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RECYCLING THE UNUSED BANDWIDTH USING PRIORITY BASED SCHEDULING ALGORITHM

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ABSTRACT

IEEE802.16 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 reserve more bandwidth than its demand. As a result, the reserved bandwidth may not be fully utilized all the time. In this paper we propose a scheme named bandwidth recycling to recycle the unused bandwidth without changing the existing bandwidth reservation. The idea of the proposed scheme is to allow other SSs to utilize the unused bandwidth when it is available. Thus the system throughput 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 recycle 35% of unused bandwidth on average. By analyzing factors affecting the recycling performance, scheduling algorithms are proposed to improve the overall throughput .the simulation results show that our proposed algorithm improves the over all throughput by 40% in a steady network.

KEYWORDS: *variable bit rate, QoS, base station, subscriber station.*

I. INTRODUCTION

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.

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. 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.

II. MOTIVATION AND RELATED WORK

Bandwidth reservation allows IEEE 802.16 networks to provide QoS guaranteed services. The SS reserves 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 reservation. It is possible that the amount of reserved bandwidth is more than the demand. Therefore, the reserved bandwidth cannot be fully utilized. Although the reserved bandwidth can be adjusted via BRs, however, the updated reserved bandwidth is applied as early as to the next coming frame and there is no way to utilize the unused bandwidth in the current frame. In our scheme, the SS releases its unused bandwidth in the current frame and another SS pre-assigned by the BS has opportunities to utilize this unused bandwidth. This improves the bandwidth utilization. Moreover, since the existing bandwidth reservation is not changed, the same QoS guaranteed services are provided without introducing any extra delay.

III. PROPOSED SCHEME

The objectives of our research are twofold: 1) The same QoS guaranteed services are provided by maintaining the existing bandwidth reservation. 2) The bandwidth utilization is improved by recycling the unused bandwidth. To achieve these objectives, our scheme named Bandwidth Recycling 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 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.

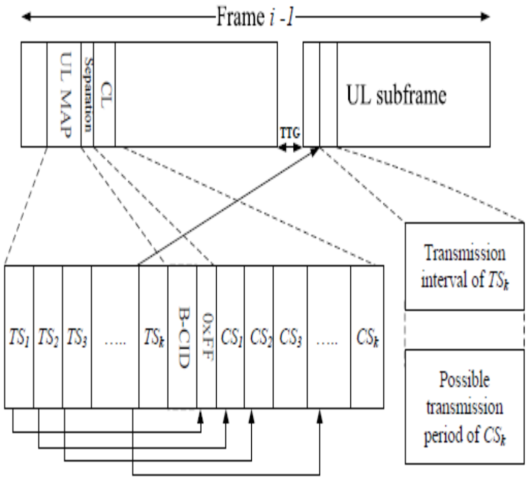

Figure 1. Frame Structure

As shown in Fig. 1, 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. The BS only specifies the burst profiles for the SSs which are only scheduled on the CL. For example, as shown in Fig. 1, *CSj* is scheduled as the corresponding CS of *TSj* , where $1 \leq j \leq k$. When *TSj* has unused bandwidth, it performs our protocol. 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.

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 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.

3.2. 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*.

IV. ANALYSES

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.

Algorithm 1 Priority-based 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.
Output: Schedule CSs for all TSs in T.
For *i* =1 to ‖T‖ do
a. $St \leftarrow TSi$.
b. $Qt \leftarrow Q - Ot$:
c. Calculate the SF for each SS in *Qt*.
d. **If** Any SS $\in Qt$ has zero granted bandwidth,
If Any SSs have nrtPS traffics and zero
granted bandwidth,
Choose one running nrtPS traffics with the
largest CR.
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*.
End For
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.

4.1. Analysis of Potential Unused Bandwidth

Based on the traffic generation rate, the applications can be classified into two types: constant bit rate (CBR) and variable bit rate (VBR). Since CBR applications generate data in a constant rate, SSs rarely adjust the reserved bandwidth. As long as the reasonable amount of bandwidth is reserved, it is hard to have unused bandwidth in this type of applications. Therefore, our scheme has very limited benefit on CBR traffic. However, VBR applications generate data in a variable rate. It is hard for a SS to predict the amount of incoming data precisely for making the appropriate bandwidth reservation.

4.2. Performance Analysis of Proposed Scheme

Assume *Qn* represents a set of SSs running non-real time connections and *QCL* is a set of SSs in *Qn* scheduled as CSs. Thus, $\| QCL \|$ is at most $\| T \|$, where *T* is the set of all TSs. For any SS, $Sn \in Qn$, the probability of *Sn* scheduled on the CL, *PCL*(*n*), is derived as:
$PCL(n) = \| QCL \| / \| Qn \| \quad \| Qn \| \geq \| QCL \|$
1 Otherwise
Suppose $Yi-1$ is the amount of non-real time data arriving in frame $i-1$. The amount of bandwidth assigned in frame *i* and $i-1$ are denoted as *Wnrt i* and *Wnrt*
$i-1$, respectively. Obviously, both *Wnrt i* and *Wnrt* $i-1$ cannot be larger than *Wnrt max*, where *Wnrt max* is the maximum burst size. If the CS recycles the unused bandwidth in frame *i*, then the amount of data in queue must be more than *Wnrt i* . In the consideration of inter-frame dependence, it can be expressed as the following condition:
$Yi-1 > Wnrt\ I - \max\{0; Qnrt\ i-1 - Wnrt\ i-1\}$
Where $\max\{0; Qnrt\ i-1 - Wnrt\ i-1\}$
is the amount of queued data arriving before frame $i-1$. Since $Yi-1$ cannot be negative, the probability of the
CS, denoted as *Su*, which has data to recycle the unused bandwidth can be obtained as :
$Pu(u) = \int \_nrt\ max\ Yi-1\ P(X)\ dX$
Where *_nrt max* is the maximal amount of non-real time data arriving in a frame the probability that a CS satisfies these two conditions is derived as:
$Pr = \| Qn \| \ \Sigma j=1\ Pu(j)\ (PCL(j))\ \| Qn \|$
If the CS recycles 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 data to recycle the unused Bandwidth

4.3. 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 *Ball* represents the total bandwidth supported by the BS. Assume *Brt* represents the bandwidth reserved 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 requested by them. The investigation of our scheme in each stage is shown as follows. All investigations are validated via simulation in 1) Stage 1 (light load): This stage is defined as that the total demanding bandwidth of SSs is much less than the supply of the BS. The formal definition can be expressed as:
$Ball \gg Brt + Bnrt + BRrt + BRnrt$

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 recycle the unused bandwidth. Therefore, the probability that the CS recycles 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.,

Ball = 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 recycle the unused bandwidth may be higher than the stage 1 but still limited. 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:

Ball = Brt + _Bnrt

Where 0 ≤ _ < 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 *Precycle*. 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 is that there are rejected BRs in stage 4. It means that the probability of SSs accumulating non-real time data in queue is much higher than the one in Stage 3. Therefore, both *Pr* and *Precycle* are significantly high. Our scheme can achieve the best performance in this stage.

V. 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. PMP mode is employed in our model. Since our proposed scheme is used to recycle the unused bandwidth in UL sub frame, the simulation only focuses on the performance of UL transmissions. CBR is a typical traffic type used to measure the performance of networks in WiMAX research. However, it may not be able to represent the network traffic existing in real life. Moreover, the IEEE 802.16 network aims to serve both data and multi-media applications.

Table 1. Simulation parameter settings

Simulation area	1000mX 1000m
Number of nodes	50
Channel bit rate	2 Mbits/s
Data packet size	1024 bytes
Pause time	10s
Max speeds	0,1,5,10,15,20 m/s
Min speed	0 m/s
RCM Interval	2s

5.1. Simulation Results

The percentage of the 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 unused bandwidth and evaluate the improvement of the proposed scheme in such network status.

VI. CONCLUSIONS

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 ban 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. 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. This algorithm and result are included in the author's another research paper media access control QoS framework structure.

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