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- O.物聯網(IOT)
- P.TWAREN與未來網路規劃與設計
- 最佳論文

資料夾	論文編號	論文題目	作者
A1	1049	實作Tree結構網管機制	方順展
	1174	智慧型網路控管和還原系統	林啟哲
	1177	利用Google Apps for Education建置全校性電子郵件服務	林恩德
	1218	QoS on the MAC level for Virtualization Platform	吳建鴻
	1235	建構以IPv6 傳送語音之學生宿舍網路電話系統-以國立暨南國際大學為例	陳家祿
A2	1196	以虛擬化技術建置具擴充延展的高可用性DNS系統	王英鼎
	1240	建置DHCPv6-以國立暨南國際大學為例	楊世偉
	1244	TANet 6to4服務與路由之改善	張瑛杰
	1259	基於集合覆蓋理論之IEEE 802.16j多重跳躍中繼網路規劃	游衛仁
	1261	在不可靠控制訊息面下的分波多工網路之區域資源資訊路由與波長指配演算法	熊金源
B1	1015	以合理輸入值驗證為基礎之組合型SQL指令植入式攻擊防禦	李安娜
	1018	用於網路入侵偵測的高效率字串比對演算法	李春良
	1022	預防RFID暴力攻擊之研究	李烱三
	1025	資訊安全管理系統結合情境犯罪預防理論保護個資之策略初探-德爾菲法的應用	楊期荔
	1231	可抵抗旋轉攻擊的浮水印方法	吳宗杉
B2	1051	跨領域群組RFID標籤所有權轉移協定	楊明豪
	1057	Chen等人RFID安全協定的改善	葉慈章
	1058	Chun等人的RFID搜尋協定之改善	葉慈章
	1073	基於機率的封包標記選擇策略改善IP回溯效能	彭士浩

	1079	一個以滑動視窗為基礎的資料串流隱私保護之研究	邵敏華
B3	1157	應用網站應用程式弱點檢測平台於TANet連線單位網站安全之研究	盧建同
	1160	以階段分析為基礎之SQL Injection 防禦系統	李玠樺
	1162	殭屍網路之攻防架構與分析研究	林智偉
	1171	適應式Fast-Flux惡意網域偵測系統之研究與實作	林輝堂、林英佑、江瑞偉
	1215	使用三張偽裝影像之可逆式資訊隱藏技術	許俊萍
B4	1036	基於Windows PC的區網防護軟體	陳世賢
	1217	分析與防禦協同運作之miniSOC：架構設計與實作	曾龍
	1219	針對可回復式取樣影像差值藏密技術之主動式藏密分析法	婁德權
	1221	使用OpenFlow Switch分析偵測殭屍網路	黃勝獅,曾黎明,陳仕明
	1223	殭屍網路控制與命令伺服主機主控權轉移現象之研究	蕭漢威；丁一賢；侯翔齡；龔恩緯
B5	1089	Analyzing Anomalous Spamming Activities in a Campus Network	Po-Ching Lin
	1092	以雙重認證與授權安全機制提升雲端運算環境的安全性	王淑卿
	1113	植基於多層混合機制之可逆式資料隱藏技術	郭文中
	1114	Robust Three-Factor Authentication Scheme Using ECC on Cloud Computing	胡貴蓉
	1115	可抵抗影印攻擊的文件浮水印	李志強
B6	1117	即刻阻攔:基於投遞行為之自動化回應IP位址信譽黑名單	邱品仁
	1121	基於GPGPU高效率的平行封包分類	洪哲倫
	1129	保護隱私的車載網路安全通訊技術	黃仁俊
	1132	應用決策樹演算法於網頁日誌分析	李仁鐘
	1135	智慧型手機的私密資料匿蹤	黃德成
	1150	植基於GAP高預測性的向量量化編碼資訊隱藏法	崔孝戎
B7	1087	校園ISMS文件管理系統之實作	蘇建郡,許賑王
	1239	輕量化網站應用程式防火牆	薛向程
	1262	Improvement of the novel authentication protocol for multi-server architecture without smart cards	Han-Cheng Hsiang
	1274	A Case Study of Integrated Authentication Server in NCNU	張瑛杰
	1304	線上節奏遊戲外掛偵測研究	黃建二
C1	1003	一個基於雲端運算的智慧型股價預測系統	王雅芬
	1006	Implementation of a Rapid Prototyping Tool for Small-scale Java Web Applications	Chun-Feng Hsiao
	1044	雲端文件的加解密之效能改善與分析	林俊淵
	1104	雲端系統中降低能源消耗之具時限排程策略	楊顗民；廖健勝；王耀德；董任軒；賴冠州
	1108	基於FAST TCP可支援長距離雲間快速資料移動之視窗管理法	洪盟峰、鍾博文

	1110	WiMAX DBA Algorithm Using a reserved 2-tier Max-Min Fair Sharing Policy	Pei-Chen Tseng, Jai-Yan Tsai and Wen-Shyang Hwang
C2	1130	雲端計算環境免憑證雙向鑑別機制	黃仁俊
	1134	以SAML為基礎之聯盟化單一帳號認證管理	楊哲男
	1136	使用雲端虛擬交換器進行網路虛擬化	曾惠敏
	1138	支援即時遷移SIP 雲端網路電話系統設計與實作	劉嘉惟；張惟翔；江易書；吳建宏；蘇暉凱
	1182	雲端環境中應用多排程器機制之研究	邱紹豐
	1195	Semantic-based Control Command and Control applications in Service-Oriented Cloud Computing	Der-Chen Huang
C3	1207	雲端環境下之關聯式資料庫查詢處理	邱淑怡
	1213	Android StageFright多媒體動態串流於異質多核心 平台之整合設計	張弘諭
	1220	多樣性配置下的效能分析來改善Xen上之虛擬路由器轉送效能	王俊棠
	1232	如影隨形的列印服務	陳永樵
	1247	Utilizing Cloud Technology and Panorama to Develop a Campus Tour Platform	潘郁仁
C4	1029	雲端運算內動態資源之真實成本量測研究	陳政國
	1276	Stopping Outgoing Spam By Decreasing Models	黃柏瑋
	1281	建置 Google 雲端服務之分析與研究	陳俊毅
	1295	架構於雲端運算系統儲存之動態負載平衡機制	吳庭育
D1	1043	社群網路中訊息影響之研究	陳謙民
	1127	影響社群網站黏著度之因果關係模式建構：期望確認理論的觀點	陳宜樫
	1186	臥床病人之多媒體社交資訊系統	蔡哲民
	1264	從噗浪客的自我揭露與觀眾的社會支持探索兩者所產生的綜效	柯秀佳
E1	1065	雲端安全之數位證據鑑識標準作業程序之探討	林宜隆
	1082	個人資料保護法舉證方式之探討-以鑑識會計應用為例	楊期荔
	1131	雲端虛擬化環境進行數位證據鑑識機制之探討	許硯舒；李國華；伍台國；林宜隆
	1265	基於柱狀平移之可回復資料?藏演算法實作	呂理銘
	1297	智慧型手機之數位證據鑑識探討與案例分析-使用MobilEdit工具	林宜隆,宋元傑
F1	1017	A New Technique For Down-Sizing the Halftoning Images	Chyi-Hwa Chu
	1053	基於影音串流分割片段之動態雙層快取機制	梁凱鈞
	1055	BitTorrent P2P檔案傳輸量測：接收端的效能實測與分析	胡誌麟
	1141	一個以螞蟻群聚系統為基礎的高效能入侵偵測系統	蔡崇煒
	1148	於Gigabit被動光纖網路IPTV頻寬估計系統之設計與實作	嚴仕佳；葉佳昊；蘇暉凱；吳承崧；侯廷昭

WiMAX DBA Algorithm Using a Reserved 2-tier Max-Min Fair Sharing Policy

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Abstract

This paper proposes an enhanced WiMAX DBA (Dynamic Bandwidth Allocation) algorithm using a reserved 2-tier Max-Min Fair Sharing Policy (2tMMFS_reserved-DBA) to improve the system performance than our previous 2tMMFS-DBA one. First, the algorithm reserves 10% of the total bandwidth for rtPS application before bandwidth reservations are set for nrtPS and BE applications. Next, the max-min fair sharing policy sets connection demands for bandwidth requests and QoS provisioning. The IEEE 802.16 MAC header is modified for piggybacking SS (Subscriber Station) queue status messages to help base stations determine bandwidth allocation. 2tMMFS_reserved-DBA prioritizes bandwidth provisioning. Simulation shows the proposed dynamic provisioning scheme 2tMMFS_reserved-DBA works better QoS quality for rtPS, even for nrtPS applications to satisfy the bandwidth requirements for different classes of traffic with equal or improved system throughput. [1]

Keywords: WiMax, IEEE 802.16e, QoS, DBA

I. Introduction

The increasing popularity of cellular phones and similar devices is driving the development of wireless communication technology for voice, media and high capacity data rate services. Accordingly, IEEE 802.16e [1] is expected to support quality of service (QoS) for real time applications such as voice over IP (VoIP), video streaming and video conferencing with different QoS requirements and transmission guarantee. IEEE 802.16e's Mobile Broadband Wireless Access (BWA) is an extension providing for mobile subscriber stations (MSSs) and can even support MSSs moving at vehicular speeds. IEEE 802.16e also provides for combining fixed and mobile broadband wireless access. Compared to wired internet service providers, BWA systems are capable of faster deployment and lower deployment cost. BWA installations are workable in both metropolitan and rural areas, without requiring any wired infrastructure (Fig. 1). Because of large transmission range and high data transmission rate, BWA systems can complement or perform as an alternative to last mile wired broadband access systems such as ADSL and cable modem.

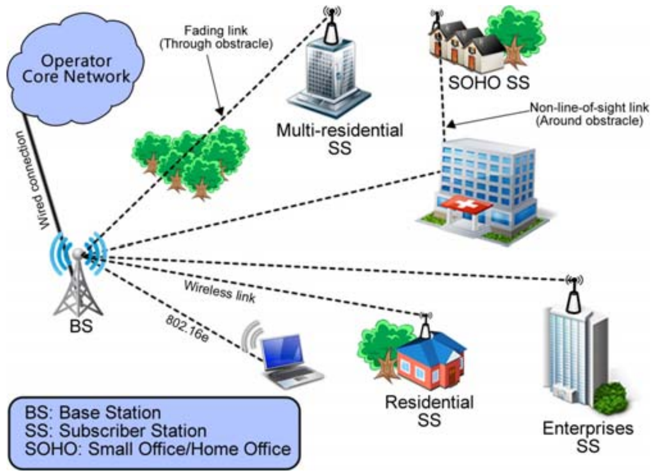

Figure 1. Example of a BWA network environment.

IEEE 802.16e is currently the most promising medium access control (MAC) protocol for high-speed wireless access in both the developed and developing world. IEEE 802.16e is a connection-oriented MAC protocol [1], [2]. At the MAC layer, each connection belongs to a single service flow type and is characterized by a set of QoS parameters. A number of uplink scheduling mechanisms are defined, including unsolicited bandwidth grants, polling and contention procedures. For uplink scheduling services, it supports five service flow types which identify specific sets of QoS parameters: UGS (unsolicited grant service), ertPS (extended real-time polling service), rtPS (real-time polling service), nrtPS (nonreal-time polling service), and BE (best effort). QoS in 802.16e is supported by allocating each connection between the SS and the BS (called a service flow) to a specific QoS class. Among them, UGS, ertPS, rtPS are suitable for real-time multimedia applications such as VoIP services.

Based on the IEEE 802.16 standard [2], WiMAX (Worldwide Interoperability for Microwave Access) provides high-speed data access for various transmission modes, e.g.

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point-to-multipoint links to portable and fully mobile Internet access. Two types of duplex methods separate uplink (UL) and downlink (DL) communication signals: Time Division Duplex (TDD) and Frequency Division Duplex (FDD). This present paper considers only the TDD system. IEEE 802.16 defines two operation modes: the mesh mode and the point-to-multipoint (PMP) mode [3], [4]. In the mesh mode, direct communication between SSs without the need of a BS is supported. For the PMP mode (Fig. 2), multiple SSs and various public networks are connected by a BS.

Before SSs send data packets to a BS, one or more connections are established between the application and the BS. Each BS/SS connection is identified by a 16-bit connection identifier (CID). The communication path is bi-directional: DL and UL. Downlinking is from BS to SS, and uplinking is from SS to BS. When using TDD for UL and DL transmissions (Fig. 3), the frame is subdivided into UL and DL subframes. Subframe duration is dynamically determined by the BS, with each subframe being composed of a number of time slots. The BS and SSs must be synchronized before data packet transmission. After coordination is established between the BS and the SSs, data packets are transmitted into predetermined time slots. Data cannot be transmitted by an SS until the BS allocates an UL grant. When taking part in contention resolution, an SS can send a bandwidth request. 802.16e thus provides strong QoS support. Although providing the main principles for a QoS architecture that supports multimedia applications, certain important issues like uplink bandwidth allocation are left to the vendors.

The remainder of this study will focus on the issue of implementation of an efficient bandwidth allocation algorithm, such as is not specified in the IEEE 802.16 standard. This paper proposes a high performance WiMAX DBA algorithm using a reserved 2-tier Max-Min Fair Sharing Policy. This algorithm first reserves 10% of the bandwidth for rtPS applications, then adopts bandwidth reservation and the max-min fair sharing policy (MMFS) for efficient allocation of the remaining bandwidth. Section 2 introduces the related studies. Section 3 describes the proposed 2tMMFS_reserved-DBA algorithm. Simulation results are found in section 4. A final summary is presented in a concluding section.

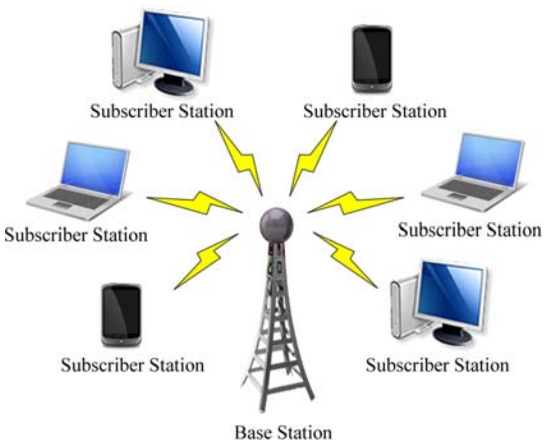

Figure 2. Topology of WiMAX PMP networks.

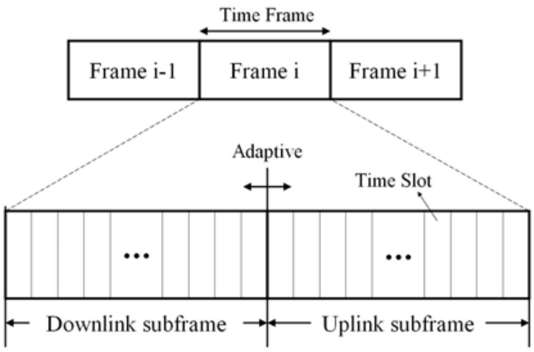

Figure 3. IEEE 802.16e frame structure with TDD.

II. RELATED WORK

The Implementation of the bandwidth allocation algorithm was not specified in the 802.16 standard [2]. A performance challenge in 802.16 TDD systems is the determination of the ratio of downlink to uplink capacities. TDD can handle flexibly both symmetric and asymmetric broadband traffic. Symmetric traffic using an equal split between uplink and downlink channels may lead to inefficient bandwidth utilization. Asymmetric traffic, such as ADSL, more demand for downloading and less for uploading, makes the bandwidth ratio determination problem even more complicated when the transport layer issue is taken into account. The last mile access for residential users tends to be asymmetric (i.e. more demand for downloading and less for uploading).

Chiang [5] proposed an Adaptive Bandwidth Allocation Scheme (ABAS) and Lei [6] proposed a CQQ scheme, dynamically adjust the Downlink/Uplink (DL/UL) bandwidth to match current DL/UL traffic in order to get better channel quality, but the method requires more complicated computing, resulting in reduced practical applicability. Chou [7] proposed the UBAR protocol (uplink bandwidth allocation and recovery), which employs a proportionally fair sharing scheme for efficient bandwidth utilization and further adopts a timeout-based UL-MAP retransmission scheme with uplink bandwidth reallocation algorithms to solve simultaneously bandwidth waste problems. But UBAR increases system complexity by modifying the TDD access mode. With regard to opportunity cost consideration, Bader [8] proposed what can be called the Rev scheme, which spans multiple time slots/frames and optimally allocates them to the different classes of traffic depending on their weights, the real-time bandwidth requirements of their connections, the channel quality conditions and the expected obtained revenues, but this scheme leads to least priority traffic BE starvation, therefore failing to achieve optimized fairness. Thus, Tsai [9] proposed the MMFS-DBA algorithm (a WiMAX DBA algorithm using a Max-Min Fair Sharing Policy). This system results in a real-time drop in calls due to insufficient real-time bandwidth reservation because no classification of real-time and non-real-time application traffic is included at the start. Therefore, our previous paper proposed a 2-tier Max-Min Fair Sharing Policy

(2tMMFS-DBA) [10] to deal with this problem, but better QoS was obtained only for rtPS applications.

III. 2tMMFS_Reserved-DBA Algorithm

The presented 2tMMFS_reserved-DBA algorithm is divided into two parts. The first part of the algorithm, before bandwidth reservation, reserves 10% of the total bandwidth for the rtPS connection, and then performs traffic classification, bandwidth reservation and QoS provisioning, i.e. the different bandwidth reservations are set. The max-min fair sharing policy (MMFS) is used for the maximum connection demand for requested bandwidth, with QoS provisioning for rtPS applications. The requested bandwidth is allocated first to rtPS applications, then to nrtPS applications and finally to BE applications. BE applications have the least priority, i.e they have no QoS guarantee. To avoid starvation of BE applications, each applications has a weighting factor to make sure each achieves a relative QoS guarantee, with BE achieving at least a minimum available bandwidth to keep the BE alive in the WiMAX network. In the second part of the algorithm, the two reserved fields of the IEEE 802.16 generic MAC header are modified via monitoring of the SS queue status for urgent packets which need to be transmitted before other packets. It also monitors remaining packets in the SS queue. SSs are also allowed to ask for bandwidth via PiggyBack messages to the BS. Under the condition no requiring additional overhead, this allows the BS to make decisions for efficient allocation of bandwidth.

The 2tMMFS_reserved-DBA scheme especially considers QoS priority for optimal allocation of BS bandwidth to the SSs with regard to quality and system performance for real-time application services. The 2tMMFS_reserved-DBA method of BS allocation of bandwidth to the SSs improves the current IEEE 802.16 network, providing better QoS quality for rtPS, even for nrtPS applications than 2tMMFS-DBA one does.

A. Bandwidth Reservation for rtPS Connection

This paper proposes a dynamic bandwidth provisioning 2tMMFS_reserved-DBA algorithm to improve the system performance relative to our previous 2tMMFS-DBA scheme for future broadband wireless systems. The proposed scheme is designed to accommodate multi-class traffic with multiple connections having different bandwidth requirements and varying channel quality conditions. The main objective of our scheme is to optimally allocate bandwidth or the corresponding time frames for each class of traffic in order to satisfy the bandwidth requirements of their connections. In addition, the proposed scheme uniquely incorporates and bounds the cost (in terms of revenue loss) of bandwidth provisioning through an opportunity cost function. This provides greater flexibility to service providers for determining the levels of bandwidth provisioning to different traffic classes so as to guarantee a certain level of revenue.

To guarantee the real-time application services have higher QoS priority, this paper first reserves 10% of the total bandwidth for the rtPS connection before bandwidth reservation, after which it considers the proportion, i.e. the number of rtPS connections occupying the number of total connections, thereby allowing determination of reserve rtPS connection bandwidth BW_{res_rtPS} as in (1). This ensures that rtPS connections have a higher QoS guarantee.

The notation in this paper is as follows:

N_{rtPS}: the number of rtPS connections

W_{rtPS} : the system weighting value for rtPS maximum connections

N_c: the total number of system connections

BW_{tot}: the total system bandwidth for the BS

BW_{res_rtPS}: the bandwidth reservation for rtPS

BW_{res_max}: the maximum bandwidth reservation for rtPS

$$BW_{res\_rtPS} = \begin{cases} BW_{res\_\max} + 10\% \times BW_{tot}, & if \ \dfrac{N_{rtPS}}{N_c} > W_{rtPS} \\ W_{rtPS} \times 90\% \times BW_{tot} + 10\% \times BW_{tot}, & if \ \dfrac{N_{rtPS}}{N_c} \le W_{rtPS} \end{cases} \quad (1)$$

Max-Min Fair Bandwidth Sharing

In order to satisfy the maximum bandwidth request for the SS connection, this paper extends the Max-Min Fair Sharing Policy (MMFS), first using (2) and (3) to obtain the average bandwidth of the rtPS and (nrtPS +BE) connections, designated respectively BW_{avg_rtPS} and $BW_{avg\_nrtPS+BE}$. Then the Max-Min Fair Bandwidth Sharing policy is executed to satisfy the demands of the maximum bandwidth request of the rtPS and (nrtPS +BE) connections.

$$BW_{avg\_rtPS} = \frac{BW_{res\_rtPS}}{N_{rtPS}} \quad (2)$$

$$BW_{avg\_nrtPS+BE} = \frac{BW_{tot} - BW_{res\_rtPS}}{N_c - N_{rtPS}} \quad (3)$$

It is first determined whether the reserved rtPS bandwidth BW_{res_rtPS} for the rtPS connection is equal to or greater than the entire bandwidth request of the rtPS connection ($BW_{req,i}$). If YES, then there is enough bandwidth for the entire bandwidth request of the rtPS connection, so the reservation bandwidth is allocated to the rtPS connection as in (4), where i is the number of SS and δ_i is the bandwidth allocated to SS_i.

$$\delta_i = BW_{req,i} \quad (4)$$

Otherwise, when the reserved rtPS bandwidth BW_{res_rtPS} is less than the entire bandwidth request of the rtPS connection ($BW_{req,i}$), then the reserved bandwidth is insufficient for the entire bandwidth request of the rtPS connection. In this case, i.e. $BW_{req,i} > BW_{avg\_rtPS}$, so the MMFS scheme in (2) is executed to allocate the minimum necessary bandwidth $R_{\min}$ to the rtPS connection, otherwise allocating the necessary bandwidth request $BW_{req,i}$ to the rtPS connection, as in (5).

$$\delta_i = \begin{cases} BW_{req,i}, & if \quad BW_{req,i} \le BW_{avg\_rtPS} \\ R_{\min}, & if \quad BW_{req,i} > BW_{avg\_rtPS} \end{cases} \tag{5}$$

Similarly, bandwidth is allocated to the nrtPS, BE connection using the same way as in (1) to (5). After allocation, the information must be updated as in (6). BW_a is the remainder of the available bandwidth. The 2nd part will execute if $BW_a > 0$ in the 1st run of 2tMMFS_reserved-DBA scheme.

$$BW_a = BW_{tot} - \sum_{1}^{N_c} \delta_i \tag{6}$$

The first part of the 2tMMFS_reserved-DBA scheme is for rtPS application service with the greatest QoS guarantee. Thus, the rtPS service is handled first, calculating the average bandwidth BW_{avg} for each service flow, then executing the MMFS scheme for fair allocation of the bandwidth. After rtPS service traffic allocation is completed, a similar process is performed for non-real-time application service and finally for the BE service.

B. Evaluation of SS Queue Status

A request may be corrupted due to a collision when SSs perform bandwidth requests. Kim [11] proposed modifying the IEEE 802.16 generic MAC header in order to let an SS pass the message to the BS by transmitting data, so the BS allows the SS bandwidth request if no collision occurs. This idea is extended in the second part of the 2tMMFS_reserved-DBA algorithm which is the same as used in the 2tMMFS-DBA algorithm [10], using two reserved bits in the IEEE 802.16 generic MAC header, one for the Critical Data bit (CD), the other for the Backlogged Data bit (BD) as shown in Fig. 4. As a result, with no additional SS overhead, the BS gets important information via an SS Piggyback message which monitors the packet status of the SS queue, including evaluation of critical data and/or backlogged data packets in the SS queue. The CD bit is for urgent packets that need to be transmitted in the SS queue. The BD bit is for packets not yet transmitted in the SS queue. The BS can use this information to allocate bandwidth more efficiently.

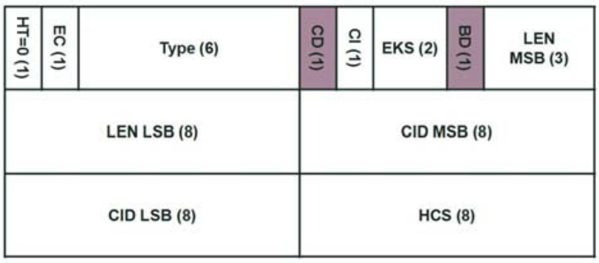

Figure 4. IEEE 802.16 generic MAC header.

Because of real-time service must take more better care of packet delay time, therefore rtPS need higher QoS priority to guarantee quality. Accordingly, the second part of the 2tMMFS_reserved-DBA system, with reference to [9], [12], calculates the rtPS packet delay expiry time $Deadline_k$ as in (7) and the expected Remain Time $RemainTime\, t_r$ for packet send-out as in (8). In (7), the rtPS packet delay expiry time $Deadline_k$ is the packet arriving time $ArrivalTime\, t_0$ plus $MaxLatency$. In (8), the expected Remain Time $RemainTime\, t_r$ for packet k to send out, is $Deadline_k$ minus the system current time $CurrentTime\, t_c$, where k is the transmitting packet number. The Critical Data CD bit is set to "1" if $RemainTime\, t_r$ is not more than one $Frame\, Duration$ time, as (9). This means that it is urgent that the packet be sent out.

$$Deadline_k = ArrivalTime\, t_0 + MaxLatency \tag{7}$$

$$RemainTime\, t_r = Deadline_k - CurrentTime\, t_c \tag{8}$$

$$If \quad t_r \le Frame\, Duration \;\; then\; CD\; bit = \;"1" \tag{9}$$

After the full run (rtPS, nrtPS, BE) of the first part of the 2tMMFS_reserved-DBA algorithm, the rest of the bandwidth BW_a is assigned averagely to the critical rtPS service flow in the SS queue. In (10), $BW_{ins,i}$ indicates the insufficient bandwidth request for rtPS service connection i after running of the first part of 2tMMFS_reserved-DBA. In (11), α_i is the average proportion to the rest of the bandwidth BW_a for the insufficient request bandwidth for rtPS service connection. The goal of (12) is to limit the obtained bandwidth so that is not greater than the original request bandwidth for rtPS service connection. Then (13) is used to update the rest of the bandwidth $BW_a^{'}$. Similar methodology is used to allocate bandwidth to the critical nrtPS and BE connections as in (10), (11) and (12).

$$BW_{ins,i} = BW_{req,i} - \delta_i \tag{10}$$

$$\alpha_i = BW_a \times \frac{BW_{ins,i}}{\sum_{SS_i \in rtPS \wedge CDbit="1"} BW_{ins,i}} \tag{11}$$

$$\delta_i^{'} = \begin{cases} \delta_i + \alpha_i, & if \;\; (\delta_i + \alpha_i) < BW_{req,i} \\ BW_{req,i}, & if \;\; (\delta_i + \alpha_i) \ge BW_{req,i} \end{cases} \tag{12}$$

$$BW_a^{'} = BW_a - \sum_{1}^{N_{rtPS}} \delta_i^{'} \tag{13}$$

After the above process, the Backlogged Data BD bit in the IEEE 802.16 generic MAC header is changed to “1” if there is rtPS service still left in SS queue, as in (14). For BSs receiving this information (i.e. BD marked to “1”), the rest of the bandwidth $BW_a^{'}$ is assigned averagely to the rtPS service flow in the SS queue. $BW_{ins,i}$ is the insufficient request bandwidth for rtPS service connection i after full run of the first part of 2tMMFS_reserved-DBA. In (15), β_i is the average proportion to the rest of the bandwidth $BW_a^{'}$ for the $BW_{ins,i}$ for rtPS service connection. Equation (16) ensures the obtained bandwidth is not greater than the original request bandwidth for rtPS service connection. Then (17) is used to update the rest of the bandwidth $BW_a^{'}$. Similar methodology is used to allocate bandwidth to the critical nrtPS and BE connections as in (14), (15) and (16).

$$If \;\; sizeof(SS_i \in rtPS) > 0 \;\; then \; BD \; bit = \; "1" \qquad (14)$$

$$\beta_i = BW_a^{'} \times \frac{BW_{ins,i}}{\sum_{BDbit="1"} BW_{ins,i}} \qquad (15)$$

$$\delta_i^{''} = \begin{cases} \delta_i{'}+\beta_i, & if \;\; (\delta_i^{'} + \beta_i) < BW_{req,i} \\ BW_{req,i}, & if \;\; (\delta_i^{'} + \beta_i) \geq BW_{req,i} \end{cases} \qquad (16)$$

$$BW_a^{''} = BW_a^{'} - \sum_{1}^{N_{rtPS}} \delta_i^{''} \qquad (17)$$

IV. Simulation Results

This paper focuses on the IEEE 802.16 point-to-multipoint (PMP) mode, which is the primary operating mode of WiMAX for residential users. Under PMP, the IEEE 802.16e wireless network with a central BS serves several SSs and each SS communicates with the BS directly (Fig. 2).

To evaluate performance, 2tMMFS_reserved-DBA functionality is simulated by the SIMSCRIPT II.5 language for numerical analysis, with the same related system and QoS parameters as [10]. The system weighting value is 0.3. The BS bandwidth is 20 Mbps. The reserved bandwidth for rtPS is 2 Mbps (=20*10%). The entry possibility of UGS, rtPS, nrtPS, BS is 30%, 50%, 70%, 100%, respectively. This means for example, if the number of the connections =100, then UGS gets 30 (=100*30%), rtPS gets 35(=(100-30)*50%), nrtPS gets 24.5(=(70-35)*70%) and BE gets 10.5(=(35-24.5)*100%). In order to obtain more detailed simulation values, the number of SSs is increased by 5.

The following result analysis is under the observation when the number of SSs is over 20. Compared with Bader’s Rev scheme [8], Fig. 5 shows that dropping rate of the proposed algorithm is 7.66% lower (better) for rtPS connections. It is 5.83% lower (better) for nrtPS connections, 13.63% lower (better) for BE connections. Compared with Tsai’s MMFS scheme [9], Fig. 6 shows that dropping rate of the proposed algorithm is 3.52% lower (better) for rtPS connections. It is 1.26% lower (better) for nrtPS connections and 1.98% lower (better) in BE connections. Compared with our previous 2tMMFS scheme [10], Fig. 7 shows that dropping rate of the proposed algorithm is 3.11% lower (better) for rtPS connections. It is 0.63% higher (worse) for nrtPS connections and 1.23% lower (better) in BE connections. Fig. 8 shows that the throughput of the proposed algorithm is 1.22 Mbps higher (better) than Rev one, 0.10 Mbps lower (worse) than MMFS one, and 0.06 Mbps lower (worse) than 2tMMFS one. The results show that the proposed 2tMMFS_reserved-DBA algorithm delivers better QoS for the prioritized rtPS users, even for nrtPS users, with approximately equal or better system throughput.

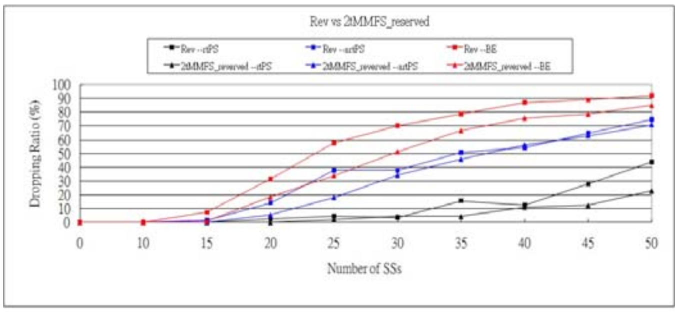

Figure 5. Dropping rate for Rev vs 2tMMFS_reserved.

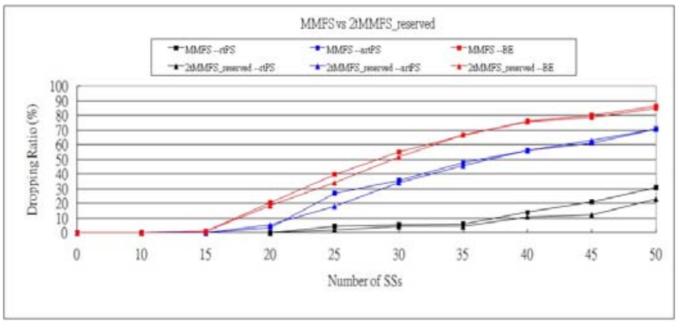

Figure 6. Dropping rate for MMFS vs 2tMMFS_reserved.

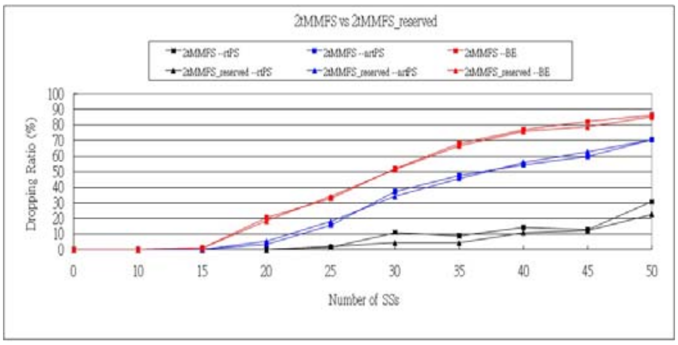

Figure 7. Dropping rate for 2tMMFS vs 2tMMFS_reserved.

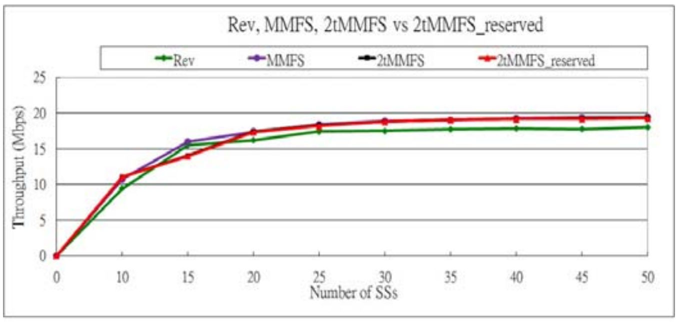

Figure 8. Throughput for Rev, MMFS, 2tMMFS vs 2tMMFS_reserved.

V. Conclusions

Future broadband wireless systems will support a wide range of multimedia applications for mobile users. However, to maximize user experience, bandwidth provisioning is critical. This paper has proposed the 2tMMFS_reserved-DBA algorithm, which improves the system performance of our previous 2tMMFS-DBA scheme. The proposed system first reserves 10% of the total bandwidth for the rtPS connection prior to bandwidth reservation, and then allows for prioritized bandwidth provisioning to different classes of traffic for support of multiple connections with different bandwidth requirements. It also incorporates a unique opportunity cost function to bound the cost of allocating bandwidth to different classes so as to maintain certain revenue levels to the service provider. Simulation results reveal the presented 2tMMFS_reserved-DBA algorithm delivers better QoS for the prioritized rtPS, even for nrtPS applications with approximately equal or superior system throughput.

Acknowledgments

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