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Cross-layer anticipation of resource allocation for multimedia applications based on SIP signaling over DVB-RCS Satellite System

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Abstract — This paper introduces a cross-layer approach for improving QoS guaranties to interactive multimedia applications over an efficient satellite access assignment scheme (on-demand). It particularly focuses on the communication opening which represents the weakness of on-demand capacity allocation in the satellite context (due to significant delays). It finally presents experimental results of the various proposed enhancements.

Introduction

Geostationary satellite offers practical and easy-to-deploy way for Internet communications over the world. Nevertheless, satellite communication's characteristics, such as large delay and resource variability require particular treatments in terms of resource management and optimization. In this context, the introduction of on-demand Quality of Service (QoS) support over satellite communications is very important for interactive multimedia applications. This is particularly accurate for the *return link* that can be considered as a bottleneck due to the large set of distributed end-users accessing a limited uplink resource.

QoS *guarantee* on the return link has been often implemented using *static resource reservation* (e.g. for TV journalists who work where terrestrial infrastructure is not available). This technique avoids complex resource management and allows strong QoS guaranties. However, multimedia application customers requiring interactivity, such as audio-video conferencing, cannot use static reservations due to the high cost.

In order to allow at the same time a more efficient use of the resource and reduce the cost from their perspective, the DVB-RCS proposes a *dynamic approach* through its DAMA access scheme (Demand Assignment Multiple Access). DAMA is a classical technique to offer such dynamicity thanks to a distributed mechanism. It offers various types of services to the satellite operator.

In spite of these advances, QoS-enabled satellite services still have to be used efficiently for multimedia communications, particularly regarding the delay accumulation issue that can result from the use of dynamic allocation. In this context, several propositions have been done to improve performances of the access scheme for multimedia communications [1], [2]; however, there is currently no solution to significantly reduce initial delay introduced by on-demand capacity assignment type for interactive multimedia applications. Yet, this incompressible delay seriously deteriorates user experience for interactive applications [10].

To fill up a part of this gap, the work presented in this paper is aimed to improve the quality of interactive applications from the end user point of view by enhancing provisioning of on-demand DAMA resources.

The paper proposes a cross-layer approach to provision resource on session start-up taking into account the QoS application requirements. Several experiments making use of the provisioning methods are carried out for different scenarios of interactive session initiation. Their impact on QoS is measured through different application level metrics, i.e. end-to-end (e2e) delay of applicative data.

The rest of the paper is structured as follow. Section II presents the considered satellite communication framework and the state of art of propositions improving QoS for interactive

multimedia applications using on-demand satellite resources. Section III shows the core of the paper contribution: The cross layer approach and the various provisioning methods proposed. Section IV introduces a case study and several experiments that allow showing the improvements of these provisioning methods. Finally, section V concludes this paper.

QoS Over Satellite

Satellite Communication Context

The main concern in the satellite communication context, and more particularly on satellite return link, is to make an efficient use of the resources, scarce and costly, while taking into account different traffic types (data, voice, video), each having specific QoS performance parameters. Thus, protocols have been designed to optimize the use of these resources and especially to share properly and efficiently the return link resources accessed by multiple distributed Satellite Terminals (ST) which act as satellite boundary nodes.

A combination of static and dynamic techniques has been integrated into the DAMA (Demand Assignment Multiple Access) protocol. This protocol is integrated in the DVB-RCS standard [3], in order to ensure both high utilization of the return link resources and to offer QoS-oriented capacity assignment types.

The return link scheduler of the DAMA protocol supports four main capacity assignment types to reach its objective: **CRA** (Constant Rate Assignment), **RBDC** (Rate Based Dynamic Capacity), **VBDC** (Volume Based Dynamic Capacity), **FCA** (Free Capacity Assignment).

CRA allocation type offers real high QoS guarantees but at a high cost: the delay is reduced to propagation delay and a guaranteed bandwidth is constantly allocated. However, due to this constant allocation to a ST, even when it is not required, this allocation type leads to a suboptimal usage of resources.

Compared to CRA allocation type, **RBDC** offers a good trade-off between QoS guarantees and bandwidth efficiency at a lower cost. Indeed, this traffic assignment is based on requests that reflect the average rate of incoming data on the ST. So we will focus more particularly on RBDC assignment type in this paper.

The return access scheme of the satellite is able to provide different types of service. However, QoS differentiation needs architectural solutions at upper layers to be effective. The next section presents an overview of these solutions and the QoS-oriented architecture considered in this study.

QoS in the Satellite context

In the satellite networking context, the interaction between the IP Layer, where the QoS might be set, and the lower layers where the traffic is finally prioritized is not covered by any standard specification [4]. However, QoS techniques and architectures for satellite networks have been widely studied in the literature. [5] [6] proposes to use Diffserv architecture [7] on both forward and return link. This architecture is well adapted to the return link due to the different classes of service of DVB-RCS capacity allocation. The satellite system, in this study, is assumed to be an access network to the Internet for end-users. Thus, as a boundary node, the ST is the most important component regarding QoS support on the Return Link. It has to implement traffic conditioning/policing functions, in addition to packet classification and per hop forwarding/scheduling according to packet's class of service, as illustrated in the Fig. 1.

Fig. 1 Mapping between MAC and IP queuing in the ST

Figure 1. Mapping between MAC and IP queuing in the ST

These recommendations introducing QoS in the ST are the starting point on which our contribution is based. The proposed mapping and admission control based on these recommendations are detailed in the following section.

Considered QoS-oriented Architecture

We assume in this paper that an e2e QoS Architecture is deployed, integrating IP differentiated services. It includes signaling mechanisms for admission control as well as resource pre reservation, such as proposed in [8][9].

In order to meet the DiffServ forwarding requirements, the IP classes of service need to be appropriately mapped into MAC QoS classes and then into DAMA capacity categories supported by the Scheduler. Here we consider that EF CoS is mapped to the highest priority MAC buffer DVB-RT using CRA capacity. AF CoS is mapped to the medium priority MAC buffer DVB-VR using RBDC capacity. And BE traffic is mapped to the lowest priority MAC buffer DVB-JT using VBDC and remaining capacity.

The Network Control Centre (NCC), which manages the satellite resources, knows the available resources on the return link. It provides this information to the Resource Allocator (RA) which performs the Admission Control.

A Service Level Agreement (SLA) is passed at logon between ST and the Satellite System. The bandwidth guaranteed for high priority classes (CRA, RBDC) in this SLA, are generally restricted due to their cost. Thus, to avoid the waste of high priority capacity, admission control is based on the remaining satellite resources and limitation per end-user. If bandwidth is available for a specific IP CoS in relation with remaining satellite resources in the corresponding DAMA class, the flow is admitted, if the user is under its contract limitation.

No per-flow admission control is done for BE traffic type, but its global rate is limited to the remaining bandwidth unused by high priority traffic. This ensures full resources utilization and limitations of congestion inside the ST.

This QoS Architecture includes differentiated services and admission control. It enables a flow to use a satellite access type without any interference with concurrent traffic. Thus, a prioritized flow is able to use CRA or RBDC access class, and won't be delayed by Best Effort traffic that would rather use VBDC capacity when available.

However the pre reservation of resource realized by the QoS Architecture is different from the actual allocation done by the satellite system with internal requests. Indeed, reservation could be pre reserved on the control plane but the connection could finally fail. Thus, immediate allocation of resource in a satellite environment is not feasible because of efficiency and cost considerations.

Contributions in this context

As previously exposed, CRA assignment type offers real high QoS guarantees but at a high cost. So the proposed QoS guarantees of RBDC access class at a lower cost is of great interest; Thanks to the QoS-oriented architecture previously presented, applicative multimedia flows can take benefit of differentiated access to the satellite system (where AF CoS is mapped toward RBDC).

However, RBDC suffers from initial requests issue. Indeed, initial requests introduce delay, at least 900 ms (data buffering 300ms + request delay 300ms + response delay 300ms), that is not compatible with interactive multimedia application constraints [10]. This delay might be reduced during the communication by requesting more resource. However, this initial delay degrades the overall interactivity of two-way conversational voice and video applications. Indeed, the delay accumulated in the destination receiver's buffers cannot be reduced, except if packets are discarded. In both cases the applicative quality is degraded.

Then, it enlightens the need of anticipation in provisioning resources in order for interactive applications to take benefit of this efficient access class. However, this anticipation must be as close as possible to the real application data transmission, taking into account the main concern of efficiency of a satellite system.

Thus, the contribution of this paper is to propose anticipation for provisioning RBDC resources, based on a cross-layering approach between application and link layer, in order to set up an interactive multimedia session.

Contributions

The OSI (Open System Interconnection) model has been the initial guide for developments in networking. Recent evolutions, notably in the area of wireless communications, have shown that the layered model, in which each layer is implemented independently, may lead to suboptimal performances [11]. In order to avoid such scenarios, one solution is to use cross-layering while designing mechanisms by taking the behaviour of other layers into account.

This study provides a downward cross-layering approach, achieved in a control plane, in order

to provision RBDC resources when interactive sessions start. The solution should not require modifications of layers interfaces or even to the packet headers. Indeed, this approach should take advantage of information already included within session signalling messages to provide generic QoS and session information (e.g. bitrate, packet size, session id), thus hiding the complexity introduced by dealing with the diversity of multimedia streams.

In this study, we describe a cross-layer approach using SIP (Session Initiation Protocol)/SDP (Session Description Protocol) to signal session start-up and session stream details. However, this cross-layer approach can be used with any session signaling protocol.

This cross-layer approach to provision RBDC is divided in three steps described now:

Application dependant mapping (first step)

In order to do a precise anticipation of resources reservation and request when multimedia session starts, we need to know the amount of resources required by this session. We also need to know the ST Identifier, behind which the session starts, in the satellite network.

However, information integrated in session protocols cannot be directly used to perform this resource provisioning. Then, this proposed first step consists in translating application dependant information (i.e. session protocol syntax) into a normalized representation of this information (e.g. application types, codec names).

During the SIP establishment phase, the SIP User Agents (UAs) exchange and negotiate the type of application, media and codec that is used during data transfer of the session. SIP proxies route requests to UAs because they are initially not aware of their respective location.

Knowing that the gateway (GW) represents the entry point of the satellite network, we propose to install an Outbound SIP Proxy (OSP) within the GW / NCC. This access topology allows the OSP to intercept all SIP establishment messages (SIP INVITE). A control plane is then used to retrieve from these session messages, the application and media types as well as the codec name.

A first translation toward generic application media and codec name is done if needed. In the case of SIP/SDP protocols, audio and video codecs used during session establishment are standardized by the IANA organisation [12].

To make resource reservation for multimedia flow, we also need the ST MAC Identifier behind which the session is initiated. In order to obtain this Id, we also use information from establishment session messages. The control plane at the OSP is in charge to extract the IP address and port of UAs. From this transport information, we propose to use the SARP protocol (Satellite Address Resolution Protocol) to retrieve the ST Id giving access to the UA IP Address in the satellite network. The control plane keeps track of the SIP session Id associated to the ST Id.

From session description toward precise QoS parameters (second step)

The first step provides normalized session information especially on application, media types, codec names and ST Identifier associated to the session.

However, this information are purely qualitative and cannot be used to request resource reservation to the NCC. So we propose to translate this qualitative information into precise quantitative QoS parameters. To achieve this translation, we use standard information on QoS required by generic application types [12] as well as main features of each codec available in standard specifications (like encoding/decoding bitrate). This bitrate corresponds to the throughput of the multimedia flow. The list of correspondence between application, media types and codec names toward associated quantitative QoS parameters (like throughput, maximum e2e delay, and loss rate) is stored in a Media Type Repository (MTR) defined in [9]. We implement an MTR in the architecture, located on the NCC side in the satellite network to reduce access delays to MTR.

Once the control plane has extracted the media type and codec from the establishment session message, it passes this information to the MTR. This later responds with the corresponding QoS parameters.

The obtained QoS parameters (in particular, bitrate and packets size) and the targeted ST Id, allows us (1) to perform admission control, as described in section II.D, (2) to provision, later on, the appropriate RBDC resources on satellite return link, at the very moment the data transmission will start. We now focus on the method used to send a RBDC capacity request to the NCC.

Capacity Request for RBDC resource provisioning (third step)

The TBTP (Terminal Burst Time Plan) represents the resource allocation plan for all STs to access the return link of the satellite system during one super-frame. In the best case scenario, for on-demand capacity (RBDC), the TBTP takes into account new session data 600 milliseconds after it reaches the ST (due to satellite crossings of request and response), implying at least 900 ms of one way delay for the first data packets.

To face this issue, three approaches will be considered to anticipate provisioning of RBDC resources for interactive multimedia sessions. For these three approaches the same process is followed to anticipate RBDC provisioning of resources:

1. Every SIP session initiated behind a ST is tracked by the OSP located on the GW side.
2. If the session is admitted in AF CoS by the RM, part of the QoS-oriented architecture (cf. section II.D), then on reception of the SIP OK message on GW side, session information is retrieved using cross layering approach (cf. Section III.A).
3. If the session requires interactivity (known by analyzing session requirements retrieved in the previous step, in particular the required one-way delay):

3.1. A Capacity Request (based on required bitrate and packet size to evaluate overhead) is directly sent by the control plane to the NCC in the DAMA Server. It uses the same format as usual capacity requests. Two capacity requests are sent for the first two super-frames of the session communication. This avoids any satellite crossings because the OSP and the NCC are on the GW side. For the rest of the communication, the normal capacity request mechanism based on a calculation of incoming throughput on the ST is used. Thus, due to the two first capacity requests, the initial delay should not be experienced by the streams of the session.

3.2. NCC updates its resource allocation and sends the corresponding TBTP to all STs. Three solutions are proposed to achieve this third step:

Anticipation of resource allocation with no modification of access scheme

The NCC updates its resources distribution to integrate the new Capacity Requests (as it would normally do) but TBTP frequency is not modified (sent every super-frame).

Fig. 2 cross-layering RBDC request

Figure 2. cross-layering RBDC request

Knowing that a SIP session could start at any moment, two borderline cases have to be considered (cf Fig. 2):

- The OSP sends the SIP OK message and the RBDC capacity request just before the generation and emission of the TBTP: this is the best case scenario; indeed, the request is taken into account in the current TBTP computation, and immediately sent on the forward link. Consequently, the ST receives in the same time the authorized SIP OK message and RBDC resources allocation enabling ST to immediately send data of the new session for the next two super-frames on the return link. The satellite e2e delay should be close to the satellite propagation delay (300ms).
- The OSP sends the SIP OK message and the RBDC capacity request just after the calculation and broadcast of the TBTP: this is the worst case scenario; indeed, the capacity request is not taken into account in the current TBTP that has just been emitted on the forward link. Consequently, the ST receives the authorized SIP OK message but no resource is available to emit data of the new session. Consequently, it has to wait the next TBTP for resources allocation (530ms later).

The pros and cons of this approach are the following:

pros: No modification of access scheme signaling.

cons: RBDC provisioning anticipation is not optimal.

In order to eliminate this worse case scenario, a solution could be to increase the TBTP emission frequency. Thus, for a super-frame of 530ms, that corresponds to 10 frames of 53ms, the TBTP could be proceeding and emitting for each frame. Thus, the maximum delay added to every allocation is of 53ms. However, it tends to increase signalling traffic on the satellite network.

The pros and cons of this approach are the following:

pros: RBDC provisioning is optimal.

cons: Significant signalling overhead.

Anticipation of resource allocation based on new TBTP calculation

In order to avoid increasing signalling in the satellite system, we propose to keep TBTP frequency broadcast every super-frame. However, to provision RBDC capacity requested by the OSP, we propose to update the current TBTP to integrate the new session. Thus the NCC broadcasts in the following frame to all STs, the newly calculated TBTP for the current super-frame, including the new distribution of the return link resources (cf Fig. 3).

Fig. 3 cross-layering request with TBTP update and emission

Figure 3. cross-layering request with TBTP update and emission

Due to the QoS-oriented architecture considered (cf. section II.C), once the STs have received their allocation, they serve MAC queues by priority order: DVB-RT > DVB-VR > DVB-JT queues. Knowing that the RBDC capacity request concerns the DVB-VR class, we propose to reallocate resources dedicated to the service of lower priority that concern DVB-JT class, namely VBDC and FCA assignment types. Indeed, the DVB-JT service is not guaranteed, so the current TBTP can be recalculated, decreasing VBDC allocations to reallocate these resources toward RBDC capacity, requested for the new session. However, when the NCC recalculates the TBTP, it must take care to not reallocate DVB-JT resource already consumed by the current position in the super-frame. When the amount of DVB-JT resources is not sufficient to satisfy the request of the OSP, the remaining resources are computed to be allocated in the next TBTP. This method allows the ST concerned by the SIP multimedia session to receive at the same time the authorized SIP OK message and the required RBDC resources allocation, in order to send immediately data of the new session on the return link. However the update of the TBTP for every asynchronous RBDC capacity request coming for the control plane at the OSP requires a significant modification of the DAMA server implementation, and significant computation capacities of NCC.

The pros and cons of this approach could then be summarized as follow:

pros: RBDC provisioning is optimal.

cons: Significant modification of the access scheme.

Anticipation of resource allocation based on SIP adaptation

This third solution described in Fig. 4 permits to avoid the modification of the allocation plan in real time.

Fig. 4 cross-layering request with Sip adaptation

Figure 4. cross-layering request with Sip adaptation

When the OSP receives the SIP OK message, we propose to keep it within the OSP until the TBTP is emitted by the NCC; it's equivalent at user level to let the call ringing (one super-frame = 530ms at most). So the OSP emits an RBDC capacity request to the NCC. Then, when the TBTP is being broadcasted on the forward link, the NCC emits upwards an acknowledgment to the OSP, indicating that the TBTP is about to be sent. Consequently, the OSP releases the authorized SIP OK message; thus, the SIP message and the RBDC resource allocation are transmitted at the same time to the ST. This later is then able to send immediately data of the new session on the return link for the two next super-frames. The pros and cons of this approach could be summarized as follow:

pros: RBDC provisioning is optimal, modification is minimal.

cons: slight modification of access scheme and SIP.

Experiments and results

Platform description

Experiments were conducted on Platine. Platine is a satellite emulation platform proposed in SatSix European project, aiming at functionally validate the DVB-RCS access and network layers

definitions. Platine architecture emulates components and implements communication protocols (IP/MAC/DAMA) of a regenerative satellite system.

Fig. 5 represents the emulation platform for experiments. The platform is composed by two domains, named “domainsat.org” and “domainter.org”. Domainsat.org uses a DVB-RCS satellite access network emulated by the Platine platform.

Fig. 5 Emulation Platform

Figure 5. Emulation Platform

Behind the ST, which acts as an access router, there is an Ethernet user network. The over-provisioning of the Ethernet network permits us to abstract its characteristics for the experiments. The UA and Proxy of domainsat.org are located in the user network behind the ST. The Sip Proxy, according to QoS requirements of the user, starts the configuration of QoS mechanisms up inside the ST (admission control, classification...).

The terrestrial part of the satellite network is an Ethernet network. It's composed by the GW and the OSP. On the other side, domainter.org uses an Ethernet network. This destination domain is composed by the remote UA and Proxy. This latter is in charge of Sip connection management of this domain. These domains are interconnected by a router, represented by a machine with its routing IP layer activated. Sip Proxies in these experiments are achieved by the **partysip** software and Sip User Agents by **minisip** software. Using this platform, we evaluate the impact of our proposal on the e2e applicative delay for a period of time corresponding to the first two super-frames of the communication on the return link.

Test Scenarios description

In our test scenarios, the UA inside the satellite network initiates a Sip audio communication by calling the remote UA inside the terrestrial network. To measure the performance of the proposed cross-layering RBDC access, we use an audio flow with G711 audio codec at 64kbit/s. This flow is mapped toward AF 1 DiffServ class and queued in the DVB-VR-RT buffer which used RBDC capacity request at MAC level inside the ST.

Parameters of the emulated satellite system are setup to:

- Forward link Capacity : 1024kbps
- Frame periodicity : 53ms
- Super-frame periodicity : 10 frames : 530ms
- Capacity request period : 1 super-frame : 530ms
- TBTP emission period : 1 super-frame : 530ms

For each proposition of section III is associated an evaluation scenario:

Scenario 0 is the reference test evaluating resources allocation with no anticipation (current access behavior).

Scenarios 1.1 and **1.2** evaluate the first solution with emission of the request respectively before and after the TBTP computation-emission; **scenario 1.3** evaluates the first solution with a TBTP emission period each frame (53ms).

Scenario 2 evaluates the second proposition (TBTP update and emission) with TBTP emission period at 1 super-frame (530ms).

Scenario 3 evaluates the third solution evaluation (acknowledgment from NCC).

Results presentation and Analysis

The Fig. 6 represents the satellite e2e delay for the two first super-frames for each scenario.

- In the reference test without resource anticipation (scenario 0), the e2e delay is around 1500ms which represents the sum of delay for the data buffering (530ms) in the ST, the delay for the satellite crossings of the request and response (600ms), and the propagation delay (300ms). The e2e delay experimented for this scenario is not compatible with the strict time constraints associated to interactive multimedia flow [10].
- The e2e delay of first solution varies between 300ms when the request is emitted right before the TBTP calculation (scenario 1.1) and 900ms when the request is emitted just after (scenario 1.2). Then, this approach cannot fully guaranty that the time constraints of interactive flow will be met. However the packets' e2e delay with TBTP emission frequency set to 1 frame is always around 300ms (scenario 1.3), so the time constraints objective is met in any cases for this scenario, but at the price of a significant signaling overhead.

- For both second and third solutions (scenario 2 and 3) the observed e2e delay is around 300ms. These two solutions enable to guaranty a delay compatible with time constraints of interactive flows. However, the third solution will be preferred, as the second introduces complex modification of the access scheme mechanisms and might generate significant computation overhead inside the NCC.

Fig. 6 e2e applicative delay for each scenario (mean delay for each scenario)

Figure 6. e2e applicative delay for each scenario (mean delay for each scenario)

Experimental results confirm theoretical behavior and suggest that enhancements are required to guaranty satisfactory quality for interactive application's user over the satellite. The proposed solutions (from scenario 1.3) are satisfactory in terms of provided QoS. However, if we take into account the various overhead, the third solution will be preferred because it introduces slight modifications of the present satellite architecture along with optimal results for the communication.

Conclusion

This paper has introduced and evaluated enhancements for interactive applications' user experience over satellite, using a highly efficient (thus less costly) assignment type of DVB-RCS access scheme (RBDC). This enhancements concern the communication opening where accumulation of delay introduced by this on-demand assignment type may badly degrades applicative quality. The experiments conducted, proved that the proposed anticipation of resource improves communication quality, without losing efficiency of the satellite system (no capacity is wasted). Among the three proposed enhancements, the third solution will be the preferred one, due to the slight modifications it requires. These enhancements may gain to be coupled with other enhancements proposing to anticipate requests during the communication [1] [2].

Use of dynamic CRA allocation have been foreseen but not studied for three main reasons: 1) not easy to predict release of resources, 2) constant assignment may lead to suboptimal use of resources, 3) implies modification of the global agreement of the satellite system.

In the future, we will study more in details other scenarios (including other enhancements) as well as overhead (signaling and computation) introduced by our contributions.

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