rtPS Scheduling with QoE Metrics in Joint WiMAX/Satellite Networks

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Abstract. This paper improves a previously proposed scheduling algorithm that is responsible to share the allocated capacity to the uplink traffic of an integrated satellite and WiMAX network. The target of this improvement is to schedule traffic of real time connections based on Quality of Experience (QoE) metrics. After a bibliographic search on QoE metrics, the FC-MDI (Frame Classification-Media Delivery Index) metric is chosen to be used in the proposed algorithm for the scheduling of real time connections. Two versions of the algorithm are proposed and evaluated. Simulation results show that the proposed algorithm considerably improves the QoE and the mean delay of the real time connections.

Keywords: DVB-RCS, WiMAX, QoE, rtPS, scheduling.

1 Introduction

IEEE 802.16 [1] is a standard that aims at filling the gap between local and wide area networks, by introducing an advanced system for metropolitan environments. In this system, also known as WiMAX, both point-to-multipoint (cellular) and mesh mode configurations can be supported, while node mobility is also covered by amendment 802.16e [2]. One of the main advantages of the standard is the large degree of flexibility it provides by supporting a wide range of traffic classes with different characteristics and quality of service (QoS) requirements. This is attained through a large set of parameters that allow users to describe in detail their traffic profiles and service needs. On the other hand, Digital Video Broadcasting – Return Channel Satellite (DVB-RCS) [3] is an open standard for bi-directional transmission of digital data over the satellite network. DVB-RCS is a fully mature open, satellite communication standard with highly efficient bandwidth management, making it a cost-efficient alternative in many cases. It mainly describes the uplink direction of a satellite network, providing advanced QoS capabilities for requesting and acquiring capacity for demanding services.

The advantage of combining the two technologies is that a satellite network can be used for interconnecting WiMAX islands with the Internet and avoiding layout of expensive backbone infrastructures. This can provide reliable solution, especially in rural areas or locations affected by environmental factors, e.g. islands, mountains, etc. However, a satellite network experiences large round trip delays that can deteriorate

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quality especially for real-time applications. In [4], we have investigated how the two networks can co-operate, especially in terms of QoS, in order to reduce end-to-end delays and packet losses due to expiration. In this work, we extend [4] towards improving a part of the proposed mechanism which shares capacity to real time connections of the WiMAX network based on the use of Quality of Experience (QoE) metrics, to consider the overall performance of the system from the users' perspective. QoE expresses user satisfaction both subjectively and objectively, which are the two main categories of QoE metrics.

The paper is organized as follows. Section 2 presents an overview of using specific metrics for QoE management. Section 3 describes the basic architecture of our mechanism and the proposed improvement in the sharing of capacity to real-time traffic based on QoE metric, while section 4 contains the description of the simulation model used for evaluation purposes together with the obtained results. Finally, section 5 concludes the paper.

2 QoE Metrics for QoE Management

There is a large number of papers that use QoE metrics for measurement of video quality but very few that use these metrics for QoE management. [6] is the only work in UMTS that investigates the possibility of using QoE as a metric for scheduling decision. In order to get QoE feedback in real time, Pseudo-Subjective Quality Assessment (PSQA) technique is used [5], which is a hybrid approach between subjective and objective evaluation. PSQA metric starts by selecting the factors that may have an impact on the quality, such as: codec, bandwidth, loss, delay, and jitter. Then these factors are used to generate several distorted video samples, which are subjectively evaluated by a panel of observers. The results of the observations are then used to train a Random neural network (RNN) in order to capture the relation between the factors that cause the distortion (objective approach) and the perceived quality by real-human (subjective approach). In [6] loss rate (LR) of video packet and mean loss burst size (MLBS) are considered as the quality-affecting parameters for the training of RNN. MLBS parameter is the average length of a sequence of consecutive lost packets in a period of time and captures the way losses are distributed in the flow as this affects dramatically the perceptual quality of the video. After the training of RNN, Mean Opinion Score (MOS) is estimated in real time, which is the basic subjective metric, so that the scheduler can get MOS scores for making scheduling decision. [7] proposes a novel rate-adaptation mechanism based on QoE, using PSQA tool for obtaining MOS in real-time. The parameters used in PSQA are the loss rate of the I frames, loss rate of the P frames, loss rate of the B frames, and the MLBS of the I frames. The idea of the proposed scheme is to use QoE feedback from mobile stations to provision the current condition of the network and then adapt the rate accordingly. In [8], a novel packet scheduling algorithm for multi-hop wireless networks that jointly optimizes the delivery of multiple video, audio, and data flows according to the QoE metrics is developed. A previously proposed model to determine user satisfaction is used, where quality is given in terms of the objective metric Peak signal to noise ratio (PSNR), while MOS is produced through a non-linear curve mapping PSNR to MOS. The proposed scheduler locates sets of packet combinations across all active flows of all users that pass the node that would satisfy a given buffer reduction. For each of these combinations, an estimation of the user satisfaction expressed in MOS decrease for each flow is calculated. The scheduler then drops the packets whose combination results in the smallest decrease in QoE satisfaction based on a proposed cost function.

The target of this paper is to improve a previously proposed mechanism, in order to make the scheduling of Real-time Polling Service (rtPS) connections based on the use of QoE metrics. rtPS is the service in WiMAX that supports data streams consisting of variable-sized data packets that are transmitted at fixed intervals, such as MPEG video. QoE metrics are usually used for the assessment of the transmission of video on different network conditions, and rarely used in scheduling solutions, while they have never been used till now for scheduling in satellite networks. Subjective metrics are the most accurate for QoE measurements, as they are evaluated by real human. Their main shortcoming is that they are time-consuming and high-cost in man power. Thus, they cannot be easily repeated several times nor used in real-time (being a part of an automatic process). As the need for the proposed improvement is to be part of an automatic procedure, subjective and hybrid QoE metrics are excluded. From the already proposed solutions in other kind of networks, the solutions proposed in [6] and [7] have the drawback of using the PSQA metric for scheduling and QoE management. On the other hand, the solution proposed in [8] has increased complexity, as it calculates the QoE produced by every possible packet dropping. Our proposal aims to be simpler in order to be used in satellite networks, which have the drawback of delays. For all these reasons, the Media Delivery Index based on Frame Classification (FC-MDI) metric is chosen to be used in the existing mechanism, as it is an objective metric that gives a different weight to the loss of I, P, B frames which is useful for the scheduling of different categories of frames. The FC-MDI metric is an extension of the MDI (Media Delivery Index) metric [9], which is an objective metric that contains two numbers separated by colon: the delay factor (DF) and the media loss rate (MLR). DF is a time value indicating how many milliseconds' the buffer must be able to contain to eliminate jitter, while MLR is the computed difference between the number of media packets received during an interval and the number of media packets expected during an interval. Nevertheless, in MLR some important information is lost, such as whether the IP packets lost are consecutive or inconsecutive. It does not consider the quality degradation that suffered some propagated loss from previous temporally related frames, so [10] proposes FC-MDI which takes frame classification into account to improve the performance of the MDI measurement. It distinguishes the packet loss based on the frame classification, and gives in each frame a different weight. In all types of frames, the I-frame plays the most important role, as the rest frames of the whole group of pictures (GOP) cannot decode normally if the I-frame is lost. Compared with B-frame, P-frame relies less on its previous I-frames and P-frames.

3 Proposed Scheduling Solution

In [4], an interconnection of a satellite and a WiMAX network is proposed, assuming that one or more of the Return Channel Satellite Terminals (RCSTs) are also WiMAX

Base Stations (BSs) serving a number of Subscriber Stations (SSs). This integrated scheduling provision mechanism consists of three main parts: PartA is an entity at the RCST/BS that makes the capacity requests following a prediction-based approach, PartB is an entity at the Network Control Center (NCC) that allocates resources and creates the Terminal Burst Time Plan (TBTP), while PartC is an entity at the RCST/BS that shares the given capacity among its WiMAX subscribers. PartB accepts the capacity requests made from all PartAs, processes them and creates the TBTP in order to allocate the capacity of a superframe among the different RCSTs. PartC, located at the RCST/BS, contains the scheduling algorithm that is responsible to share the allocated capacity, to the uplink traffic arriving from the WiMAX network. In more detail, PartC classifies uplink traffic arriving from the SSs into five queues (UGS_queue, rtPS_queue, ertPS_queue, nrtPS_queue, BE_queue based on each packet's QoS service type). It then interprets TBTP (knows exactly which slots has been assigned to it) and selects which packets will be transmitted. This selection is made based on a priority scheme: it first selects packets from the UGS_queue, then from the rtPS_queue, then from the ertPS_queue, then from the nrtPS_queue and finally from BE_queue. Finally, it is also responsible to discard packets that are expired based on the deadlines set for their transmission to the satellite network and keep statistics on the packets transmitted and discarded. The *RTFS* (Real Time FIFO Scheduler) algorithm treats the transmission of packets of video connections with the logic of a First In First Out (FIFO) queue. The packets of all video connections are inserted in the rtPS_queue based on the order of their arrival. During the superframe, the PartC transmits, whenever it has available capacity based on the TBTP, the packets from this queue. A packet is dropped, if it has been expired due to delay. The performance of the mechanism was demonstrated in paper [4].

The target of this paper is to improve the *RTFS* algorithm, in order to make the scheduling of rtPS connections based on the use of FC_MDI QoE metric. The proposed *FC_MDI_S* algorithm makes the following procedures in the beginning of every superframe :

a) Dropping of the packets that are expired due to delay factor.
b) Computing of the *FC-MLR* value of every connection based on the loss of I, P, B frames in the previous superframe. The *FC-MLR* value is computed as follows :

$$FC - MLR = \frac{\alpha * I_{PLoss} + \beta * P_{PLoss} + \gamma * B_{PLoss}}{interval},$$

where α, β, γ are weights with $(3 \geq \alpha > \beta > \gamma \geq 0, \alpha + \beta + \gamma = 3)$ and I_{PLoss}, P_{PLoss}, and B_{PLoss} are respectively the number of lost I, P and B frames.

c) Sorting of the video connections based on the *FC-MLR* value of the connections computed on step b under two versions. The first version is named *FC_MDI_SG* and has a greedy logic. In order to preserve the connections that have good quality, the connections are sorted based on *FC-MLR* value in ascending way, from the best quality to the worst. This will lead to the maintenance of the quality of some connections and the starvation of some other connections. The second version is named *FC_MDI_SF* and has a fair logic. In order to be fair and maintain all connections (even in worse quality), the connections are sorted in the opposite way than the previous version from the worst quality to the best.

$P_{3,3}$	$P_{1,3}$	$B_{2,1}$	$B_{3,1}$	$P_{3,2}$	$P_{2,2}$	$B_{1,1}$	$P_{1,2}$	$P_{2,1}$	$P_{3,1}$	$I_{3,1}$	$I_{2,1}$	$P_{1,1}$	$I_{1,1}$

Fig. 1a. Packets of three connections to the rtPS_queue of PartC

$B_{3,1}$	$B_{2,1}$	$B_{1,1}$	$P_{3,3}$	$P_{3,1}$	$P_{2,3}$	$P_{2,2}$	$P_{2,1}$	$P_{1,3}$	$P_{1,2}$	$P_{1,1}$	$I_{3,1}$	$I_{2,1}$	$I_{1,1}$

Fig. 1b. Transmission of packets under FC_MDI_SG algorithm

$B_{3,1}$	$B_{2,1}$	$B_{1,1}$	$P_{3,3}$	$P_{1,3}$	$P_{3,2}$	$P_{2,2}$	$P_{1,2}$	$P_{3,1}$	$P_{2,1}$	$P_{1,1}$	$I_{3,1}$	$I_{2,1}$	$I_{1,1}$

Fig. 1c. Transmission of packets under FC_MDI_SF algorithm

During the superframe, the PartC transmits whenever it has available capacity based on the TBTP. The *FC_MDI_SG* versio*n* transmits all the packets of one category, giving priority to I frames, then to P frames and last to B frames, and then moves on to packets of the same category of another connection. The order of the connections is the one computed to step c of the algorithm. On the contrary, the *FC_MDI_SF* versio*n* transmits one packet of one category from all connections, and then another packet of the same category from all connections, until exhausting all the packets of this category. After the transmission of all packets of the previous category, it moves on to the next category giving priority to I frames, then to P frames and last to B frames. The order of the connections is the one computed to step c of the algorithm. Figure 1 presents an example of transmission of packets under the previously proposed versions. In more detail, Figure 1a presents the frames of three connections as they have arrived in the rtPS_queue of PartC, Figure 1b presents the transmission of frames under *FC_MDI_SG* version and Figure 1c presents the transmission of frames under *FC_MDI_SF* version. The pointer i in the $Frame\_Categor_{yi,j}$ of Figure 1 shows the connection, while the pointer j shows the order of the packet of the specific frame category of i connection. Finally, the transmission of these packets as well as the dropping of the packets described in step a, are admeasured to the computing of the *FC-MLR* value of the connections for the next superframe.

4 Simulations

In order to measure the performance of the proposed algorithm, we accommodated the simulation program presented in [4]. The program is constructed in C++ and simulates the full operation of WiMAX network, as well as the DVB-RCS for the return link of a satellite network. We use the simulation scenario presented in [4] with three DVB-RCS terminals each one interconnecting a WiMAX network, all with the same number of subscribers. In the previous simulation scenario, every SS had multiple types of traffic, including video, compressed and uncompressed voice, ftp

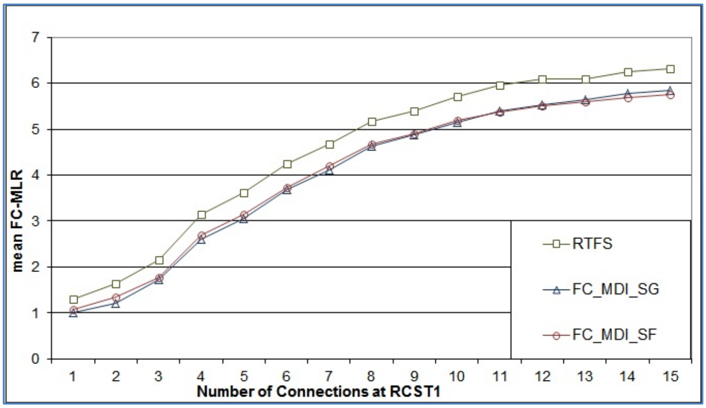

Fig. 2. FC_MLR per proposed algorithm

and http. In order to present the difference of the proposed mechanism regarding the QoE of the video connections, in the present simulation scenario every SS has only one video connection. The same video trace is used for every SS, in order to present the difference between the greedy and fair version. The source of this video trace is the "Alladin" film from "http://trace.eas.asu.edu/TRACE/ltvt.html" in high quality ("Verbose_Alladin.dat" file).

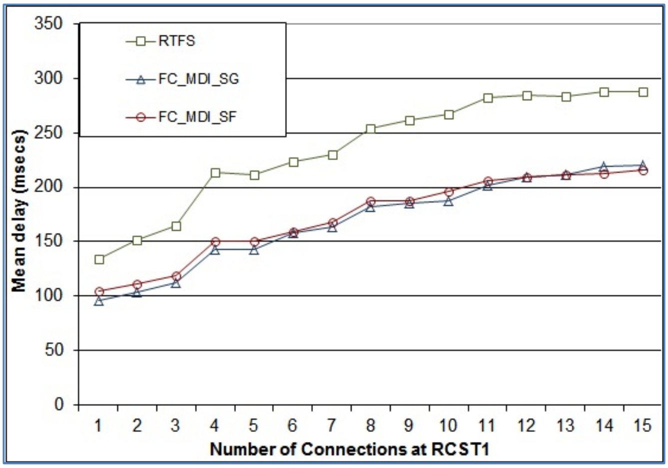

Fig. 3. Mean delay per proposed algorithm

The time frame length in WiMAX is set to 1msec, the packet size to 54 bytes and the modulation to 64-QAM for all SSs, leading to a transmission speed of 120Mbps (as indicated in the standard). The latency used in the WiMAX network for rtPS connections is 50msec.

The maximum transmission rate in the return link of the satellite network is 6Mbit/s, while the duration of the frame is set to 50msec and the superframe to

500msec, equal to the round trip delay. During the logon phase, each RCST terminal sets the CRA_level equal to zero (in order to present the difference between the quantity of the requested slots), the RBDC_max to 700kbps, the RBDC_timeout equal to 2 and the VBDC_max equal to 11 slots per frame. The latency used in the satellite network is 300msec.

Figure 2 presents the mean *FC-MLR* value for all connections of a SS of the two different algorithms. In the RTFS algorithm, the transmission as well as the dropping of packets are admeasured to the computing of the *FC-MLR* value of the connections for reasons of comparison. The proposed *FC_MDI_S* algorithm has lower values for *FC-MLR* than the *RTFS* one, which means that video connections under the proposed algorithm have better QoE.

Moreover, Figure 3 presents the mean delay of the proposed algorithm, which shows that both versions of the *FC_MDI_S* algorithm reduce considerably the mean delay of the connections. This was presumable, as the *RTFS* algorithm serves first the packets with the larger delay in the system, while the *FC_MDI_S* algorithm serves packets based on their frame category. The reduction in the mean delay is a substantially improvement, as we prefer video connections to have reduced delay.

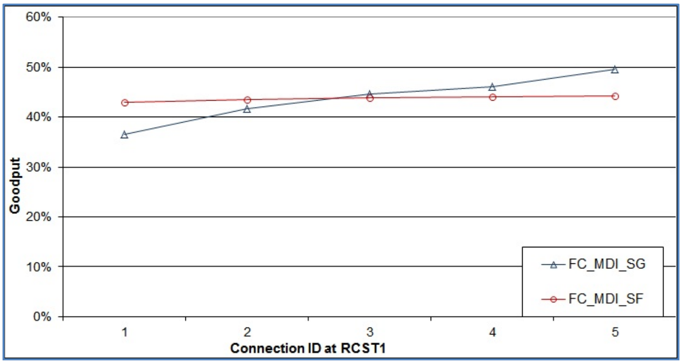

Fig. 4. Goodput per connection id for five connections per SS

The greedy and fair version of the proposed algorithm have the same performance concerning the goodput and mean delay, as the logic of the versions for sharing capacity is the same. They differentiate in the way they deal with the different connection identifiers. Figure 4 presents the goodput per connection identifier for five connections per SS. This figure shows the different performance of the greedy and the fair version, where the connections have differentiated goodpout under the greedy version and equal goodput under the fair version. In the fair version, the goodput is less than the goodput of the best connection and better than the goodput of the worst connection of the greedy version. It is due to the operator of the system to choose between them.

From the presented results, we conclude that the *FC_MDI_S* algorithm improves the QoE performance relatively to the *RTFS* algorithm, and it substantially improves the mean delay of the connections.

5 Conclusion

In this paper, we improve a previously proposed scheduling algorithm named *RTFS*. This algorithm is responsible to share the allocated capacity to the uplink traffic arriving from the WiMAX network in an integrated satellite/WiMAX network. After a bibliographic search for QoE metrics in WiMAX and satellite networks, the FC_MDI QoE metric is selected to be used in the proposed algorithm named *FC_MDI_S*. This is considered novel, as QoE metrics are mainly used for the assessment of video quality and not for scheduling. Especially in satellite networks, QoE metrics have never been used in management tools. We proposed and evaluated two versions for *FC_MDI_S*, and simulation results show that it considerably improves the QoE of video connections and reduces their mean delay.

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