

# Interconnection between a Satellite Interactive Network and wireless broadband networks

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**Abstract.** This doctoral thesis deals with the problem of interconnection between a satellite interactive network and broadband networks. An interconnection mechanism is proposed, which consists of three parts: 1) an entity at the satellite terminal responsible for capacity requests, 2) resource allocation to the satellite terminals and 3) sharing the capacity of a satellite terminal among the subscribers of the broadband network. The main contribution of the proposed mechanism is the introduction of a prediction mechanism in the first part for bandwidth requests. Simulation results show that the proposed mechanism can provide a differentiated treatment to services of different type, leading to improved performance, especially in terms of throughput and packet delay, compared to a simpler one that does not use prediction.

We propose solutions for all three parts of the interconnection mechanism aiming to improve the overall performance of the system, especially for real time traffic that can tolerate less delay. The NLMS (Normalized Least Mean Square) algorithm is chosen to be used in the first part of the proposed mechanism. In addition, we extend the second part of the mechanism for performing the slot allocation in MF-TDMA. Finally, we improve the scheduler of the third part of the proposed mechanism. The target of this improvement is to schedule traffic of real time connections of the broadband network based on Quality of Experience (QoE) metrics. We propose a new quality of experience metric and a new algorithm, based on this metric, for resource allocation. This use of QoE metrics for scheduling is rather novel, since the main use of such metrics so far has been for the assessment of video quality. Simulation results show that the proposed algorithm attains a sizeable reduction of the mean delay and a considerable improvement of the quality of experience for video connections.

**Keywords:** traffic scheduling, quality of service, quality of experience, video prediction

## 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 such a system, also known as WiMAX, both point-to-multipoint (cellular) and mesh mode configurations can be supported, while node mobility is also covered by the recent amendment 802.16e [2]. One of the main advantages of the standard is the large de-

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gree 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, the standard of Digital Video Broadcasting – Return Channel Satellite (DVB-RCS) ([3],[4]) 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 be advantageous, 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 quality especially for real-time applications. In this doctoral thesis, we investigate 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 the literature there is a number of proposals for interworking between satellite and WiMAX networks, however these focus mainly on the architectural aspects. For example, in [5] a resource reservation scheme for a hybrid wireless scenario, between satellite, WiMAX, and WiFi networks is proposed, based on the use of intelligent mobile agents, while [6] presents a new hybrid network solution relying on synergy between IEEE 802.16-based and DVB-RCS networks.

A set of proposals focus on the way a satellite terminal makes its capacity requests. These proposals follow mainly a bandwidth-on-demand approach. In [7] and [8], a dynamic bandwidth allocation in satellite networks is addressed, using adaptive predictive control methods. In [9], a new connection admission control algorithm is proposed with the aim of efficiently managing only real-time multimedia video sources both with constant and high variable data rate transmissions. According to [10], whenever a capacity assignment is performed, the NCC predicts the length of the queues which will be experienced at the RCST. This prediction is achieved through a sliding window based mechanism tailored to the satellite traffic. In [11], an efficient but complex method for optimal timeslot scheduling in an interactive satellite multimedia network is developed, so that the system's (weighted) throughput is maximized. The timeslot assignment problem is formulated as a binary integer programming problem, with a vast number of decision variables.

Finally, in [12] a dynamic traffic management strategy for the return channel of a DVB-RCS satellite system has been presented, consisting of two parts: the Resource Manager scheduler and the Terminal scheduler.

## **2 Dissertation Summary**

In [14], we propose an interconnection of a satellite and a WiMAX network, assuming that one or more of the RCSTs are also WiMAX BSs serving a number of SSs as shown in Fig. 1. 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 NCC that allocates resources and creates the 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 main contribution of the proposed mechanism is that it takes into account the different QoS characteristics of the WiMAX traffic and proposes a prediction mechanism used in PartA for bandwidth requests. Simulation results show that the proposed mechanism can provide a differentiated treatment to services of different type, leading to improved performance, especially in terms of throughput and packet delay, compared to a simpler one that does not use prediction.

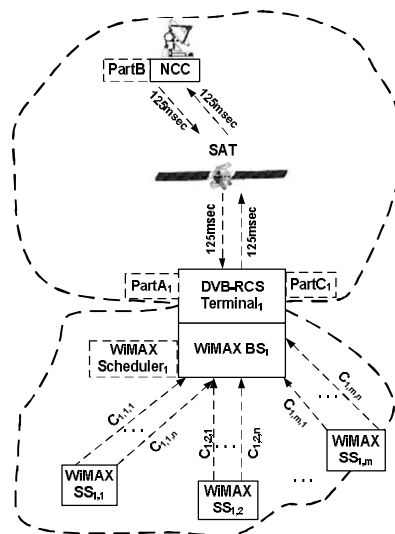


Fig. 1. Network architecture with three BS/RCST

An accurate traffic predictor for a satellite terminal is crucial in order to enhance channel utilization and guarantee the QoS requirements of real-time connections. In [15] and [16], we extend [14] towards improving the video prediction mechanism.

The traffic prediction algorithm used in PartA in [14] is based on the mean data rate of the connections, named BMDR (Based on Mean Data Rate).

After bibliographic search, we can conclude that there are three main categories of methods for traffic prediction. The first one uses the characteristics of traffic of real data, like self-similarity and long range dependency and tries to model the traffic in order to make the prediction ([17], [18], and [19]). The main drawback of this category is that the values of parameters of the different models must be predetermined, in order to achieve the optimal performance, particularly for real-time videos in which the traffic characteristics are unknown in advance. This is the main reason we do not consider it in our selection.

The second category uses neural networks [20], which are powerful tools for traffic prediction, but their implementation can be quite complicated resulting in large computational overheads. Besides, the training procedure of a neural network may suffer slow convergence and can be time consuming. These disadvantages make neural networks unattractive for use in applications with limited computational capability like satellite networks.

The third category make stochastic prediction of data that may arrive in the queue in the time interval between a request is made and the time this request is granted ([21]- [23] and [24]). We consider the third category as the most appropriate for our goal. Among them, [21] and [24] show better results.

For the prediction of rtPS traffic, the NLMS algorithm is used with three different alternative mechanisms. The first one proposes the implementation of the NLMS algorithm in the WiMAX BS, the second one proposes the implementation of the NLMS algorithm in the satellite terminal, while the third one proposes the implementation of the NLMS algorithm in both the WiMAX BS and the satellite terminal. The simulation results and the complexity analysis lead us to choose the second alternative, named VPNLMSb, as the most suitable for our system, which is presented and evaluated.

In [25], we start with a bibliographic search for slot allocation methods in static MF-TDMA satellite systems, followed by a multi-frequency extension of the algorithm used in PartB. Simulation results show improved performance of slot allocation in MF-TDMA, especially in terms of throughput and delay.

[26] improves the scheduler of rtPS connections in Part C 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 named FC\_MDI\_S, 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.

### **3 Scheduler based on QoE metrics**

The target of this part of the doctoral thesis is to improve a previously proposed mechanism, in order to make the scheduling of rtPS connections based on the use of

QoE metrics. 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 we need the proposed improvement to be part of an automatic procedure, subjective and hybrid QoE metrics are excluded in our case. From the already proposed solutions in other kind of networks, the solutions proposed in [27-29] have the drawback of using the PSQA metric for scheduling and QoE management. On the other hand, the solution proposed in [30-31] is considered complex, 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 FC-MDI metric was chosen to be used in the existing mechanism [32], as it is an objective metric that gives a different weight to the loss of different categories of voice and video frames. The FC-MDI (Media Delivery Index based on Frame Classification) metric is an extension of the MDI (Media Delivery Index) metric [33], an objective metric that contains two numbers separated by colon: the delay factor (DF) and the media loss rate (MLR). DF is time value indicating how many milliseconds the buffer must be able to contain to eliminate jitter, while MLR is computed difference between number of media packets received during an interval and number of media packets expected during an interval, everything scaling in the value of one second. Because the MLR is a rate, some important information is lost, such as whether the IP packets lost are consecutive or not. It does not consider the quality degradation that suffered some propagated loss from previous temporally related frames, so [33] 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 the different frame a different weight. In all types of frames, I-frame plays the most important role, as the rest frame of the whole group of picture (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. FC-MLR (Media Loss Rate based on Frame Classification) improves the definition of the MLR and takes frame classification into account as follows:

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

where  $\alpha$ ,  $\beta$ ,  $\gamma$  are weights with ( $3 \geq \alpha > \beta > \gamma \geq 0$ ,  $\alpha + \beta + \gamma = 3$ ) and  $I_{P_{Loss}}$ ,  $P_{P_{Loss}}$ , and  $B_{P_{Loss}}$  are respectively the number of lost I, P and B frames. The results of experiments demonstrate that when two videos of different qualities have a same number of total dropped-packet, the traditional MDI measurement cannot tell the difference between them, as MDI does not take into account the quality degradation that suffers some propagation loss from previous temporally related frames, while FC-MDI possesses a distinguishing feature.

The FC-MDI takes frame classification into account by giving different weights to the number of I-frames lost, P-frames lost and B-frames lost. However, it does not take into account if the frames lost from a specific category are consecutive or not,

which makes a difference. In [34], the LA-MDI is proposed (which is an improvement of FC-MDI), in order to give a greater importance to the consecutive lost frames of a specific category. In the LA-MDI, the definition of the DF is the same with its definition in the simple MDI, where the LA-MLR improves the definition of the FC-MLR in order to take into account the consecutive lost frames as follows:

$$LA - MLR = \frac{\alpha \cdot \frac{I_{P_{Loss}}}{ngI} + \beta \cdot \frac{P_{P_{Loss}}}{ngP} + \gamma \cdot \frac{B_{P_{Loss}}}{ngB}}{interval}$$

where  $\alpha, \beta, \gamma$  are weights with ( $3 \geq \alpha > \beta > \gamma \geq 0, \alpha + \beta + \gamma = 3$ ),  $I_{P_{Loss}}, P_{P_{Loss}}$  and  $B_{P_{Loss}}$  are respectively the number of lost I, P, B frames, and  $ngI, ngP,$  and  $ngB$  are respectively the number of group of lost I, P, B frames. The greater the number of group of lost frames, the more dispersed the lost frames are, and so the QoE is better. Generally, as the FC-MLR and the LA-MLR grows, the QoE becomes worse as the number of lost frames increases.

We further improve the scheduling algorithm of PartC, in order to make the scheduling of rtPS connections based on the use of the proposed LA-MDI metric.

In the beginning of every superframe, the proposed algorithm, referred to as LAQoE, drops the packets that are expired due to delay factor. Then, it sorts the video connections based on their mean LA-MLR. The mean LA-MLR of a connection in

superframe  $t$  is defined as  $\frac{\sum_{i=t-T}^{t-1} LA-MLR_i}{T}$ , where  $T$  is a small number of superframes (time window), in order to reflect the quality of the connection in the recent past. Two alternatives are studied for sorting the connections according to the mean LA-MLR. The first alternative is named LAQoEG and has a greedy logic. In order to preserve the connections that have good quality, the connections are sorted based on mean LA-MLR in ascending way, from the best quality to the worst. This may lead to the maintenance of the quality of some connections and the starvation of some others. The second alternative is named LAQoEF 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 algorithm based on the mean LA-MLR of the connections from the worst quality to the best.

In the beginning of every superframe, the PartC has accepted the TBTP generated from the NCC, so it has the knowledge of the available capacity for transmission. For every connection with the order of the previous sorting, the PartC creates a binary tree named QoE Tree (QoET) based on the available capacity for this connection.

PartC knows from PartA the sequence of packets that have arrived during the previous superframe. For every rtPS connection, PartC constructs a QoET that represents the possible combinations of packet transmission in this superframe. If, for example,

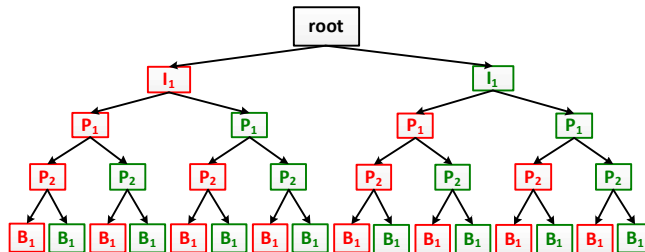


Fig. 2. Example of a QoE tree

PartC wants to transmit the sequence of I1P1P2B1 packets, then the QoET that is constructed is shown in Fig. 2.

Every path of the tree represents a combination of packet transmission, where a red node shows that a packet is not transmitted and a green node that a packet is transmitted. Knowing the TBTP, PartC can compute if a packet will expire due to delay before it's time for transmission. If the packet expires, then naturally it is not transmitted. In addition, the construction of a path stops, if its capacity comes to the available capacity that this connection has for transmission.

The leaves of the tree also contain the information of the LA-MLR metric for the specific path, which is easy to compute as we know the sequence of lost frames from every different category, as well as the total amount of bytes to be transmitted.

The LAQoE selects the path (sequence of packets) from the QoET of this connection with the best LA-MLR value. The available capacity for the next connection is reduced by the size of transmitted bytes of the selected path.

During the superframe, the PartC transmits, whenever it has available capacity based on the TBTP, the packets from the path selected of a connection based on the order of the sorted connections. If the packets of the selected paths of all connections are transmitted and PartC has still available capacity, then it transmits packets that have arrived in this superframe, using the logic of the FC\_MDI\_S algorithm. The transmission of these packets as well as the dropping of the packets is admeasured to the computing of the LA-MLR of the connections to the next superframe.

The LAQoERA algorithm is an improvement of the LAQoE algorithm that makes rate adaptation. PartC has the possibility of transmitting video in three rates: high, medium and low. Low quality is corresponded to rate 1, medium quality to rate 2 and high quality to rate 3. The greater the LA-MLR metric becomes, the worse it is. In the LAQoERA algorithm, the corresponding path of the QoET is not able to be transmitted upon a LA-MLR threshold. Instead, the connection transmits to a lower quality. If it is already in the lowest quality, then the connection transmits the best path that it is able to.

The LAQoERA algorithm differentiates the sorting of video connections, the creation of the QoET and the selection of the transmitting path so as to take into account the rate of video connections. The sorting of the video connections is based on the mean LA-MLR of the connections and the mean rate (mR) of the connections. The

mR of a connection in superframe  $t$  is defined as  $\frac{\sum_{i=t-T}^{t-1} Rate_i}{T}$ , where  $T$  is a small number of superframes (time window), in order to reflect the rate of the connection in the recent past. The connections are sorted according to the mean LA-MLR and mR under two versions. The first version is named LAQoERAG and has a greedy logic. In order to preserve the connections that have good quality, the connections are sorted based on mR in descending way, from the best rate to the worst, and then based on mean LA-MLR in ascending way, from the best quality to the worst. The second version is named LAQoERAF 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 algorithm based on mR in ascending way, from the worst rate to the

best, and then based on mean LA-MLR in descending way, from the worst quality to the best.

The difference in the creation of the QoET from the previous algorithm is that there are flags in every path showing if this path is able to be transmitted in rate 3, rate 2 and rate 1. The flag of one rate becomes false only when the capacity of a path overcomes the available capacity of this connection. If the flags of the three rates are false, then the path stops. In addition there are flags in the whole tree showing the existence of a path in rate 3, rate 2 or rate 1.

Finally, the LAQoERA algorithm selects the path (sequence of packets) with the best LA-MLR value in the best rate that this connection has the ability to transmit. This is shown from the flags of the QoET. If the flag of the whole tree in rate 3 is true, then the path with the best LA-MLR metric will be selected (from these paths that have the respective flag in rate 3 set to true). If the LA-MLR metric of the selected path is over a threshold (thresrate3), then PartC prefers to transmit in lower grade but in better quality. The same procedure is repeated for rate 2. If the path selected in rate 2 has the LA-MLR metric over a threshold (thresrate2), then PartC will select the path with the best LA-MLR metric in rate 1.

The available capacity for the next connection is reduced by the size of transmitted bytes of the path selected in the respective rate.

In order to measure the performance of the proposed algorithms, we accommodated the simulation program presented in [14]. 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 [14] with three DVB-RCS terminals each one interconnecting a WiMAX network, all with the same number of subscribers. In order to present the difference of the proposed mechanisms 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 versions. 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). Especially, for the LAQoERAG and LAQoERAF algorithms, we also use the same video trace in medium (“Verbose\_Alladin\_10.dat” file) and low quality (“Verbose\_Alladin\_10\_14\_18.dat” file).

Fig. 3 presents that the LAQoE, and LAQoERA algorithms reduce the mean delay of the video connections. This is due to the philosophy of the algorithms that take into account the TBTP to the construction of QoET and the selection of packets for transmission with the best QoE metric. This is a substantial improvement, as we prefer video connections to have reduced delay.

The two lastly proposed algorithms use the LA-MLR metric for their QoE evaluation. Fig. 4 shows that the FC\_MDI\_S and the LAQoE algorithms have the same mean FC-MLR value, while Fig. 5 shows that the LAQoE algorithm improves the LA-MLR value regarding to the FC\_MDI\_S one, as it takes account the number of group of lost frames of different categories. This is a proof of the differentiation and improvement of the LA-MLR metric. Fig. 5 presents the mean LA-MLR value for all connections of a SS. This figure shows that the two lastly proposed algorithms sub-



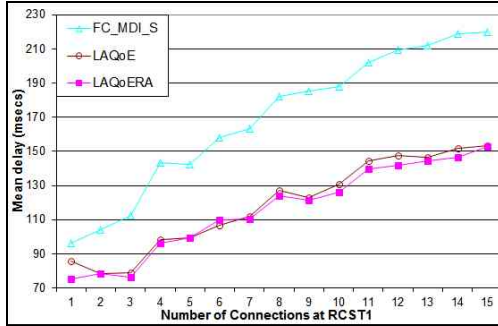


Fig. 3. Mean delay per proposed algorithm

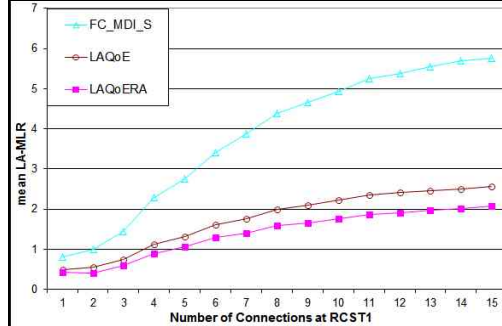


Fig. 5. Mean LA-MLR per proposed algorithm

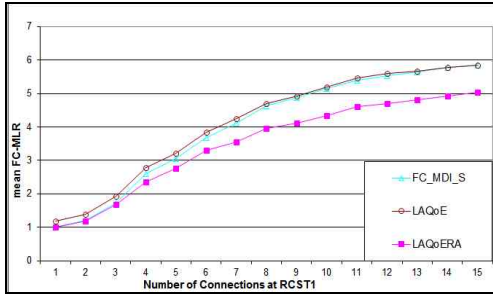


Fig. 4. Mean FC-MLR per proposed algorithm

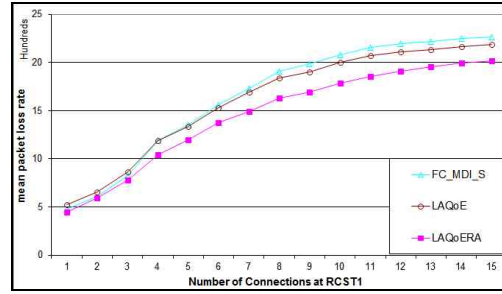


Fig. 6. Loss rate per proposed algorithm

stantially improve the QoE performance of the video connections. Especially, the LAQoERA algorithm has the best QoE performance. This is due to the rate adaptation of this algorithm, which loses the least of the transmitted information. It may transmit in lower quality but it transmits more information. This is better presented in Fig. 6, which presents the percentage of lost bandwidth.

From the presented results, we conclude that the LAQoE algorithm further reduces the mean delay of the connections, and improves the QoE performance of the video connections relatively to the FC\_MDI\_S algorithm. This is due to the philosophy of this algorithm which serves the sequence of packets with the best QoE metric. Finally, the LAQoERA algorithm has the best mean delay and QoE performance for video connections, as it loses less of the transmitted information due to the rate adaptation that it makes.

## 4 Conclusions

In this doctoral thesis, a scheduling mechanism for interconnecting satellite and WiMAX networks is presented. The proposed mechanism consists of three parts: PartA, located at the RCST, is responsible for making capacity requests, PartB, located at the NCC, is responsible for assigning bandwidth per RCST and creating the TBTP, while PartC, located at the RCST, is responsible for sharing the given capacity among its WiMAX subscribers. The main contribution of the proposed mechanism is that it takes into account the different QoS characteristics of the WiMAX traffic and

proposes a prediction mechanism used in PartA for bandwidth requests. Simulation results show that the proposed mechanism can provide a differentiated treatment to services of different type, leading to improved performance, especially in terms of throughput and packet delay, compared to a simpler one that does not use prediction.

Following a bibliographic search for video prediction in WiMAX and satellite networks, we select NLMS as the most suitable algorithm in order to improve the prediction of rtPS traffic in joint WiMAX/Satellite networks. Although the NLMS algorithm has been proposed for prediction of traffic in satellite networks, it is novel the research of the most effective way using it for prediction of video in an integrated satellite and WiMAX network. Three alternatives for the extension of an existing scheduling mechanism were investigated. Both the simulation results and the complexity analysis lead us to choose the second alternative, named VPNLMSb, as the most suitable for our system, which is presented and evaluated.

A bibliographic search for slot allocation in static MF-TDMA satellite systems is followed by multi-frequency extension of the scheduling algorithm lays in PartB proving the multi-frequency capability. Simulation results show improved performance, especially in terms of throughput and packet delay, compared to single frequency slot allocation.

We further improve the proposed scheduling algorithm used in PartC 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.

Finally, we propose an improvement of the FC\_MDI metric named LA\_MDI. We propose and evaluate two alternative algorithms based on this new metric named LAQoE and LAQoERA. The second algorithm is an improvement of the first one that also makes rate adaptation. Simulation results show that the proposed algorithms, and especially the second one, considerably improve the QoE of video connections and reduce their mean delay.

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