Recycling the Unused Bandwidth in IEEE 802.16 Networks

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ABSTRACT

The Physical and MAC layers have been specified in IEEE 802.16 networks. The quality of service is ensured by the bandwidth reservation. The subscriber station should reserve the bandwidth more than its demand. But the bandwidth is fully utilized by SS but not all the time. So the bandwidth has recycled by the process of recycling the unused bandwidth. The main objective of the proposed scheme is to utilize the unused bandwidth by recycling and maintain the QOS service. By recycling the throughput can be improved which maintains the QOS in the proposed scheme. During this recycling process to maintain the QOS services, the amount of reserved bandwidth is not changed. The proposed scheme can utilize the unused bandwidth up to 70% on average. Protocols and the scheduling algorithms are used to improve the utilization and throughput.

Index terms: Bandwidth Recycling, IEEE 802.16, WiMAX.

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I.INTRODUCTION

A. Subscriber Station

The Subscriber Station (SS) is generalized equipment which is used to provide the connectivity between the base station and the subscriber. Each and every subscriber station is connected with the base station; the base station allows the reservation of bandwidth by the subscriber station. Bandwidth reservation is an important part of the data transmission. Transmission SS (TS) is one type of SS which has the ability to transfer the data from one SS to another. The amount of incoming data will vary for the variable bit rate applications.

B. WiMAX

Physical and medium access layers are used in the WiMAX networks. The data can be transferred from one node to another by Physical layer. Medium access layer is used to exchange the information between two systems. It lives in the data link layer which handles the breakdown of the packets into bits. WiMAX is used to provide portable mobile broadband connectivity across cities and countries through a variety of devices.

The original version of the standard on which WiMAX is based (IEEE 802.16) [2], [3] specified a physical layer operating in the 10 to 66 GHz range. The WiMAX MAC uses a scheduling algorithm for which the subscriber station needs to compete only once for initial entry into the network. After network entry is allowed, the subscriber station is allocated an access slot by the base station. The time slot can enlarge and contract, but remains assigned to the subscriber station, which means that other subscribers cannot use it.

In addition to being stable under overload and over-subscription, the scheduling algorithm can also be more bandwidth efficient. The scheduling algorithm also allows the base station to control Quality of service (QoS) parameters by balancing the time-slot assignments among the application needs of the subscriber station [15].

II Background Information

A. Traffic Classes in IEEE 802.16 Networks

IEEE 802.16 networks have traffic classes [10], 1. Unsolicited grant services which is used to support real time data with fixed size, 2. Real time polling service is to support real time data with variable size, 3. Non real time polling service is to support non real time data with fixed size, 4. Best effort service does not have any specific QoS requirements for example email and web [16].

B. Bandwidth Request

The 802.16 standard defines two types of BR strategies, namely incremental requests and aggregate requests. When the BS receives an incremental bandwidth request, it adds the quantity of bandwidth requested to its current perception of the bandwidth needs of the connection. When the BS receives an aggregate bandwidth request, it replaces its perception of the bandwidth needs of the connection with the quantity of bandwidth requested. The self-correcting nature of the request-grant protocol requires that the SSs should periodically use aggregate Bandwidth requests. The standard states that this period may be a function of the QoS of a service and of the link quality, but do not give a precise value for it. The grant-request may be sent in two possible MAC frame types that are described in the following subsection. Only the first one (the standalone bandwidth request) can be aggregate or incremental.

III Proposed Scheme

The bandwidth request is sent to the BS to reserve the bandwidth for the data transmissions. And also the bandwidth will be adjusted by these requests. Data transmission between the SS may not utilize the reserved bandwidth. But the unused bandwidth is not recycled that is not utilized in the current frame. Releasing message should be produced by the SS which has the unused bandwidth after the data transmission. The objective of the proposed system is without introducing the extra delay and no change in existing bandwidth reservation, the same QOS guaranteed services are provided.

IEEE 802.16 networks are connection oriented. It contains BS and SS and is a centralized access control to prevent collisions. It supports the applications with different QOS services. The main objective of this paper is: 1. The Quality of service is maintained by maintain the amount of existing bandwidth.2. Utilize the unused bandwidth to increase the bandwidth utilization. The subscriber station which has opportunities to transmit data then it is called as a transmission subscriber station. Base station maintains those transmission subscriber station list called black list. Complementary station (CS) is a backup for the subscriber station which maintains the list called complementary list.

Based on the actual number of active connections, the amount of reserved resource is changed dynamically [5]. The dynamic bandwidth reservation for hybrid networks is investigated in [4] [7]. The effectiveness and performance for the hybrid network is evaluated. While minimizing signaling cost and signal blocking probability, the optimum reservation and utilization of bandwidth is ensured. In mesh mode, the system throughput is enhanced by using concurrent transmission [6]. In [8], the dynamic bandwidth request allocation algorithm is proposed for real-time services.

The subscriber station is used with non real time applications in the proposed systems. The delay requirements have more flexibility for the bandwidth recycling. Proposed scheme is to improve the throughput without introducing extra delay with same QoS services. During the data transmission, if there is some unused bandwidth then TS should transmit Releasing message (RM) to complementary station for bandwidth recycling. Due to some interruption, the releasing message may not receive at the complementary station. So the purpose and efficiency of the scheme will be reduced.

We have to ensure that the message is successfully received at the complementary station. There are some factors that are affecting the proposed system and that may reduce the effectiveness and producing extra delay, the factors are: 1. RM cannot received by the Complementary Station, 2. for the data transmission, there is no real time data in the CS.

Algorithms and protocols are used to design the proposed system. By using Scheduling algorithms and IEEE 802.16 protocol, the efficiency, accuracy and throughput are improved. Complementary list is maintained at the CS. For each transmission SS, CS is pre-assigned by the BS in the proposed system. Bandwidth recycling is proposed to utilize the unused bandwidth during the data transmission [1]. CS is mapped at least one TS. Uplink transmission is to transfer the messages from SS to BS. CL has the connection ID (CID). Between the CS and its TS, the information may be reduced to the mapping information. Bandwidth recycling is performed by the protocol and algorithm which is used by the proposed system. If there is an opportunities to recycle then inform to CS.

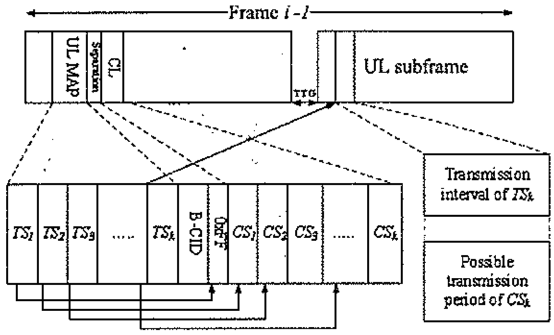

Fig. 1. The mapping relation between CSs and TSs in MAC frame

A. Protocol

IEEE 802.16 protocol is used in the proposed system. The unused bandwidth should be initialized to a known state. Unused bandwidth is calculated to utilize the unused bandwidth. Fig 2 describes the format of RM. While the TS have the unused bandwidth, it should transmit Releasing Message to CS. No agreed modulation occurred between TS and CS. To maximize the probability of receiving of RM by CS, increase the transmission coverage of the RM. BPSK has the largest coverage among all modulations supported in the IEEE 802.16 standard. RM is transmitted via BPSK without maximize the transmitted power of the TS.

Fig 3 describes an example of corresponding locations of TS, BS and CS. The coverage of modulation is represented in the solid circle. If the unused bandwidth is used by the TS then Stuff Byte Value (SBV). Broadcast Connection (B-CID) is attached with the CL and transmitted first, then SBV is transmitted to distinguish the CL from other broadcast DL transmission intervals. SBV is transmitted to inform the BS that TS has no more data. To increase the coverage of the RM without increasing the transmission power of the TS, the RM is transmitted by the TS via dished circle that is BPSK.

HT: Header Type, CI: CRC Indicator

MSB: Most Significant Bit, EC: Encryption Control

CID: Connection ID, EKS: Encryption Key Sequence

LSB: Least Significant Bit,HCS: Header Check Sequence

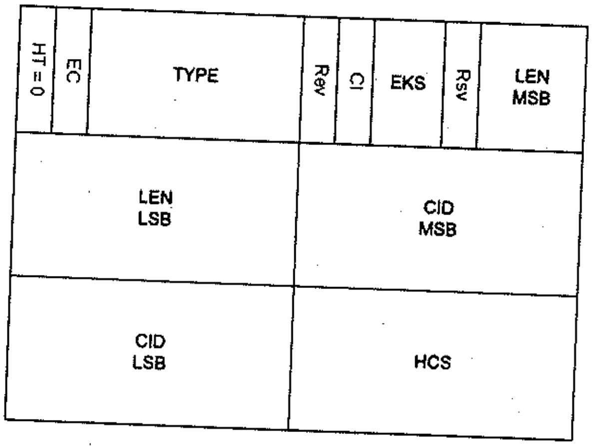

Fig.2. the format of RM

UL transmission interval is known by the CS, since both CL and UL map can be received by the CS. This time period is monitored by CS and TS receiving the RM. The unused bandwidth is recycled by the CS by using the burst profile residing in either CL or UL map. CS pads the remaining transmission interval when it does not have any date to transmit.

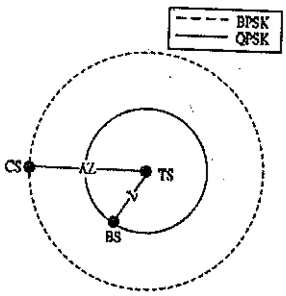

Fig. 3. An example of corresponding locations of TS, BS and CS

B. Scheduling Algorithm

Priority scheduling algorithm is described to schedule a SS with the highest priority as the CS. The scheduling factor (SF) is defined as the ratio of the current requested bandwidth (CR) to the current granted bandwidth (CG). Based on the SF, the priority of each candidate is decided. Higher priority is given to the SS when bandwidth demand is increased by the SS with higher SF. The SS with zero CG has the highest priority. Because of the quality of service requirements, the highest priority is given to the non real time polling services, then Best effort services.

1. Priority Scheduling Algorithm (PSA)

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.

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 ← TSi.

b. Qt ← Q-Ot:

c. Calculate the SF for each SS in Qt.

d. If Any SS Qt has zero granted bandwidth,

If Any SSs have nrt PS 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

2. Rejected Bandwidth Request First Algorithm (RBRFA)

Based on the available resources and scheduling policy, BRs are granted or rejected. SS has the rejected requests in the last frames because it can ensure that the SS scheduled as CS has data to recycle the unused bandwidth. This scheduling algorithm is called Rejected Bandwidth Requests First Algorithm (RBRFA). Similar to Algorithm 1, Ot represents the set of SSs which transmission period overlaps with the TS, St, in QR. All SSs in Qt are considered as possible CSs of St. A rejected BR shows that the SS must have extra data to be transmitted in the next frame and no bandwidth is allocated for these data. The RBRFA schedules those SSs as CSs on the CL, so the probability to recycle the unused bandwidth while the CS receives the RM is increased.

Algorithm 2 Rejected Bandwidth Requests First Algorithm

Input: T is the set of TSs scheduled on the UL map.

QR is the set of SSs which have rejected BRs sent from non-real time connections in the last frame.

Output: Schedule a CS for each TS in T.

For i =1 to ||T|| do

a. St ← TSi.

b. Qt ← QR-Ot:

c. Randomly pick a SS Qt as the corresponding CS of St

End For

3. History Based Scheduling Algorithm (HBA)

The performance of bandwidth recycling is the probability of the RM to be received by the CS successfully. To increase this probability, a scheduling algorithm, named history-Based Scheduling Algorithm (HBA), is proposed. The HBA is summarized in Algorithm 3. For each TS, the BS maintains a list, called Black List (BL). The basic CID of a CS is recorded in the BL of the TS if this CS cannot receive RMs sent from the TS. According to our protocol, the CS transmits data or pad the rest of transmission interval if a RM is received. The BS considers that a CS cannot receive the RM from its corresponding TS if the BS does not receive either data or padding information from the CS. When the BS schedules the CS of each TS in future frames, the BS only schedules a SS which is not on the BL of the TS as the CS. After collecting enough history, the BL of each TS should contains the basic CID of all SSs which cannot receive the RM sent from the TS. By eliminating those SS, the BS should have high probability to schedule a CS which can receive the RM successfully [14].

Algorithm 3 History-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

BL is the set of black lists of TSs.

Output: Schedule a CS for each TS in T.

For i =1 to ||T|| do

a. St ← TSi.

b. Qt ← Q - Ot - BLi

c. Randomly pick a SS Qt as the corresponding CS of St

d. IF the scheduled CS did not transmit data or SBV

Then put this CS in the BLi

End For

HBA can increase the probability of scheduling a SS which is able to receive the RM as the CS. To support the mobility, the BL of each TS should be updated periodically. Moreover, the BS changes the UL burst profile of the SS when it cannot listen to the SS clearly. There are two possible reasons which may make the BS receive signals unclearly: 1) the SS has moved to another location. 2) The background noise is strong enough to interfere the data transmissions. Since those two factors may also affect the recipient of RMs, therefore, the BL containing this SS should be updated as well.

IV Analysis And Results

The percentage on VBR traffic and potentially unused bandwidth occupied in the reserved bandwidth are calculated. Whenever the TS has unused bandwidth then it should transmit RM to CS. The transmission range depends on the transmission power and location of the TS. The transmission range may not be able to cover the CS. CS could not receive the RM, so the bandwidth cannot be recycled. The use of proposed scheme is reduced. The probability of receiving RM by CS is analyzed mathematically. Bandwidth recycling rate (BBR) is affected by this probability. BBR is to analyze the recycling percentage of unused bandwidth. Throughput gain (TG) is calculated for the performance analysis. The performances are evaluated under the traffic load.

A. Analysis of Potential Unused Bandwidth

Two types classified based on the traffic generation: variable bit rate (VBR) and constant bit rate (CBR). SSs adjust the reserved bandwidth rarely in the CBR and it generates the data in a constant rate. It reserving reasonable amount of bandwidth. So there is less amount of unused bandwidth. The proposed scheme has very limited benefit on CBR traffic. VBR generates the data in variable rate. SS could not predict the incoming data which is for appropriate bandwidth reservation. The simulation can be done by using Qualnet 4.5 [11], it is used to measure the network performances.

To serve the possible burst data, the amount of reserved bandwidth is kept by the SS. The bandwidth is reserved based on the request sent by the SS to the BS, but not all the bandwidth is utilized. There is some amount of unused bandwidth. The main analysis focuses on the unused bandwidth, the percentage of the unused bandwidth of VBR traffic is calculated potentially. The defined traffic models are based on the time interval between the arriving packets of the VBR traffic is considered as exponential distribution. The Poisson distribution is used to characterize the steady state of the traffic model.

Let λ and λmax be the mean and maximal amount of data arriving in a frame, respectively. Suppose X represents the amount of data arriving in a frame and $p(X)$ is the probability of X amount of data arriving in a frame, where $0 \leq X \leq \lambda max$. The connection passes the admission control to ensure that the BS has enough resource to provide QoS guaranteed services during the SS establishes the new connection with the BS. The policy can be considered as a set of predefined QoS parameters such as minimum reserved traffic rate ($Rmin$), maximum sustained rate ($Rmax$) and maximum burst size

($Wmax$) [9]. The BS initially assigns the bandwidth, B, to each connection in the analysis phase. The BS guarantees to support the bandwidth until reaching $Rmin$ and optionally to reach $Rmax$. Suppose Df represents the frame duration and W is the assigned bandwidth per frame (in terms of bytes). Because of the admission control policy, the burst size that the BS schedules in each frame cannot be larger than $Wmax$. The relation between W and B can be formulated as:

$$W = BDf \leq Wmax \quad (1)$$

where Qi-1 is the amount of data stored in queue before transmitting frame i - 1. Wi and Wi-1 are the amount of bandwidth assigned in frame i and i - 1, respectively. Again, both Wi and Wi-1 are at most $Wmax$. max{0;Qi-1 - Wi-1} represents the amount of queued data arriving before frame i - 1. As mentioned, Xi-1 is the amount of data arriving in the frame i -1. Thus, Xi-1 must be nonnegative. Consequently, the probability of having unused bandwidth in frame i, $Pu(i)$, is derived as:

$$P_u(i) = \int_0^{X_{i-1}} p(X)\,dX \quad (2)$$

Thus, the expected amount of unused bandwidth in frame i, $E(i)$, can be derived as:

$$E(i) = \int_0^{X_{i-1}} Xp(X)\,dX \quad (3)$$

The ratio of the totally unused bandwidth to total reserved bandwidth in N frames, Ru can be presented as :

$$R_u = \frac{\sum_{t=0}^{N-1} E(i)}{\sum_{i=0}^{N-1} W_i} \quad (4)$$

B. The Coverage of St is within the Coverage of SB

The coverage of St, denoted as Ain, can be derived as:

$$A_{in} = \pi R_t^2 \quad (5)$$

The probability of Sj receiving a RM, denoted as $Pc(t)$, is the same as the ratio of converges of St to SB:

$$P_0(t) = \frac{R_t^2}{R^2} \quad (6)$$

The coverage of the two stations (St and SB) must intersect on no more than one point. Suppose L represents the distance between St and SB.

The condition can be expressed in terms of L:

$$L \leq R - R_t \quad (7)$$

Because Rt represents the BPSK transmission range of St, we can have:

$$R_t = KL \quad (8)$$

Where K is a constant depending on the transmission power and modulation that St uses to communicate with SB. By combining equations,

$$L \leq \frac{R}{K+1} \quad (9)$$

By calculating the area with radius L, the probability of St within this category, Poc(t), is

$$P_{0c}(t) = \frac{1}{(K+1)^2} \quad (10)$$

V. 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 Qn, the probability of Sn scheduled on the CL, PCL(n), is derived as:

$$P_{CL}(n) = f(x) = \begin{cases} \frac{\|Q_{CL}\|}{\|Q_n\|}, & \|Q_n\| \geq \|Q_{CL}\| \\ 1, & otherwise \end{cases} \quad (11)$$

It is possible that the CS fails to recycle the unused bandwidth due to the lack of no-real time data to be transmitted. Thus, it is necessary to analyze this probability. 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 Wnrti and Wnrt i-1, respectively. Obviously, both Wnrt i and Wnrt i?1 cannot be larger than Wnrt max, where Wnrtmax 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 Wnrti . In the consideration of inter-frame dependence, it can be expressed as the following condition:

$$Y_{i-1} > W_i^{nrt} - \max\{0, Q_{i-1}^{nrt} - W_{i-1}^{nrt}\} \quad (12)$$

Where max{0;Qnrti-1-Wnrti-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 :

$$P_u(u) = \int_{Y_{i=1}}^{\lambda_{max}^{nrt}} P(X)dX \qquad (13)$$

RM is received at the CS and scheduled on the CS, then the unused bandwidth is recycled by the CS and it has non-real time data to be transmitted. The probability that a CS satisfies these two conditions is derived as:

$$P_r = \frac{\sum_{j=1}^{||Q_n||} P_u(j)(P_{CL}(j))}{||Q_n||} \qquad (14)$$

If the unused bandwidth is recycled by the CS, then it satisfies the following conditions: 1. CS should receive the RM successfully, 2. CL has the schedule on the SS, and 3.there is some data to recycle the unused bandwidth by the CS. The unused bandwidth is recycled by the CS, the probability for this recycling is obtained by:

$$P_{recycle} = P_r P_t \qquad (15)$$

The total bandwidth is represented by Bg and the unused bandwidth is by Bw. The total throughput gain TG is derived as:

$$TG = \frac{P_{recycle} B_w}{B_g - B_w} \qquad (16)$$

The CS cannot recycle the bandwidth until the RM is received by the CS which is sent by the TS. The system does not introduce any delay; Bandwidth Recycling does not affect any data transmissions.

In our simulation, the traffic model for these streaming videos are based on related research[12] [13] [14].

VI. THE PERFORMANCE METRICS

The simulation for evaluating the performance of the proposed scheme is based on the three metrics:

A. Throughput gain (TG):

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

$$TG = \frac{T_{recycle} - T_{no-recycle}}{T_{no-recycle}} \qquad (17)$$

Where Trecycle and Tno recycle represent the throughput with and without implementing our scheme, respectively. The higher TG achieved shows the higher performance that our scheme can make.

B. 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 recycling. It can be defined formally as:

$$UBR = \frac{B_{unused-bw}}{B_{total-bw}} \qquad (18)$$

where Bunused bw and Btotal 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 recycling opportunities.

C. Bandwidth recycling rate (BRR):

It illustrates the percentage of bandwidth which is recycled from the unused bandwidth. The percentage can be demonstrated formally as:

$$BRR = \frac{B_{recycled}}{B_{unused-bw}} \quad (19)$$

VII. Conclusions

VBR applications generate data in variant rates. The amount of data arrived is hard to predict for SSs. SS adjusts the reserved bandwidth by sending the bandwidth request to the BS 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 priority-based scheduling algorithm, three additional algorithms have been proposed to improve the recycling effectiveness.

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