate request. The BS resets its perception of that service's needs upon receiving the request. Consequently, the reserved bandwidth calculation may be decreased.

III. MOTIVATIONS AND RELATED WORK

Bandwidth calculation allows IEEE 802.16 networks to provide QoS guaranteed services. The SS calculates the required bandwidth before any data transmissions. Due to the nature of VBR applications, it is very difficult for the SS to make the optimal bandwidth calculation. It is possible that the amount of reserved bandwidth calculation is more than the demand. Therefore, the reserved bandwidth cannot be fully calculated. Although the reserved bandwidth can be calculated via BRs, however, the updated reserved bandwidth calculated is applied as early as to the next coming frame and there is no way to calculate the unused bandwidth in the current frame. In our scheme, the SS releases its uncalculated bandwidth in the current frame and another SS pre-assigned by the BS has opportunities to calculate this unused bandwidth. This improves the bandwidth utilization. Moreover, since the existing bandwidth reserved calculation is not changed, the same QoS guaranteed services are provided without introducing any extra delay. Many research works related to bandwidth calculation improvement have been proposed in the literature. In [2], a dynamic resource reservation mechanism is proposed. It can dynamically change the amount of reserved resource depending on the actual number of active connections. The investigation of dynamic bandwidth calculation for hybrid networks is presented in [6]. The authors evaluated the performance and effectiveness for the hybrid network, and proposed efficient methods to ensure optimum reservation and calculation of bandwidth while minimizing signal blocking probability and signaling cost. In [5], the authors enhanced the system throughput by using concurrent transmission in mesh mode. The authors in [4] proposed a new QoS control scheme by considering MAC-PHY cross-layer resource allocation. A dynamic bandwidth request-allocation and calculation algorithm for real-time services is proposed in [15]. The authors predict the amount of bandwidth to be calculated based on the information of the backlogged amount of traffic in the queue and the rate mismatch between packet arrival and service rate to improve the bandwidth calculation. The research works listed above improve the performance by predicting the traffic coming in the future and it shows calculation of used and unused Bandwidth. Instead of prediction, our scheme can allow SSs to accurately identify the portion of uncalculated bandwidth and provides a method to calculate the unused bandwidth. It can improve the calculation of bandwidth while keeping the same QoS guaranteed services and introducing no extra delay.

IV. PROPOSED SCHEME

The objectives of our research are twofold: 1) The same QoS guaranteed services are provided by maintaining the existing bandwidth reservation calculation. 2) the bandwidth calculation is improved by calculating the unused bandwidth. To achieve these objectives, our scheme named Bandwidth calculating is proposed. 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 calculate 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. As shown in Fig. 1, each CS is mapped to at least one TS. The CL is broadcasted followed by the ULmap. 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

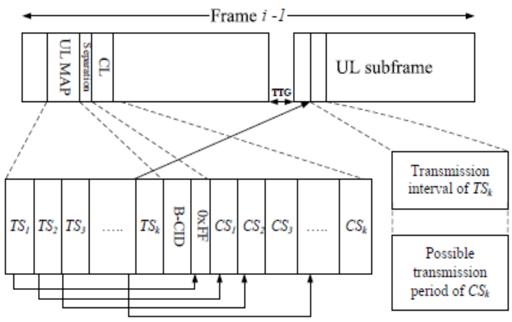

Fig. 1. The mapping relation between CSs and TSs in a MAC frame

Fig.1. the mapping relation between CSs and TSs in a MAC frame information (e.g., burst profile) residing in the CL may be reduced to the mapping information between the CS and its corresponding TS. The BS only specifies the burst profiles for the SSs which are only scheduled on the CL.For example, as shown in Fig. 1, CS_j is scheduled as the corresponding CS of TS_j , where $1 \leq j \leq k$. When TS_j has unused bandwidth, it performs our protocol introduced in below. If CS_j receives the message sent from TS_j , 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 uncalculated bandwidth and informs calculating opportunities to its corresponding CS. The scheduling algorithm helps the BS to schedule a CS for each TS.

3.1 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 uncalculated byte should be set as a padding value (i.e., 0xFF), called stuffed byte value (SBV). If the size of the uncalculated region is at least the size of a MAC header, the entire uncalculated 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 calculate the uncalculated bandwidth for data transmissions. Instead of padding all portion of the uncalculated bandwidth in our scheme, a TS with un calculate bandwidth transmits only a SBV and a RM shown in Fig. 2.

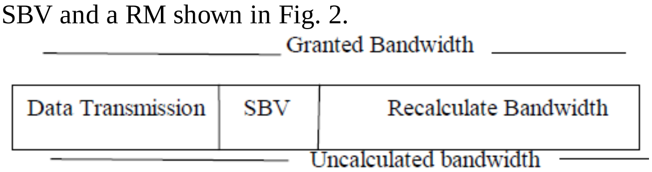

Fig. 2. Messages to release the uncalculated bandwidth within UL transmission interval.

Fig. 2. The format of RM 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 the IEEE 802.16 standard. For example, Fig. 4 illustrates the physical location of the BS, TS and CS, respectively. The solid circle represents the coverage of QPSK which is the modulation for data transmissions between BS and TS. When the TS has calculate bandwidth, it transmits a SBV via this modulation (i.e., QPSK) to inform the BS that there are no more data coming from the TS. It is easy to observe that the corresponding CS is out of QPSK coverage. In order to maximize the coverage of the RM under the circumstance of without increasing the transmission power of the TS, the TS transmits the RM via BPSK which coverage is represented by the dished circle. The radius of the dished circle is KL, where L is the distance between TS and BS and K is the ratio of transmission range of BPSK to the transmission range of QPSK depending on the transmission power. Assume all channels are in good condition. As long as the CS is within the coverage of BPSK, it can receive the RM successfully and start to calculate the unused bandwidth. Since both UL map and CL can be received by the CS, the CS knows the UL transmission period of its corresponding TS. This period is called the UL transmission interval. The CS monitors this interval to see if a RM

V. 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 cannot be performed simultaneously, we cannot 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.

VI. ANALYSIS

The percentage of potentially calculation 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 calculating 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 calculated 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,

Algortithm 1 Priority-base Scheduling algorithm
Input: T is the set of TSs scheduled on the UL map.
Q is the set of SSs scheduled on the non-realtime applications.
Output: Schedule CSs for all TSsin T.
For i=1 to ‖T‖ do

a. S_t TS_i
b. Q_t Q--- O_t
c. Calculate the SF for each SS in Q_t
d. IF Any SS € Q_t has zero granted bandwidth,
IF ANYSSs have nrtPS traffics and zero granted Bandwidth
Choose one running nrtPS traffics with largestCR.
Else
Choose one with largest SF and CR.
e. Schedule the SS ad the corresponding CS of S_t

End For

this probability affects the bandwidth calculating rate (BBR). BBR stands for the percentage of the unused bandwidth which is calculated. 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 in Section 6.

5.1 Performance Analysis of Proposed Scheme:

The traffic load in a network may vary dynamically. Thus, the network status can be classified into four stages: light, moderate, heavy and fully loaded. The performance of the proposed scheme may be variant in different stages. We investigate the performance of our scheme in each stage. Suppose B_{all} represents the total bandwidth supported by the BS. Assume represents the bandwidth reserved or calculated by real time connections and BRrt is the amount of additional bandwidth requested by them via BRs. Similarly Bnrt represents the bandwidth assigned to non-real time connections and BRnrt is the amount of additional bandwidth recalculated by them. The investigation of our scheme in each stage is shown as follows. All investigations are validated via

{
i−1
}
where $\max\{0;Q_{nrt}\, i-1-W_{nrt}\, i-1\}$ (1)
}

is the amount of queued data arriving before frame i − 1. Since Y_i-1 cannot be negative, the probability of the CS, denoted as S_u, which has data to calculate the recalculate bandwidth can be obtained as :

$P_u(u) = \int^{\gamma\ nrt\ max} P(X)dX \quad Y_{i-1}$ (2)

Where _nrt max is the maximal amount of non-real time data arriving in a frame and bandwidth occupying. A CS which recalculates the unused bandwidth successfully while receiving a RM must be scheduled on the CS and have non-real time data to be transmitted and calculated. From equations (1) and (2), the probability that a CS satisfies these two conditions is derived as:

$\|Q_n\|$
$Pr = \Sigma\, P_u(j)\, (P_{CL}(j))$ j=1

$\|Q_n\|$ (3)

If the CS recalculates the unused bandwidth successfully, then it must meet the three conditions: 1) a RM must be received, 2) this SS must be scheduled on the CL and 3) the CS must have space to calculate the unused bandwidth. From equations (1) and (4),(5), the calculating rate , the average probability that a CS calculates the unused bandwidth successfully, can be obtained as:

$P_{recalculate} = P_r\, P_t$ (4)

Suppose Bg is the total bandwidth in the system and the unused calculated bandwidth of the system is Bw. By equation (5), The total throughput gain, TG, is derived as:

$TG = P_{recalculate} Bw$
Bg – Bw (5)

Delay is a critical factor affecting the QoS of services. In our scheme, we preserve the existing bandwidth calculation. Moreover, the CS cannot calculate the bandwidth until receiving the RM which is sent by the TS. Therefore, Bandwidth calculating does not affect any data transmissions operated by the TS and thus, does not introduce any extra delay.

5.2 Performance Analysis Of The Proposed Scheme Under Different Traffic Load:

The traffic load in a network may vary dynamically. Thus, the network status can be classified into four stages: light, moderate, heavy and fully loaded. The performance of the proposed scheme may be variant in different stages. We investigate the performance of our scheme in each stage. Suppose B_{all} represents the total bandwidth supported by the BS. Assume Brt represents the bandwidth calculated by real time connections and BRrt is the amount of additional bandwidth requested by them via BRs. Similarly Bnrt represents the bandwidth assigned to non-real time connections and BRnrt is the amount of additional bandwidth calculated by them. The investigation of our scheme in each stage is shown as follows. All investigations are validated via simulation in Section 5.4) Stage 1 (light load): This stage is defined as that the total demanding and calculating bandwidth of SSs is much less than the supply of the BS. The formal definition can be expressed as:

$B_{all} >> B_{rt} + B_{nrt} + BR_{rt} + BR_{nrt}$

Since all BRs are granted in this stage, the BS schedules the CS randomly. Moreover, every SS receives its desired amount of bandwidth. Therefore, for any given CS, Su, the probability to have data to recalculate the unused bandwidth, derived from equation (2,3,4), is small. It leads to low Pr (from equation (4)). Therefore, the probability that the CS calculates the unused bandwidth successfully is small and the throughput gain of our scheme is not significant. 2) Stage 2 (moderate load): This network stage is defined as equal demand and supply of bandwidth, i.e.,B_{all} = Brt + Bnrt. In this stage, the BS can satisfy the existing demand but does not have available resource to admit new BRs. Since the currently desired bandwidth of every SS can be satisfied, the probability of CS to calculate the unused bandwidth (equation (1,2,3,4)) may be higher than the stage 1 but still limited. Based on equations the throughput gain is still insignificant. 3) Stage 3 (heavy load) : This stage is defined as that the BS can satisfy the demand of real time connections, but does not have enough bandwidth for the non-real time connections. However, there are no rejected BRs in this stage. We can express this in terms of formulation as: B_{all} = Brt + _Bnrt where $0 \leq \_ < 1$. Since the bandwidth for non-real time connections has been shrunk, there is a high probability that the CS accumulates non-real time data in queue. It leads to higher Pr and Precalculate. Thus, the throughput gain can be more significant than Stage 1 and 2. 4) Stage 4 (full load) : This stage describes a network with the heaviest traffic load. The difference between stage 3 and 4 isthat there are rejected BRs in stage 4. It means that the probability of SSs accumulating non-real time data inqueue is much higher than the one in Stage3. Therefore, both P_r and $P_{Calculate}$ are significantly high. Our scheme can achieve the best performance in this stage.

5.3 Tradeoff:

In the IEEE 802.16 standard, the SS can adjust the amount of calculating reserved bandwidth via BRs. In this subsection, we analyze the performance between the proposed scheme and the scheme with BRs. However, there are no rules specified in the standard to tell the SS when to adjust the amount of calculating reserved bandwidth. The objective of this paper is to improve the bandwidth calculation and system throughput. We define a case, named Case with BRs, that each SS requests bandwidth for each connection in every frame based on the queued data. The unicast polling opportunity is given to each connection in every frame for making BRs.In this case, in each frame, the SS always asks the amount of bandwidth as the number of data it will transmits and calculates. Therefore, the amount of unused bandwidth in this case is very limited. However, the SS has to transmit BR for every connection in every frame. Moreover, according to the IEEE 802.16 standard, the BR is made in per connection basis. Suppose there are m connections running on a SS. The SS has to send m BRs which are 19m bytes (considering standard alone bandwidth calculates) in each frame. The overhead is dramatically large in this case. Since the size of UL sub frame is limited in each frame, the throughput for transmitting real data(i.e., eliminating the overhead) may not be high. On the other hand, in the proposed scheme, the overhead that each SS transmits is a constant (6 bytes for a RM) which is much smaller than 19m bytes. Since the CS needs to stay in active in order to listen to a possible RM from the corresponding TS, the CS cannot enter into sleep mode for power conservation. On the other hand, the probability of a CS to recalculate the unused bandwidth decreases if a sleeping SS is scheduled as the CS. Therefore, there is a tradeoff between the benefit of the proposed scheme and power conservation. If the CS does not enter into sleep mode, obviously, it can always listen to a possible RM sent from the corresponding TS. On the other hand, it enters into sleep mode. The SS switches its state between active and inactive. As described in the IEEE 802.16e standard, the BS has the information of available and unavailable period of the SS. Thus, the BS should avoid scheduling a SS which is in unavailable period as a CS. Furthermore, if the BS schedules an inactive SS as a CS, the whole network still operates successfully but the benefit of the proposed scheme is reduced.

5.4 Simulation Results:

Our simulation is conducted by using Qual net 4.5 [12]. In this section, we first present our simulation model followed by introducing the definition of performance metrics used for measuring the network performance. The simulation results are shown as the third part of this section. At the end, we provide the validation of theoretical analysis and simulation results.

5.4.1 Simulation Model

Our simulation model comprises one BS residing at the center of geographical area and 50 SSs uniformly distributed in the service coverage of BS. The parameters of PHY and MAC layers used in the simulation are summarized in Table 1. PMP mode is employed in our model. Since our proposed scheme is used to calculate the unused bandwidth in UL sub frame, the simulation only focuses on the performance of UL transmissions. Parameters Value Node number 51 (including BS) Frame duration 20MS UL/DL sub frame duration 10MSModulation scheme BPSK, QPSK, 16QAM, 64QAM DCD/UCD broadcast interval 5S TTG/RTG 10US SS transition gap (SSTG) 4US TABLE 1The system parameters used in our simulation CBR is a typical traffic type used to measure the performance of networks in Wi MAX research. However, it may not be able to represent the network traffic existing and calculating bandwidth in real life. Moreover, the IEEE 802.16 network aims to serve both data and multi-media applications. Most of the modern streaming videos are encoded by industrial standards (e.g., H.264 or MPEG 4) which generate data in variant rates. In this research, we include VBR traffics to illustrate H.264 and MPEG 4-encoded videos. In our simulation, the traffic models for these streaming videos are based on related research [9][10][12] [13] [14] [15]. Additionally, other commonly used VBR traffics such as HTTP and FTP applications are also included in our simulation. The characteristics of traffic types are summarized in Table .In our simulation, each SS serves at least one and up to 5 connections. Each connection serves one type of traffic which is mapped to the scheduling classes supported in the IEEE 802.16 standards (i.e., UGS, rtPS, ertPS, nrtPS and BE). Table enumerates all types of traffic and their corresponding scheduling classes used in our simulation. In particular, all VBR traffic in our simulations considered as ON/OFF traffic. We fix the mean data rate of each application but make the mean packet size randomly selected from 512 to 1024 bytes. Thus, the mean packet arrive rate can be determined based on the corresponding mean packet size. As mentioned earlier, the size of each packet is modeled as Poisson distribution and the packet arrival rate is modeled as exponential distribution. For example, in order to simulate the network traffics and calculation of bandwidth more realistically, the start time of each connection is randomly selected from 0 to 15th second. Moreover, the real time connection stops to generate data from 75th to 100th second. It is for investigating the performance of our scheme when the large amount of calculate unused bandwidth is available. Therefore, the number of active connections (the connections which are transmitting data) may be different during the simulation. Application

Application	VoIP	Multimedia	HTTP	FTP
Traffic type	CBR	VBR	VBR	VBR
Scheduling class	UGS	rtPS	BE	nrtPS
Start Time(sec.)	m*	m*	m*	m*
End Time	n*	n*	n*	n*
Means Packet Size	512	512	512	512
Mean BitRate	12.2Kbps	2Mbps	2Kbps	50Mbps
Max burst Size (Byte)	31	7.5K	10	1500k
Packect Size	Fixed	P*	P*	P*
Packet Arrival Size	Fixed	E*	E*	E*
Note: m* is a random number between 0 and 15. n* is a random number between 75 and 100. z* is a random number between 512 and 1024 bytes. p* stands for Poisson distribution. E* stands for Exponential distribution				

Parameters	Value
Node Number	51 (includingBS)
Frame Duration	20 Ms
UL/DL subframe duration	10 MS
Modulation Scheme	BPSK, QPSK, 16QAM,64 QAM
DCD/UCD broadcast interval	5s
TTG/Rtg	10 US
SS transition gap (SSTG)	4US

5.5 The Performance Metrics:

The simulation for evaluating the performance of the proposed scheme is based on the three metrics: 1) Throughput gain (TG): It represents the percentage of throughput which is improved by implementing our scheme. The formal definition can be expressed as:

$TG = T_{calculate} - T_{no\ recalculates}$ where $T_{recalculate}$ and $T_{no\ recalculate}$ represent the throughput with and without implementing our scheme, respectively. The higher TG achieved shows the higher performance that our scheme can make. 2) Calculating unused bandwidth rate (UBR):It is defined as the percentage of the unused bandwidth occupied in the total granted bandwidth in the system without using bandwidth recalculating. It can be defined formally as:$UBR = B_{calculate\ bw}\ B_{total}$ bwwhere $B_{recalculatebandwidth}$ bw and B_{total} bw are the unused bandwidth and total allocated bandwidth, respectively. The UBR shows the room which can be improved by our scheme. The higher UBR means the more recalculating opportunities. 3) Bandwidth recalculating rate (BRR):It illustrates the percentage of bandwidth which is calculated from the unused bandwidth. The percentage can be demonstrated formally as:

$BRR = B_{calculate}\ B_{unused\ bw}$

1) Throughput gain (TG):

It represents the percentage of throughput which is improved by implementing our scheme. The formal definition can be expressed as:

$TG = Tcalculate - Tno\ calculate / Tno\ calculate$

VII. SIMULATION RESULTS:

Figures presents the percentage of the calculating unused bandwidth in our simulation traffic model (i.e., UBR). It shows the room of improvement by implementing our scheme. From the simulation results, we conclude that the average UBR is around 38%. In the beginning, the UBR goes down. It is because each connection still requests bandwidth from the BS. As time goes on, the UBR starts to increase when the connection has received the requested bandwidth. After 75th second of simulation time, UBR increases dramatically due to the inactivity of real time connections. The purpose to have inactive real time connections is to simulate a network with large amount of calculated unused bandwidth and evaluate the improvement of the proposed scheme in such network status. The evaluation is presented in the later of this section.The simulation results of calculating rate are presented in Fig. 9. From the figure, we observe that the recycling rate is very close to zero at the beginning of the simulation. It is because that only a few connections transmit data during that time and the network has a light load. Therefore, only few connections need to calculate the unused bandwidth from others. As time goes on, many active connections join in the network. The available bandwidth may not be able to satisfy the needs of connections. Therefore, there is a high probability that the CS calculates the unused bandwidth. It leads a higher BR R .Fig. 10 shows the total bandwidth demand requested by SSs during the simulation. In the figure, the dashed line indicates the system bandwidth capacity. During the simulation, the BS always allocates the bandwidth to satisfy the demand of real time connections due to the QoS requirement. Therefore, the amount of bandwidth allocated to non-real time connections may be shrunk. At the same time, the new non-real time data are generated. Therefore, the non-real time data are accumulated in the queue. It is the reason that the demand of bandwidth keeps increasing. Fig. 11 presents the results of TG calculated from the cases with and without our scheme. In the figure, the TG is very limited at the beginning of the simulation, which is similar to the results of the BRR. It shows Stage 1 and 2 described in section 5 that there is no significant improvement on our scheme when the network load is light. As the traffic increases, the TG reaches around 15 to 20%. It is worth to note that the TG reaches around 20% at 35th second of the simulation time. It matches the time that the bandwidth demand reaches the system capacity shown in Fig. 10. Again, it confirms our early observation (Stage 3 and 4 in section 5) that the proposed scheme can achieve higher TG when the network is heavily loaded. After the 75th second, the TG increases dramatically. It shows that our scheme can have significant improvement on TG when the large amount of calculating unused bandwidth is available. We also investigate the delay in the cases with and without our scheme. By implementing our scheme, the average delay is improved by around 19% comparing to the delay without using our scheme. It is due to the higher overall system throughput improved by our scheme. From the simulation results shown above, we conclude that the proposed scheme can not only improve the bandwidth calculation and throughput but also decrease the average delay. Moreover, the scheme reaches the higher performance when the network is heavily loaded. This validates our performance analysis shown in stage 1 to 4 in Section 5. Fig. 12 shows the throughput comparison between our scheme and Case with BRs defined in Section 5.6. From the figure, we obtain that the throughput of Case with BRs can maintain higher throughput than the proposed scheme in most of time but the achievable throughput of our scheme is higher. It is because the SS in the former case always requests bandwidth based on the number of queued data. However, the BS has to reserve sufficient amount of bandwidth for BRs. Therefore, it limits the number of bandwidth for data transmissions. Additionally, this comparison is based on the proposed scheduling algorithm, named Priority-based Scheduling algorithm. The throughput of the proposed scheme is

VIII. CONCLUSION

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 calculated reserved bandwidth via risk of failing to satisfy the QoS requirements. Moreover, the unused bandwidth occurs in the current frame cannot be calculated 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 focus on proposed bandwidth calculation to calculate 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 calculate the unused bandwidth. Besides the naive priority-based scheduling algorithm, three additional algorithms have been proposed to improve the calculating 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.

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