Adaptive Multi-dimensional QoS-based Packet Scheduling Scheme for Multimedia Broadcasting over Geostationary Satellite Networks

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Abstract— **Future success towards 3G and beyond systems is in supporting a variety of multimedia services with diverse quality-of-service (QoS) demands. With their inherent broadcast capabilities, the broadband satellite networks are regarded as a promising platform for delivering multimedia services. For these systems, it is highly desired that the available resources can be utilized in an optimized way. Packet scheduling schemes play a key role in providing various QoS support for provisioning multimedia services. By taking into account essential aspects of QoS provisioning whilst preserving the system power/resource constraints, the proposed Adaptive Multi-dimensional QoS-based (AMQ) packet scheduling scheme aims to effectively satisfy diverse QoS requirements and adaptively optimize the resource utilization for satellite multimedia broadcasting. Simulation results show that the AMQ achieves much better performance than those of existing schemes by satisfying multiple QoS aspects, such as delay, throughput, channel utilization and fairness.**

Index Terms — **Packet scheduling, radio resource management, S-DMB, MBMS, quality of service.**

I. INTRODUCTION

RECENT advances in the mobile multimedia broadcasting have offered the mobile and broadcast industries a beneficial platform to deliver multimedia services to mass-market in a spectrum-efficient and cost-effective way. The rapid growth in high-speed and high-quality multimedia communications entails diverse quality-of-service (QoS) requirements to be supported for various multimedia applications including voice, data as well as real-time video streaming. A variety of initiatives [1-4] has been envisaged to provide one-to-many content distribution to mobile users. As a complementary technology to 3G mobile networks, the Satellite Digital Multimedia Broadcasting (S-DMB) system is attracting a lot of attention within the satellite community [4] as a cost-effective approach for delivering Multimedia Broadcast/Multicast Services (MBMS) services over satellite broadcasting networks. Based on its broadcast nature, the S-DMB system offers extensive coverage, low transmission cost for large numbers of terminals as well as high QoS guarantees for real time multimedia applications. By employing the wideband code-division multiple access (WCDMA) with frequency division duplexing (FDD), the system can be closely integrated with existing mobile cellular networks, and minimise potential cost impacts on both 3G cellular terminals and network operators.

Given the unidirectional nature of the S-DMB system and the point-to-multipoint services it provides, aimed at maximizing spectrum efficiency and satisfying diverse QoS requirements whilst preserving the radio resources, the design of Radio Resource Management (RRM) functionalities, especially the packet scheduling scheme, proves to be an challenging task. Although numerous studies on packet scheduling schemes have been proposed in the literature for both wire- and wireless-network [5-7], they cannot be easily applied to S-DMB because of its unique nature. One popular research subject foreseen in this context is to exploit the channel quality of fast-varying wireless link for more efficient packet scheduling [6]. However, given the unidirectional nature and long propagation delay, the S-DMB system is unable to track real time channel state information from the mobile terminal side, which makes the channel-state dependent scheduling not feasible. Even if such information were available, it still has to be exploited in an unconventional manner considering the point-to-multipoint nature of the supported services, i.e. increased heterogeneity of users interested in the same content. Furthermore, future multimedia applications feature increasingly diverse range of capabilities and QoS requirements, hence the packet scheduling has to take into account both the differentiation and fulfilment of these requirements. Finally, given the limited available power for satellite transmission, the packet scheduling has to be designed so as to optimize the overall transmit power.

Previous work on the packet scheduling in S-DMB has been systematically formulated and addressed via adaptation of two well-known scheduling algorithms [7], namely weighted fair queuing (WFQ) and multi-level priority queuing (MLPQ), both of which prove difficult and inefficient in provisioning QoS-differentiated multimedia services in satellite networks. In order to achieve better packet scheduling performance in terms of both efficiency and fairness, inherited from the proportional delay differentiation (PDD) in the context of differentiated service networks, a delay differentiation queuing (DDQ) was proposed in our early work [8], offering improved performance on delay, jitter, and channel utilization. However, DDQ experiences unbalanced performance among multiple QoS attributes, namely the gain achieved in one attribute leads to the performance degradation on other attributes. Furthermore, multimedia services feature differentiated delay constraints, applying the delay constraints for differentiated services in an equal way may lead to inferior QoS guarantee for high priority queue, therefore the delay profile has to be considered against the respective delay constraints (i.e. maximum acceptable delay) specified by the service. Finally, rather than scheduling competing flows in a static manner, to provide more adaptive and flexible QoS provisioning, it is highly desired that the scheduler is capable of adaptively selecting the best scheduling policy according to the diverse QoS preferences of the services and the instantaneous performance dynamics.

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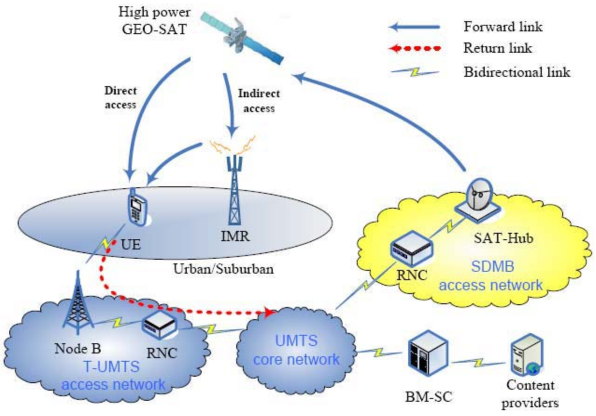

Figure 1. S-DMB system overview.

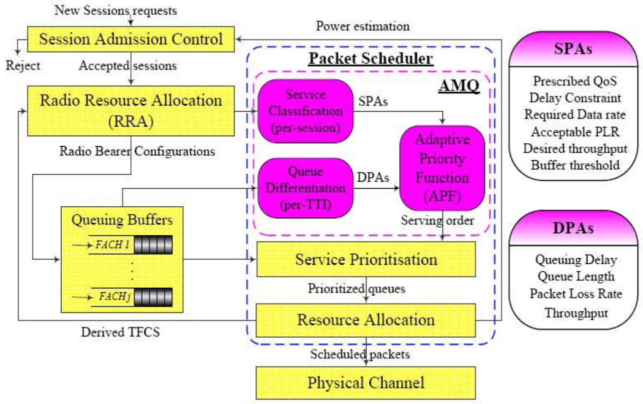

Figure 2. Proposed AMQ packet scheduling framework.

For these reasons, we propose a novel packet scheduling scheme, namely adaptive multi-dimensional QoS-based (AMQ) algorithm, at the Medium Access Control (MAC) layer that considers multiple performance criteria across layers in order to adopt the most appropriate packet scheduling policy in response to diverse QoS demands and traffic dynamics. The *novelties* of the proposed AMQ scheme are that: 1) it satisfies multiple essential QoS requirements at both application layer and transport layer, 2) adaptively tracks the queuing dynamics induced by heterogeneous traffics at the Radio Link Control (RLC) sub-layer of the data link layer, and 3) is capable of dynamically adapting itself to the most appropriate scheduling policy according to service QoS preferences and instantaneous performance variations. The proposed AMQ scheme is mathematically formulated and evaluated in a unidirectional geostationary satellite broadcast system (i.e. S-DMB) through extensive analysis/simulation studies; nevertheless, the proposed methodology can also be applied adaptively to any WCDMA-based broadcast/multicast network.

The paper starts with a brief review of S-DMB and packet scheduling. The subsequent section details the proposed AMQ algorithm and addresses its scalability and complexity. Performance of AMQ against a variety of existing packet scheduling schemes is then evaluated in Section IV, where the simulation methodology is presented and performance results are discussed. Finally, we conclude this paper in Section V.

II. S-DMB SYSTEM AND PACKET SCHEDULING

As shown in Fig. 1, the S-DMB system defines a hybrid satellite-terrestrial communication system, featuring a unidirectional geostationary satellite component that is responsible for the delivery of the point-to-multipoint MBMS services and provides a European coverage by multiple umbrella cells. Being closely integrated into the 2.5G/3G baseline architecture, the system enjoys maximum reusing of technology and infrastructure and minimum system development cost. The user equipment (UE) applies the standard 3G terminal enriched with S-DMB-enabling functions, which, given the unidirectional nature, are very limited. The terrestrial gap-fillers, identified as intermediate module repeater (IMR), are co-installed physically at the terrestrial base stations to enhance the signal reception quality and provide adequate coverage in urban, built-up areas.

It is noteworthy that no direct satellite return link is envisaged under the baseline S-DMB infrastructure, the return path is rather provided via the terrestrial link if needed. It is assumed that MBMS services are intended for transmission to UEs in either a broadcast or multicast way. In the latter case service is only delivered to the UEs within a specific multicast group. Packets from the BM-SC are firstly buffered at the satellite hub (SAT-Hub) - or Node B - in a FIFO manner before being scheduled for transmission over satellite link.

In S-DMB, the nonavailability of a return link penalizes the system effectiveness and efficiency on short-term resource allocation. Therefore, no fast power control mechanism is applicable in such a system, whilst the packet scheduling algorithm, which is the single function performing fast resource allocation, is the focus of efficient resource allocation. As shown in Fig. 2, the packet scheduling strategy can be conceptualised into the following two main steps:

- Service Prioritization: The incoming service requests are re-ordered according to the priority criteria. In selecting the respective criteria, the multiple performance attributes are considered to provide dynamic scheduling task.
- Resource Allocation: Once all the sessions are prioritized, bit rate and transmit power are assigned to each session in the each transmission time interval (TTI).

III. AMQ PACKET SCHEDULING

A. Overview

Advances in multimedia applications entail the packet scheduling algorithm to support diverse QoS among heterogeneous traffics. The proposed AMQ algorithm takes into account several key performance criteria simultaneously for assuring comprehensive QoS satisfaction. On one hand, rather than differentiating the competing sessions with respect to their inherent traffic priorities (i.e. service types), the AMQ scheme considers the application prescribed QoS requirements as a combination of multiple QoS attributes. On the other hand, the queuing dynamics of the competing flows at the RLC layer are monitored and considered in response to the fast-varying traffic dynamics. The proposed AMQ mechanism operates at the MAC sub-layer of the data link layer within the S-DMB RRM functionality entity.

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As shown in Fig. 2, the admitted ongoing sessions comprise multiple MBMS sessions with diverse QoS demands. In S-DMB, each session is assumed to retain an individual Forward Access CHannel (FACH) queue in the RLC buffer. Packets in the FACH queues are prioritized in decreasing order, based on the parameters abstracted from both radio resource allocation (RRA) at the beginning of each session starts and the RLC queuing buffer at per-TTI scale. The involved parameters are then become subject to two formulated mechanisms: service classification and queue differentiation. The former is performed as the QoS classification of competing service flows depending on their QoS requirements, which performs once during the phase of service establish or re-negotiation. Whilst the latter keeps tracking the queuing dynamics for competing flows during the session transmissions, on a TTI-by-TTI basis.

To consider both QoS criteria and queuing behaviours, we introduce an adaptive priority function (APF) for handling the contributing parameters from aforementioned two modules. The involved parameters can be effectively sub-categorized into two main streams: static priority attribute (SPA) and dynamic priority attribute (DPA). SPA refers to the QoS guarantees expressed in terms of service prescribed QoS rank, required data rate, queuing delay/buffer occupancy bound and targeted packet loss rate (PLR)/throughput, which keep constant during the session transmission. Whilst the DPA represents the instantaneous queuing behaviours at current TTI in terms of queuing delay, queue length, packet loss rate and throughput, these performance criteria keep tracking the queuing status dynamically and update themselves in per-TTI scale.

Upon receiving the SPAs/DPAs in either per-session or per-TTI scale, APF carries out the ranking and priority derivation process and comes up with a quantified priority associated with each FACH queue for current TTI. The queue with the highest priority is to be served ahead of the other competitors. The objective of the AMQ problem is to provide the highest possible level of diverse QoS satisfaction among heterogeneous multimedia subject to the system resource and power constraints. The prioritized queues are then passed to "Resource Allocation" for the allocation of required resources.

B. Algorithm Description

Taking into account the parameters abstracted from the SPA/DPA list, we define APF function $\vartheta_j(n)$ for FACH transport channel j at the current TTI n as:

$$\vartheta_j(n)=\alpha_j\cdot T_j(n)\cdot\Lambda_j(n)\cdot\Gamma_j(n)\cdot\Xi_j(n)\cdot H_j(n),\qquad j=1,\ldots,J;\ n=1,\ldots,N. \tag{1}$$

where α_j is the prescribed QoS rank for the j^{th} session, J is the total number of FACH queues, N is the total number of TTIs. For each TTI n, the instantaneous queuing behaviors in queue j can be characterized by a multi-dimensional vector ($T_j(n)$, $\Lambda_j(n)$, $\Gamma_j(n)$, $\Xi_j(n)$, $H_j(n)$), denoting the performance coefficients of queuing delay, buffer occupancy, data rate, packet loss rate and throughput, which reflect the current distance between achieved performance and its desire threshold.

The first involved profile α_j, namely the *QoS profile*, is essentially a time-independent parameter designated for each queue, reflecting the relative priority level of the service carried by the j^{th} FACH queue. The higher α_j is, the higher priority of the session is. It is noteworthy that QoS profile is the premier criterion in the APF, which means that in majority of the time, the high QoS sessions will be served ahead of their low QoS counterparts. However, this is not necessarily the truth when one or more performance criteria are degraded to such an extremely severe condition that the scheduler must take immediate action to prevent the session getting undesired loss (e.g. buffer overflow, exceptional long delay).

Due to the unidirectional nature of the envisaged S-DMB, the end-to-end delay in the network is not obtainable at the SAT-Hub. Queuing delay experienced in the RLC buffer is thereby employed in defining the delay-related metric in this paper. We define the mean queuing delay for the j^{th} FACH queue until the n^{th} TTI as:

$$\overline{\tau_j}(n)=\frac{\sum\limits_{k\in\Delta}\tau^q_{j,k}(n)+\sum\limits_{k\in\Theta}\tau^q_{j,k}(n)}{N^l_j(n)+N^q_j(n)},\qquad \begin{array}{l}\mathrm{j}=1,\ldots,\mathrm{J}.\\ \mathrm{n}=1,\ldots,\mathrm{N}.\end{array} \tag{2}$$

where $N^l_j(n)$ the number of packets that have left the j^{th} queue before TTI n, $N^q_j(n)$ is the number of packets that are queuing in the j^{th} FACH buffer at TTI n, $\Delta := \{1,2,\ \ldots,\ N^l_j(n)\}$, $\Theta := \{N^l_j(n)+1,\ldots,N^l_j(n)+N^q_j(n)\}$, $\tau^q_{j,k}(n)$ is the current queuing delay for k^{th} packet arrived in the queue j, defined as:

$$\tau^q_{j.k}(n)=\begin{cases}T^{lev}_j(k)-T^{avl}_j(k) & if\ \mathrm{k}\le \mathrm{N}^{\mathrm{l}}_{\mathrm{j}}(n)\\ n\cdot T_{tti}-T^{avl}_j(k) & if\ \mathrm{k}>\mathrm{N}^{\mathrm{l}}_{\mathrm{j}}(n)\end{cases},\qquad \begin{array}{l}\mathrm{j}=1,\ldots,\mathrm{J}.\\ \mathrm{n}=1,\ldots,\mathrm{N}.\end{array} \tag{3}$$

where $n\cdot T_{tti}$ represents current timing (T_{tti} is the value of TTI, i.e. 80ms in our simulation), $T^{avl}_j(k)$ and $T^{lev}_j(k)$ denote the arrival time and leaving time of the k^{th} packet in the j^{th} queue.

In S-DMB, a queuing delay threshold is assigned to each admitted session, representing the maximum acceptable queuing delay for the corresponding service. Let τ_j^* denote the maximum acceptable queuing delay for the j^{th} FACH queue specified by session's QoS requirements. We associate with each FACH queue j a *queuing delay profile* $T_j(n)$ given by:

$$T_j(n)=\begin{cases}1 & if\ \overline{\tau_{\mathrm{j}}}(n)\le\tau^*_j\\ \dfrac{\overline{\tau_{\mathrm{j}}}(n)}{\tau^*_j} & if\ \overline{\tau_{\mathrm{j}}}(n)>\tau^*_j\end{cases},\qquad \begin{array}{l}\mathrm{j}=1,\ldots,\mathrm{J}.\\ \mathrm{n}=1,\ldots,\mathrm{N}.\end{array} \tag{4}$$

This attribute depends on the maximum queuing delay tolerated by the corresponding service, which proportionally adjusts itself in response to the difference between the mean queuing delay($\overline{\tau_{\mathrm{j}}}(n)$) and its delay threshold. It is only effective when the mean queuing delay is beyond the designated delay threshold. It is noted that the delay threshold can be regarded as a tuneable parameter upon balancing the system performance.

Once the finite length buffer at the SAT-Hub is employed, it is vital, especially for loss-sensitive service, to maintain the queue length at a safe level to prevent the system from the excessive packet loss due to buffer overflow. Let λ_j^* denote the maximum buffer length for the j^{th} FACH queue. The *buffer occupancy profile* $\Lambda_j(n)$ for the j^{th} FACH queue is given by:

$$\Lambda_j(n)=\begin{cases}1 & if\ \lambda_j(n)\le\lambda_j^*\cdot\sigma_j\\ \dfrac{\lambda_j(n)}{\lambda_j^*\cdot\sigma_j} & if\ \lambda_j(n)>\lambda_j^*\cdot\sigma_j\end{cases},\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{5}$$

where σ_j is the buffer occupancy threshold, providing a safe bound for the buffer length, $\lambda_j(n)$ denotes the instantaneous queue length of the j^{th} FACH at current TTI.

The *date rate profile* is calculated as the ratio of the service required/guaranteed data rate against the mean data rate at current time. The instantaneous priority of each queue is affected proportionally by the difference between the mean transmitted data rate and the required data rate of each queue. Let γ_j^* denote the guaranteed data rate for the j^{th} FACH queue, the data rate profile $\Gamma_j(n)$ of the j^{th} FACH queue is defined as:

$$\Gamma_j(n)=\begin{cases}1 & \text{if } \overline{\gamma_j}(n)\le\gamma_j^*\\ \dfrac{\overline{\gamma_j}(n)}{\gamma_j^*} & \text{if } \overline{\gamma_j}(n)>\gamma_j^*\end{cases},\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{6}$$

where $\overline{\gamma_j}(n)$ denotes the mean data rate of j^{th} FACH achieved until TTI *n*, which is determined as:

$$\overline{\gamma_j}(n)=\sum_{k=1}^{N_j^l(n)}S_{j,k}\Big/n\cdot T_{tti}\ ,\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{7}$$

where $S_{j,k}$ represents packet size for k^{th} packet in queue *j*.

Similar to the queuing delay profile, the packet loss available at the SAT-Hub is also confined to the packet loss due to buffer overflow, although the packet loss in the propagation path is the most crucial factors impacting the QoS performance. Nevertheless, the packet loss due to buffer overflow is the single metric that can be monitored and controlled by the RRM entity. Let ξ_j^* denote the acceptable packet loss rate due to buffer overflow for the j^{th} FACH queue, δ_j is the packet loss rate threshold for the j^{th} FACH queue. The *packet loss rate profile* $\Xi_j(n)$ is defined as:

$$\Xi_j(n)=\begin{cases}1 & \text{if } \overline{\xi_j}(n)\le\xi_j^*\cdot\delta_j\\ \dfrac{\overline{\xi_j}(n)}{\xi_j^*\cdot\delta_j} & \text{if } \overline{\xi_j}(n)>\xi_j^*\cdot\delta_j\end{cases},\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{8}$$

where $\overline{\xi_j}(n)$ denotes the mean PLR of j^{th} FACH achieved until TTI *n*, which is defined as:

$$\overline{\xi_j}(n)=\frac{N_j^d(n)}{N_j^q(n)+N_j^l(n)},\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{9}$$

where N_j^d represents the total number of packets that are dropped due to buffer overflow for the j^{th} FACH until TTI *n*.

In this paper, we consider the throughput as the buffer throughput at SAT-Hub, which is obtained by dividing the total bits successfully scheduled and delivered to the physical channel for radio frame transmission with the total bits arrived in a specific FACH queue until current time. Let η_j^* denote the target throughput for the j^{th} FACH queue, the *throughput profile* $H_j(n)$ for the j^{th} FACH queue is given by:

$$\mathrm{H}_j(n)=\begin{cases}1 & \text{if } \overline{\eta_j}(n)\le\eta_j^*\cdot\varphi_j\\ \dfrac{\overline{\eta_j}(n)}{\eta_j^*\cdot\varphi_j} & \text{if } \overline{\eta_j}(n)>\eta_j^*\cdot\varphi_j\end{cases},\qquad \begin{matrix}j=1,\ldots,J.\\ n=1,\ldots,N.\end{matrix}\tag{10}$$

$\overline{\eta_j}(n)$ denotes the mean throughput of j^{th} FACH that has been achieved so far, which is defined as:

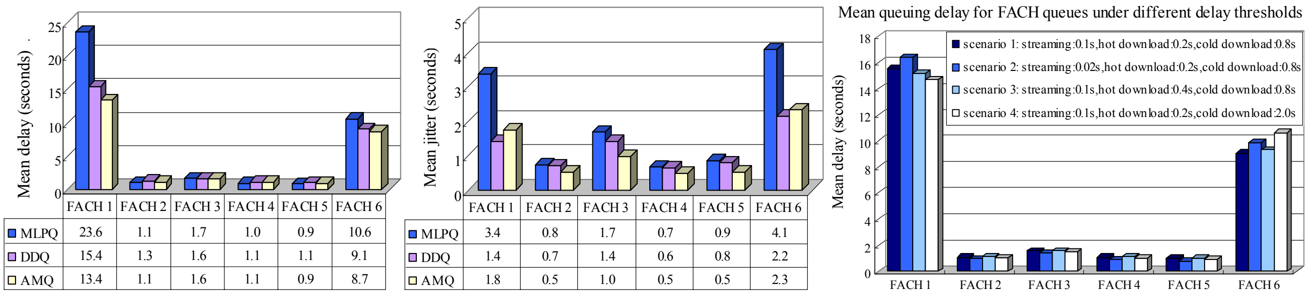
$$\overline{\eta_j}(n)=B_j^s\big/B_j^a\ ,\qquad j=1,\ldots,J;\ n=1,\ldots,N.\tag{11}$$

where B_j^s represents the total number of bits that are successfully scheduled for transmission for the j^{th} FACH until current TTI, B_j^a represents the total number of bits that are arrived in the j^{th} FACH so far.

C. Flexibility and scalability

In the above context, we assume all the contributing profiles influence the APF in an equal way during the session transmission. However, fixed setting upon all performance criteria may not work well in provisioning multimedia data with diverse QoS demands and fast-varying traffic dynamics, the performance gain achieved in one profile may sacrifice the performance on other profiles, which may be even more important for the specific service. The proposed AMQ algorithm provides a tuning ability over essential performance profiles to further optimize the scheduling performance. By observing the QoS preferences specified by service and the behaviours of queuing status, the AMQ scheduling entity dynamically adjusts the following "tuning knobs" on a TTI-scale: 1) queuing delay threshold (σ_j), 2) PLR threshold (δ_j), and 3) throughput threshold (φ_j). By selecting an appropriate combination of the above thresholds for each queue, the serving orders of competing flows can be effectively managed. According to the sensitivity preferences of service QoS classes, through giving flexible weights to different profiles in terms of delay, PLR and throughput, it is therefore possible to adaptively select the scheduling policy to allow for different treatment of diverse QoS demands and to maintain optimal resource utilization. For example, the σ_j is preferred to be set higher for delay-tolerant PLR-sensitive service, whilst preserving a target δ_j, φ_j. Some applications have stringent constraints on the achieved throughput rather than PLR, thus the scheduler should apply lower φ_j for better throughput performance whilst releasing the constraints set by σ_j, δ_j.

From the viewpoint of implementation, the proposed AMQ algorithm introduces extra computation complexity due to its nonlinear (with loop iterations for selection sort operation) and nondeterministic (with unpredictable variable) nature. In order to examine the scalability of the proposed AMQ algorithm, the *Big O notation* [9] is employed for determining the involved computational complexity. We assume that there are *n* sessions to be transmitted to UEs in a number of multicast groups, located within multiple sectors of a satellite beam. We consider a single typical TTI period, with all the tuneable thresholds already assigned for current TTI. Derived from the worst case scenario, where the processing time is the most expensive among all possible scenarios, with the input size of *n*, the involved computational time complexity (i.e. running time)



(a) (b) (c)

Figure 3. Queuing delay/jitter statistics for AMQ scheduling at the RLC buffer in SAT-Hub.

TABLE I. RADIO BEARER MAPPING CONFIGURATION (KB/S)

S-CCPCH id	1			2		3
S-CCPCH bit rate	384			384		384
FACH id	1	2	3	4	5	6
Streaming	-	256	64	256	128	-
Hot Download	64	-	-	-	-	-
Cold Download	-	-	-	-	-	384

required for MLPQ and DDQ are $O(n)$ and $O(n^2)$ respectively, whilst the AMQ algorithm requires an overall complexity of $O(n^2)$, featuring typical quadratic statistics.

IV. PERFORMANCE EVALUATION

A. *Simulation Methodology*

In order to evaluate the performance enhancement of the proposed cross-layer packet scheduling scheme, a system-level simulator implementing the S-DMB system has been developed with *ns2* and MATLAB. Taking advantage of its available built-in code blocks, relying heavily on the C++ code modules, we developed additional code modules implementing S-DMB specific features. The AMQ packet scheduling mechanism is physically implemented in the SAT-Hub (Node-B) employing the S-DMB functions, supporting three types of QoS classes, namely: 1) real-time video streaming, 2) hot download, and 3) cold download [10]. The streaming traffic model applies publicly available trace files for video streaming traffics. Traffic characteristics associated with hot- and cold- download services -or, push-and-store services- follow the ns-2 *Pareto* distribution, with different traffic priority assigned. In addition, we choose different guaranteed data rate in order to examine the performance between users with different rate requirement.

Our link budget simulation results provide the E_b/N_o v.s BLER look-up curves of each FACH. The simulation period is set as 1000s or 12500 TTIs. Various queuing delay threshold values are applied and examined for the specific scenario, showing the range of the performance gain against tuning the delay threshold parameter.

A wide variety of traffic mix scenarios and physical channel capacities are evaluated via simulations, we select an indicative scenario, where 6 individual MBMS sessions with diverse QoS profiles in terms of service type, data rate, and QoS constraints are considered for broadcast transmission; each session is carried by a single FACH queue. Three Secondary Common Control Physical CHannels (S-CCPCHs) are used for carrying heterogeneous multimedia services, the considered radio bearer mapping scenario is given as Table I. We compare the performance of the proposed AMQ packet scheduling with those of MLPQ and DDQ in this paper. Several main parameters, which have significant impact upon the overall system performance, are analyzed and discussed in the following.

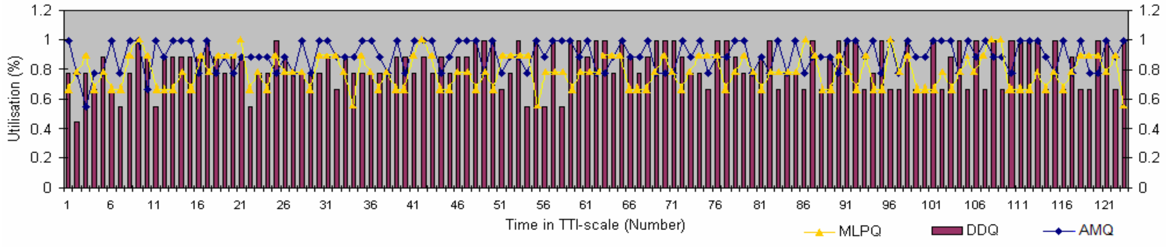
B. *Queuing delay evaluation*

In Fig. 3(a), the queuing delay performance for AMQ is compared to MLPQ and DDQ for all the allocated real-time streaming and download sessions. Rather than achieving lower download delay by scarifying streaming delay performance in DDQ case, the proposed AMQ managed to deliver download sessions with even further lower queuing delay whilst maintaining the similar performance on streaming sessions. From the viewpoint of human perception, it is worth noticing that the delay variation of MBMS streaming service shall be limited, to preserve the time variation between information entities (i.e. packets) of the stream [11]. As seen from Fig. 3(b), although the background services suffer from higher jitter for AMQ than DDQ, a considerable performance gap with respect to queuing jitter is achieved for all streaming services, which makes it an attractive solution for real-time jitter-sensitive streaming service.

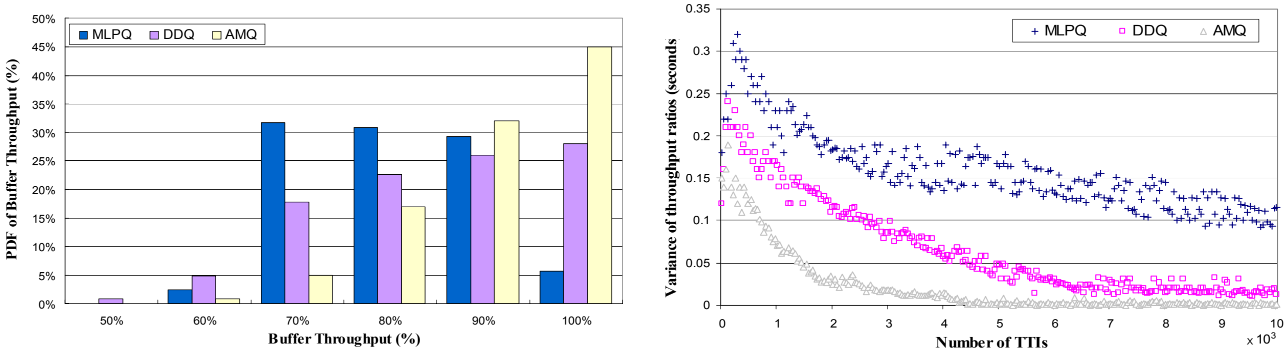
Fig. 3(c) investigates the range of performance gain obtained by adjusting variable delay threshold values. By tuning the delay threshold value for a specified QoS service class, the AMQ is capable of optimizing the delay performance amongst competing flows. For example, in comparison with Scenario 1, cold download FACH 6 suffers from worse delay in Scenario 4 when its delay threshold is increased from 0.8 second to 2.0 second, but this leads to the performance gain on the streaming and hot download FACHs.

C. *Channel utilization and buffer throughput*

The impacts of AMQ on the performance of channel utilization and throughput are studied. Herein the channel utilization refers to the ratio obtained by dividing the total information bits transmitted over the air with the maximum supported capacity bits for considered physical channels. the From Fig. 4(a), by adaptively re-utilizing wasted resources among sessions with diverse QoS class, it is observed directly that AMQ has managed to offer better resource utilization over the existing schemes.



(a)Instantaneous physical channel utilization over a sample simulation period



(b)PDF of buffer throughput

(c)Variance of buffer throughput

Figure 4. Physical channel utilization, throughput and fairness analysis.

As defined in section III, herein the parameter of interest is the buffer throughput achieved amongst different schemes. The comparison of probability distribution function (PDF) of buffer throughput is depicted in Fig. 4(b). By having achieved higher buffer throughput with higher probabilities, AMQ outperforms MLPQ and DDQ with a considerable improvement.

D. Fairness analysis

The variance of buffer throughput represents the fairness of a packet scheduling algorithm, lower variance means a fairer scheduling scheme. In Fig. 4(c), the performance of the proposed scheme is compared to MLPQ and DDQ in terms of fairness, where AMQ achieves the lowest variance values with the fastest convergence curve, which proves that it can provide better throughput equality in a shorter time.

V. CONCLUSIONS

A novel AMQ packet scheduling algorithm is proposed for the S-DMB system in this paper. By taking into account multiple essential performance aspects simultaneously, the proposed AMQ scheme not only satisfies diverse QoS demands, but also is capable of adopting the best possible scheduling policy according to traffic priority and queuing dynamics. The proposed scheme is employed at the satellite hub for the S-DMB system, the performance is evaluated via simulation studies. The results show that, compared with the existing schemes, the AMQ is capable of achieving considerable performance gain on queuing delay/jitter, throughput, channel utilization and fairness with desired flexibility and scalability features. In the future research, we will develop the packet scheduling algorithms for the S-DMB system in the presence of a return link, where the channel quality associated with each user can be investigated so as to improve the scheduling decision.

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