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Analysis of Bandwidth Recycling in Wireless 802.16 Networks to Improve Bandwidth Utilization

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Abstract-

IEEE 802.16 Working Group and was designed to support the bandwidth demanding applications with quality of services (QoS) in metropolitan areas. Bandwidth is reserved for each application to ensure the quality of services (QoS). It is difficult for subscriber station (SS) to predict the incoming data for variable bit rate application. To ensure the QoS guaranteed services, the SS may reserve more bandwidth than its demand due to which the reserved bandwidth may not be fully utilized all the time. Based on these assumptions, new scheme is proposed, named Recycling of Unused Bandwidth without changing the existing bandwidth reservation. It allows other SS in that network to utilize the unused bandwidth when it is available of any SS through BS allocation policy. The SS accurately identify the portion of unused bandwidth and it provides the information to BS then BS provides the method to recycle the unused bandwidth. Rejected Bandwidth Request First Algorithm (RBRFA) schedules SSs those require extra bandwidth as CSs (Complementary Stations) on CL (Complementary List), so the probability to recycle the unused bandwidth while the CS receives the RM (Request Message) is increases. Hence the system throughput can be improved while maintaining the same QoS guaranteed services.

***Keywords*-IEEE802.16, WiMax, QoS, Bandwidth recycling, performance measures IEEE**

I. INTRODUCTION

A. Introduction to IEEE 802.16

The IEEE 802.16 Working Group is the IEEE group for wireless metropolitan area network. The IEEE 802.16 standard defines the Wireless MAN (metropolitan area network) air interface specification (officially known as the IEEE Wireless MANs* standard). The IEEE 802.16 designed to operate in the 10-66 GHz spectrum and it specifies the physical layer (PHY) and medium access control layer (MAC) of the air interface BWA systems [7]. IEEE 802.16 is working group number of IEEE 802, specializing in point-to-multipoint broadband wireless access (BWA).

The IEEE 802.16 standard specifies three types of transmission mediums supported as the PHY, single channel (SC), orthogonal frequency-division multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA). The assumption is that, the 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 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 SS's are classified into downlink (DL) and uplink (UL) transmissions. Time Division Duplex (TDD) and Frequency Division Duplex (FDD) supported in IEEE 802.16. Both UL and DL transmission scan not be operated simultaneously in TDD mode but in FDD mode. For Time Division Duplex (TDD)-based WirelessMAN systems, a transmission frame is defined as a fixed time duration that consists of two subframes, that is, downlink and uplink, designated for BS-to-SS and SS-to-BS transmissions, respectively [10]. This paper is focused on the TDD mode. In WiMAX, the BS is responsible for scheduling both UL and DL transmissions. All scheduling behaviour is expressed in a MAC frame. 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 BS resets its perception of that service's needs upon receiving the request. Consequently, the reserved bandwidth maybe decreased**.**

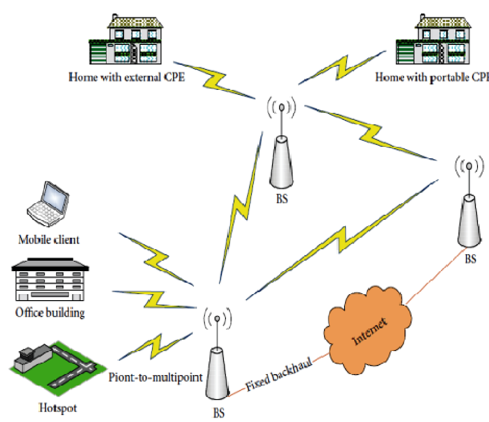

Fig. 1 IEEE 802.16 Architecture [3]

Figure 1 illustrates an example of general architecture of IEEE 802.16 networks [3]. The fixed or mobile customer premise equipment's (CPEs) connect to the central BS, the BS receives transmissions from multiple sites and sends to internet directly or via other BSs. End users (laptop, telephone, computer, . . . , etc.) inside the building, through in building networks such as Ethernet or WLAN, can connect to an outside CPE and then link to the IEEE 802.16 network.In the IEEE 802.16, PMP (Point to Multipoint) system is used where the downlink operates on a PMP basis. Thewireless link operates with one central BS and many SSs.In the downlink direction, the BS is the only transmitter andthus need not coordinate with other stations, except for theoverall TDD (time division duplex) that divides a frame intouplink and downlink transmission periods [9].

Resource management and allocation mechanisms are crucial to guarantee quality-of-service (QoS) performance in IEEE 802.16 networks. A polling-request-grant mechanism is defined in IEEE 802.16 MAC for efficient bandwidth allocation in uplink channel from multiple SSs to a central BS. Ina PMP network, if an SS wants to do uplink transmission, it first sends are quest to BS during the polling interval. On receiving the request from an SS, the BS should determine and grant to the SS the bandwidth, which is used by the SS to transmit the data. The IEEE 802.16 defines two main methods for SSs to send their bandwidth request messages: unicast polling, and contention-based polling including multicast or broadcast polling. In the first case each SS station is polled individually by the BS to send the request; in the latter all SSs contend to obtain transmission opportunities for sending requests using contention resolution mechanisms [2].

The IEEE 802.16 MAC is designed to be capable of accommodating a variety of traffics, including data, voice, and video. Then four scheduling service classes are defined to support different QoS requirements for kinds of applications: unsolicited grant service (UGS), real-time polling service (rtPS), non-real-time polling service (nrtPS), and best effort (BE).

B. Current status of WiMax

With many technologies, there is a tendency for expectations initially to far exceed the achievable reality. The "Gartner Hype Cycle for Wireless Networking, 2004" (Figure 2.) shows WiMAX technology at the "Peak of Inflated Expectations," with the "Plateau of Productivity" expected in the "two to five years" time frame [7].

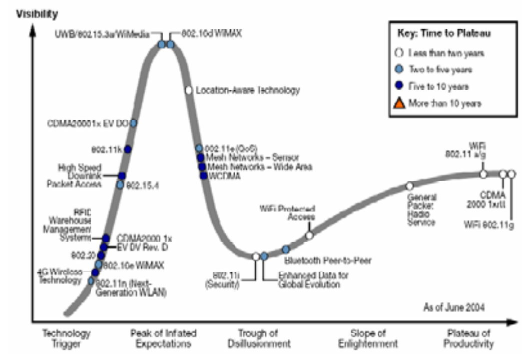

Fig. 2 Gartner Hype Cycle for Wireless Networking, 2004

C. Role of Bandwidth

There is not enough bandwidth in use nowadays and it seems that as the more of it comes into use, the more of it could be used. Of course the performance level arises all the time, but with quality of service development the bandwidth that is in hand can be used a lot better and better applications and services can be developed for the customers.

Fig. 3 Bandwidth requirement

Even if everyone knew that in a known period of time, the performance of the communications systems would grow enough for the services that one would like to implement, the developed services could already be developed and tested in the old systems with more optimal usage of the resources in hand. Surely this kind of an approach would lead to an advantage in the field of competition in data communications business, especially for the service providers.

Reliability of the transmission media plays an important role in the developed data communications equipment and in the transmission protocols. In many services, the low level of reliability makes them unusable. In a way, reliability is a component of quality of service - the more reliable the system, the higher the level of QoS.

D. MAC Frame Structure

There are two objectives of the scheme

1. To maintain the existing bandwidth reservation without changing existing bandwidth scheme.
2. The bandwidth utilization is improved by recycling the unused bandwidth.

To achieve these two objectives, a scheme named Bandwidth Recycling is implemented. The main idea of the 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 [6]. As shown in Fig. 4, each CS is mapped to at least one TS. The CL is broadcasted followed by the UL map[1].

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 maybe 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. 4,*CSj*is scheduled as the corresponding CS of *TSj*, where 1 ≤ *j* ≤ k. When *TSj*has unused bandwidth, it performs protocol.

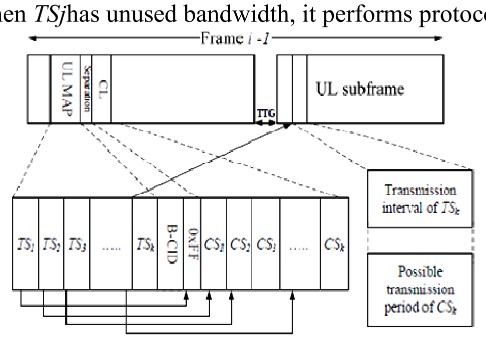

Fig.4 mapping relation between CSs and TSs in a MAC frame [5]

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. The implemented scheme is divided into two parts: the protocol and the scheduling algorithm. The protocol describes how the TS identify the unused bandwidth and informs recycling opportunities to its correspondences. The scheduling algorithm helps the BS to schedule a CS for each TS.

II. SCHEDULING CLASSES

Scheduling services represent the data-handling mechanisms supported by the MAC scheduler for data transport ona given connection. The IEEE 802.16 MAC provides QoS differentiation for the different types of applications that operate over 802.16 networks, through four defined scheduling service types. The first of the scheduling services is Unsolicited Grant Service (UGS) is designed to support real-time applications, with strict delay requirements. Grants occur on a periodic basis. The base period and the grant size are specified during the connection setup phase. Real-Time Polling Service (rtPS) is designed to support real-time applications with less stringent delay requirements, which generate variable-size data packets at periodic intervals. The BS periodically sends unicast polls to rtPS connections. The base period can be specified during the connection setup. Non-real-time Polling Service (nrtPS) and Best Effort (BE) are designed for applications that do not have specific delay requirements. The main difference between them is that nrtPS connections are reserved a minimum amount of bandwidth. Both nrtPS and BE uplink connections typically use contention-based bandwidth requests. Such requests are sent in response to broadcast/multicast polls, which are advertised by the BS in the UL-MAP. This stable data transmission relies on the scheduling mechanism of MAC layer for IEEE 802.16x.

Among these five service classes, UGS is prohibited from any polling, rtPS connections can only use unicast polling intervals to transmit bandwidth requests, nrtPS connections may adopt a mandatory unicast polling and an optional contention-based polling, while BE connections adopt a mandatory contention-based polling and do not have any unicast polling obligation. Specially, in nrtPS, the BS first has to poll the SSs by unicast polling, and then switch to contention-based polling only when no sufficient residual bandwidth to support unicast polling. Then these four service classes into two major types: the UGS and the rtPS are delay-sensitive and contention-free services; the nrtPS and the BE are delay-tolerant and contention-based services.

Table I Service Classes in WiMAX[2]

Class	Application	QoS Parameter
UGS	VOIP, E1: fixed size	Max rate, latency and jitter
rtPS	Streaming audio and video	Min rate, max rate and latency
ertPS	VOIP with activity detection	Min& max rate jitter
nrtPS	FTP	Min rate, max rate
BE	Date Transfer, Web	Max rate

III. QoS OVERVIEW

WiMAX networks are composed of two different types of nodes: the Base Station (BS) and the Subscriber Stations (SSs). The BS is responsible of performing most of the system decisions. From the perspective of QoS, these decisions include: call admission control, scheduling and resource allocation [4].

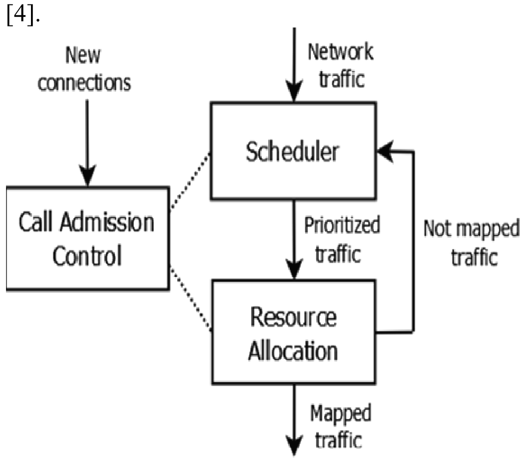

Fig. 5 IEEE 802.16 QoS architecture [4]

Call Admission Control (CAC) determines if new connections are accepted or rejected based on the available system capacity, in order to assure that the presence of a new connection will not impair the QoS requirements of the existing ones. After connections are accepted, the network traffic must be properly prioritized according to a certain scheduling policy. This scheduling policy should be able to guarantee that QoS requisites are actually being fulfilled [4].Once the traffic is prioritized, an additional process may be needed, which is resource allocation. This is the case when the OFDMA profile is used. In OFDMA the multiple access is achieved by assigning subsets of subcarriers to individual users. In principle, fully flexible allocation of the subcarriers to different users can be supported in OFDMA [8].In this physical mode, network traffic must be logically mapped into time-frequency matrix before it is actually transmitted through the wireless medium. After this step is done, some traffic may remain unmapped (traffic that does not fit in the matrix), so it must be returned to the scheduler for its transmission in a later frame. Although the scheduler is the main factor affecting QoS fulfilment, the resource allocation step may impair it. This can happen if the prioritization established by the scheduler is not fully respected.

A. Scheduling Algorithm

Algorithm 1 Priority based Scheduling Algorithm

Input: T is the group of TSs.
Q is the group of SSs on nrtPS applications.
Output: Build CSs for all TSs in T.
For x =1 to ‖T‖ do
a. St ← TSx.
b. Qt ← Q−Ot:
c. Calculate the SF for each SS in Qt.
d. If anyone SS ∈ Qt has zero granted bandwidth,
If anyone SSs has nrtPS traffics and zero granted bandwidth,
Select one running nrtPS traffics with the largest CR.
else
Select one with the largest CR.
else
Select one with highest SF and CR.
e. Build the SS as the corresponding CS of St.
End For

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, So 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 [1].

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, 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. Then rtPS 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, select one with the largest CR as the CS in order to decrease the probability of overflow.

As investigation, one of the factors causing recycling failures is that the CS does not have data to transmit while receiving a RM. To alleviate this factor, scheduling SSs which have rejected BRs in the last frame 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). It is worth to notice that the RBRFA is only suitable to heavily loaded networks with rejected BRs sent from non-real time connections (i.e., nrtPS or BE). Notice that only rejected BRs sent in the last frame are considered in the RBRFA for scheduling the current frame. The RBRFA is summarized in Algorithm 2.The BS grants or rejects BRs based on its available resource and scheduling policy. In RBRFA, if the BS grants partially amount of bandwidth requested by a BR, then this BR is also considered as a rejected BR [1].

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

Algorithm 2 Rejected Bandwidth Requests First Algorithm

Input: T is the group of TSs.

QR is the group of SSs. (which have rejected BRs sent from nrtPS Connections in the last frame.)

Output: Build a CS for each TS in T.

For y =1 to || T || do

St ← TSy

Qt← QR−Ot

Randomly pick up anyone SS ∈ Qt as the corresponding CS of St

End For

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. The other factor that may affect the performance of bandwidth recycling is the probability of the RM to be received by the CS successfully.

B.Performance Measures

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

1) *Throughput gain (TG):*

It represents the percentage of throughput which is improved by implementing our scheme [1]. The formal definition can be expressed as:

$$TG=\frac{T_{recycle}-T_{no\_recycle}}{T_{no\_recycle}}$$

Where $T_{recycle}$and $T_{no_recycle}$represent the throughput with and without implementing ourscheme, respectively. The higher *TG* achievedshows the higher performance.

2) *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:

$$UBR=\frac{B_{unused\_bw}}{B_{total\_bw}}$$

Where $B_{unused_bw}$and $B_{total_bw}$are the unusedbandwidth 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 [1].

3) *Bandwidth recycling rate (BRR):*

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

$$BRR=\frac{B_{recycled}}{B_{unused\_bw}}$$

Where$B_{recycled}$is the bandwidth recycled fromB_{unused_bw}, *BRR* is considered as the most critical metric since it directly reveals the effectiveness of our scheme [1].

IV. CONCLUSION

The 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. The reserved bandwidth may not be fully utilized all the time. Scheme is used to recycle the unused bandwidth once it occurs at any particular time. It permits 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.

The priority based scheduling algorithm can improve recycling effectively. The RBRFA 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. It schedules those SSs as CSs on the CL, so the probability to recycle the unused bandwidth while the CS receives the RM is increased.

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