DVB-RCS Return link Radio Resource Management for Broadband Satellite Systems using Fade Mitigation Techniques at Ka band

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***Abstract*—Current Broadband Satellite systems supporting DVB-RCS at Ku band have static physical layer in order not to complicate their implementation. However at Ka band frequencies and above an adaptive physical layer wherein the physical layer parameters are dynamically modified on a per user basis is necessary to counteract atmospheric attenuation. Satellite Radio Resource Management (RRM) at the Medium Access Control (MAC) layer has become an important issue given the emphasis placed on Quality of Service (QoS) provided to the Users. The work presented here tackles the problem of Satellite RRM for Broadband Satellite systems using DVB-RCS where a fully adaptive physical layer is envisaged at Ka band frequencies. The impact of adaptive physical layer and user traffic conditions on the MAC layer functions is analyzed and an algorithm is proposed for the RRM process. Various physical layer issues associated with the resource management problem are also analyzed.**

***Keywords*—Broadband Satellite Systems, Adaptive Physical layer, QoS, Radio Resource Management, Ka band**

I. INTRODUCTION

As Broadband Satellite Systems gear themselves up to offer a variety of broadband and telecom services like high speed Internet access, GSM or WiMAX backhauling at Ka band frequencies the subject of capacity optimization and Quality of Service (QoS) provisioning has become crucial and all the more complex. To better compete with or complement the terrestrial services, and to reduce the service cost, not only must the system capacity be maximized during design phase but it also needs to be used in an optimal manner during system operation. Radio Resource Management (RRM) processes at the Medium Access Control (MAC) layer bear the responsibility of ensuring that the radio resources are optimally utilized with the objective of maximizing capacity and guaranteeing the required QoS to different applications [1][2].

Fig. 1 and Fig. 2 show a typical Multibeam Satellite System offering broadband and telecom services, with the focus on the DVB-RCS return link [3] which connects the Users with the Gateway (GW) or Hub. The different applications shown in Fig. 2 may have differing needs in terms of capacity, availability, priority etc. Even within a single application different levels of QoS or capacity might be needed depending on the type of service being offered. For example in the GSM backhauling case emergency calls have higher priority and availability over standard voice calls. Similarly a premium user in an internet application might have priority over a basic user. Such diverse needs in capacity and QoS over a spectrum of applications can only be achieved by proper management of the radio resource at the MAC layer. In this paper the focus will be on the issue of managing the radio resource assigned by the system to the uplink spot beam or whatever area served by the Network Control Center (NCC). The RRM process is carried out at the level of GW/NCC.

The physical layer design at Ka band and above frequencies must take into account the influence of atmosphere on the signal quality. At these frequencies the signal attenuation could easily be several 10s of dBs. The dominant contributor to this attenuation is rain. The only practical way to counteract these levels of attenuation is to have an adaptive physical layer where the physical layer parameters such as power, modulation order, channel coding rate, etc are modified to suit the propagation conditions. These techniques are collectively called Fade Mitigation Techniques (FMT). It is well known that the technique of adapting the modulation order and coding rate, called Adaptive Coding and Modulation (ACM), significantly increases the system capacity and availability [4]. The use of ACM renders the actual system capacity a dynamic entity depending on the propagation conditions. Contrary to this a static physical layer implies a constant system capacity at all times.

Current DVB-RCS systems, at Ku band do not use ACM and the RRM is limited to the Demand Assignment Multiple Access (DAMA) algorithm partitioning the static available resource to users upon request.

The organization of the paper is as follows: section II describes the idea of RRM for a DVB-RCS system using ACM at Ka band and proposes an algorithm for it. Section III explores the various important physical layer and other related issues associated with the RRM process. Finally the observations are summarized.

II. Radio Resource management

The satellite radio resource that needs to be managed is the bandwidth assigned by the system for a particular uplink spot beam. In the current DVB-RCS systems this bandwidth is divided into groups of carriers having different symbol rates. But they all utilize the same physical layer configuration i.e., the same modulation and coding scheme.

With an adaptive physical layer where there are several modulation and coding schemes, as in an ACM implementation, the carriers need to be grouped and associated with various modulation and coding schemes, called modes, that the system can choose from. Assuming that the spot beam bandwidth is divided into several carriers of identical bandwidth, the central issue is then what should be the distribution of these carriers among various modes. Evidently the criteria for allocating carriers to any particular mode are the likelihood of that mode being needed by the user terminals, the capacity needed by those terminals that will be using this mode, and the QoS accorded to the user terminals. In other words the carrier distribution depends on the propagation and traffic conditions over the spot beam under concern along with the QoS required.

Concerning the time scale of the RRM process DVB-RCS specifies that any change in the carrier configuration needs to be broadcast to all the terminals in the coverage by using the Superframe Composition Table (SCT), Frame Composition Table (FCT), and Time Composition Table (TCT). The principal constraint on the RRM time scale is the time needed to broadcast these tables and ensuring that all the terminals are aware of the changes in the carrier configuration. The time scale of the DAMA process is on the order of 50 ms whereas the time scale of RRM process can be anywhere from few seconds to few minutes.

The RRM time scale implies that the propagation and traffic conditions over the spot beam need to be predicted on a time scale of few seconds to few minutes. These two prediction processes determine the carrier distribution, and the efficiency of the RRM process, obviously, depends on the accuracy of these predictions. The RRM process is illustrated in Fig. 3. The DAMA process takes as input the carrier distribution output by the RRM process. The resource allocation process for each terminal is carried out by the DAMA for every superframe, and the global resource management is carried out by the RRM process. Existing RRM algorithms like in [5] [6] considerably simplify the problem by assuming that the RRM and DAMA processes operate over the same time scale which is not the case in reality. This avoids the need to predict the propagation and traffic conditions over the spot beam. Also they suppose that the carrier reconfiguration could be done for every DVB-RCS superframe and that the process is assumed to be instantaneous which is not realistic. The algorithm that we intend to propose explicitly takes into account the information available from channel and traffic prediction. Also the time scale is more realistic of the order of few seconds to few minutes depending on how the system implements the SCT, FCT, and TCT broadcast schedule whenever there is a change in the carrier configuration.

In general the inputs to the RRM process are:

- Bandwidth allocated to the spot beam
- Predicted propagation conditions over the spot beam
- Predicted capacity needs for the terminals
- QoS criteria like fairness, priority etc.

For the purposes of developing an algorithm for the RRM process let us suppose that the propagation and capacity predictions are available to the process, and that the spot beam bandwidth is divided into carriers of identical bandwidth. The problem of prediction will be explored in section III. Also let us suppose that the satellite capacity has to be fairly allocated among competing entities (implying that all the terminals are considered equal).

A. RRM Problem formulation

Inputs:

- L User Terminals over the spot beam
- N carriers
- K modes designated as $[M_1\ M_2 \ldots M_K]$
- Predicted Capacity need for each user terminal in terms of CRA, RBDC, and VBDC requests [3]
- Predicted mode for each user terminal
- QoS criterion: Fairness

The first task is to compute the number of carriers each mode needs from the capacity and propagation prediction information. Given the total resource (carriers) available the next task is to assign the optimum number of carriers to each mode based on the demand and the QoS criteria.

B. Algorithm

Step 1: The capacity request of each terminal in terms of CRA, RBDC, and VBDC requests is translated into number of packets of MPEG/ATM data as follows:

$$P = \left\lceil \frac{(CRA + RBDC)T_S}{l_{MPEG/ATM}} \right\rceil + VBDC\Big|_{MPEG/ATM} \qquad (1)$$

Here the CRA and RBDC requests are assumed to be in bit rate and VBDC in number of MPEG/ATM packets. P is the number of MPEG/ATM packets that the terminal needs to satisfy its capacity demands. $l_{MPEG/ATM}$ is the number of bits in an MPEG/ATM packet. T_S is the DVB-RCS superframe duration.

Step 2: Considering that in DVB-RCS the capacity is allocated in terms of time slots in the Multi Frequency Time Division Multiple Access (MF-TDMA) structure, the number of MPEG/ATM packets obtained in step 1 need to be converted into number of time slots needed by the terminal. DVB-RCS specifies that each time slot can carry 1, 2, or 4 ATM cells or (1, 2, 4, 6…24) MPEG packets. Assuming that each time slot can carry 'n' MPEG/ATM packets we have the number of time slots N_{TS} needed by a terminal as

$$N_{TS} = \frac{P}{n} \tag{2}$$

Step 3: The number of time slots that a carrier could carry in a super frame depends on the ACM mode associated with it. The more spectrally efficient the mode the more the number of time slots carried by it and vice versa as the information content for each time slot is fixed. This can be seen in Fig. 3. Let us assume that a carrier could carry a maximum of $N_{TS,max,M}$ time slots depending on the mode M associated with it. It is obvious that for any user terminal only a maximum of $N_{TS,max,M}$ time slots could be allocated for otherwise it would imply that the terminal is using more than one carrier at a time. Hence the number of time slots $N_{TS,a}$ that could be allocated to a terminal in principle is

$$N_{TS,a,M} = \min\left(N_{TS}, N_{TS,\max,M}\right) \tag{3}$$

Step 4: We now have table I taking into account information available so far. As the resources need to be allocated in a fair manner among the terminals we could add all the time slots associated with the same mode providing us with Table II.

Step 5: The number of carriers needed for each mode to accommodate the time slots provided in Table II is calculated as

Number of carriers needed for mode M_i,

$$C_{M_i} = \left\lceil \frac{\sum_j \min(N_{TS,j}, N_{TS,\max,M_i})}{N_{TS,\max,M_i}} \right\rceil \tag{4}$$

Step 6: Now we have the number of carriers needed for each mode [C_{M1} C_{M2}…C_{MK}] obtained from (4) and the total number of available carriers (N). The QoS criterion is fairness. We might suppose that a minimum resource must be allocated to any mode irrespective of its demand.

TABLE I. TIME SLOTS NEEDED FOR EACH TERMINAL

Terminal	Mode i € (1,2…K)	Time slots needed	Max. time slots for the carrier	Time slots that could be allocated
1	M_i	$N_{TS,1}$	$N_{TS,max,Mi}$	$\min(N_{TS,1}, N_{TS,max,Mi})$
2	M_i	$N_{TS,2}$	$N_{TS,max,Mi}$	$\min(N_{TS,2}, N_{TS,max,Mi})$
…	…	…	…	…
L	M_i	$N_{TS,L}$	$N_{TS,max,Mi}$	$\min(N_{TS,L}, N_{TS,max,Mi})$

TABLE II. TOTAL TIME SLOTS NEEDED FOR EACH MODE

Mode	Total Time slots needed
M_1	$\sum_j \min(N_{TS,j}, N_{TS,max,M_1})$
M_2	$\sum_j \min(N_{TS,j}, N_{TS,max,M_2})$
…	…
M_K	$\sum_j \min(N_{TS,j}, N_{TS,max,M_K})$

When the total demand in terms of carriers for all the modes is less than the available number of carriers then the allocation problem is a trivial one. However when the total demand exceeds the available resource an optimum distribution procedure has to be devised. This problem lies within the domain of Constrained Optimization. A similar optimization problem is treated in [6] within the context of DAMA process for DVB-RCS. Taking a similar approach the solution to our problem is given by the waterfilling solution:

$$C_{a,M_i} = C_{M_i,\min} + \left(\nu - C_{M_i,\min}\right)^{C_{M_i} - C_{M_i,\min}} \tag{5}$$

where C_{a,M_i} is the allocated resource for mode M_i, C_{M_i} is the demand for mode M_i, $C_{M_i,\min}$ is the minimum resource that must be allocated to mode M_i, and ν is the threshold parameter chosen to satisfy the total capacity constraint with equality. The computation procedure provided in [7] could be used to arrive at the value of C_{a,M_i}.

The algorithm could easily be modified to take into account any priority mechanism for the modes and other considerations before the carriers are allocated to the modes.

III. PHYSICAL LAYER AND OTHER ISSUES RELATED TO RESOURCE MANAGEMENT

The following assumptions were made in the previous section in order to develop a basic algorithm for the RRM process:

- Information about propagation conditions over the spot beam over a time scale of few seconds to few minutes is known which in turn is used to calculate the modes needed by the terminals
- Information about the capacity needs of the terminals over the RRM time scale is known
- The modulation and coding schemes used in the ACM technique are known considering that their choice affects several system parameters like average spectral efficiency, encapsulation efficiency etc.

These three issues require careful analysis for they are the inputs to the RRM process and any amount of optimization in the allocation process would be useless if they are not accurate or reliable enough.

A. Prediction of Propagation conditions

The objective of predicting the propagation conditions over the spot beam is to identify the modes that will be needed by the terminals which will then be used as an input for the RRM process. The time scale as explained previously can range from few seconds to few minutes. The problem is illustrated in Figs 4 and 5:

Let us assume that there are N users in the spot beam. In the figure the Signal to Noise Ratio (SNR) scale is shown with the thresholds for various modes. At t=t0 the distribution of users among the modes i.e., the number of users, whose identities are known, using a particular mode is known. The problem is, given this current user distribution among the modes, what would be distribution after, say, x minutes i.e. at t=t0+x minutes? In Fig. 4 N1+N2+…+N6=N, the total number of users in the spot beam. The rain event is assumed to be happening only in the uplink i.e. the link connecting the user terminals with the satellite.

The idea is then to predict this distribution of users among the modes over a time scale of few minutes. In other words the problem is to identify the users that will be suffering from a certain attenuation range. The SNR scale could easily be mapped into an attenuation scale thereby giving the attenuation range for each mode.

This distribution could be obtained by using images of precipitation over the coverage area. These images could be in the form of radar images (Met office Networks) or numerical weather forecast models [8], or Space-Time channel models [9]. The approach using radar images looks promising and is being investigated. Also radar images are available over the time scale that will be useful for the RRM process.

B. Terminal capacity prediction

The capacity needed by the terminals in terms of RBDC and VBDC requests over the RRM time scale need to be predicted from the current traffic pattern. The issue hasn't been addressed yet in our study.

C. Mode selection

An important aspect of the ACM technique is the use of appropriate modulation and coding schemes, modes, to achieve the desired gain in the system capacity. ACM modes that are optimal in the sense that they are pertinent to the propagation characteristics of the coverage, ones that respect the constraints coming from higher layers (like encapsulation aspects), implementation details, etc greatly increase the efficiency of an RRM process. If the modes are not optimal the RRM can only achieve so much. Given that the mode are what the RRM process works with its importance cannot be overstated The mode selection process depends on several factors like average spectral efficiency, encapsulation efficiency, Rain fade characteristics, Channel state estimation accuracy and reliability, FMT control loop implementation, etc [10]. The companion paper [11] discusses one possible methodology to select the modes from a given list.

IV. SUMMARY

In this paper we have discussed the problem of Radio Resource Management at Ka band frequencies for Satellite systems using DVB-RCS. We have proposed an RRM strategy with a realistic time scale for the RRM process and one that explicitly takes into account the information available from the channel and traffic predictions. An algorithm for the RRM process has been proposed following certain assumptions on the information available to the MAC layer. The objective is to improve system capacity and provide better quality of service to the users. Further work will be to validate this algorithm on a DVB-RCS system model. We have also discussed the problem of predicting the propagation conditions over the coverage along with the problem of selection of ACM modes for the return link.

ACKNOWLEDGMENT

Parts of the work have been carried out under the framework of the European Union funded Satellite Network of Excellence (SATNEX).

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Figure 1. System architecture-Global

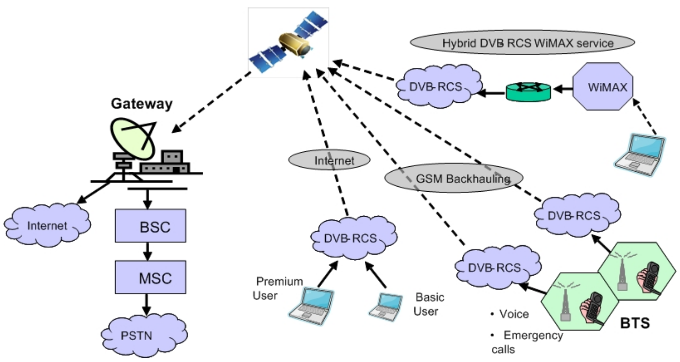

Figure 2. System architecture-Applications

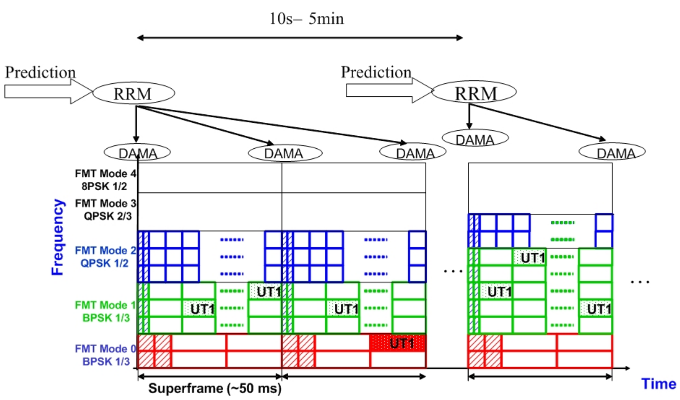

Figure 3. RRM process showing the time scale and inputs

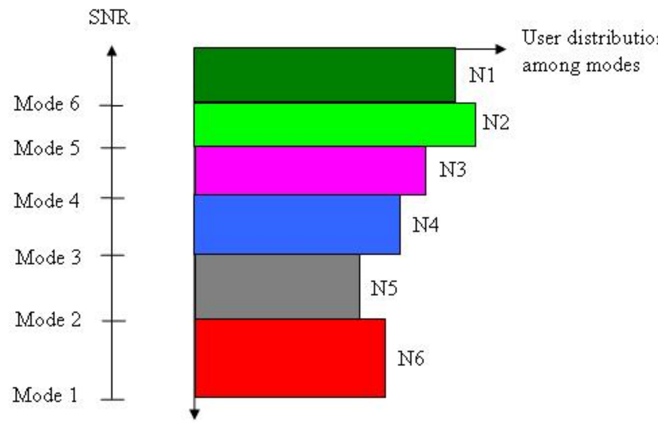

Figure 4. Fade prediction-Current scenario at t=t0

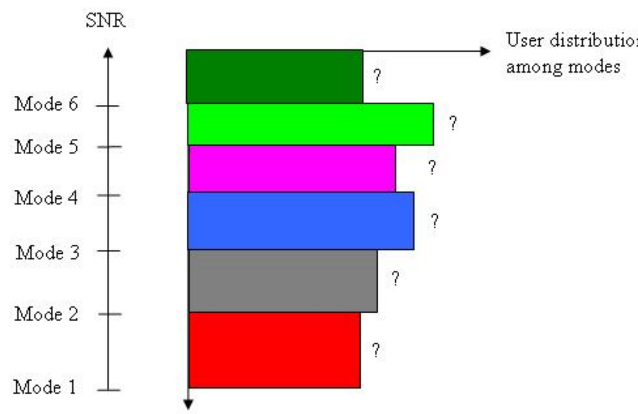

Figure 5. Fade prediction-Scenario after t=t0+xmin