A Closed-loop Transmission Control Mechanism for Satellite Interactive Services

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***Abstract* - The Second-generation digital satellite broadcasting system (DVB-S2) offers not only increased efficiency in static transmission schemes, but also provides adaptability for time-varying propagation environments via the ACM (Adaptive Coding and Modulation) feature. This paper analyses the efficiency of a closed-loop transmission control scheme in an interactive DVB-S2/DVB-RCS network providing triple-play services. A Satellite Resource Management System is proposed, which receives reception quality feedback from end-users in order to adapt in real-time the downlink transmission scheme. Since the capacity of the downlink changes, a cross-layer adaptation scheme is employed to adapt the bandwidth of the offered services.**

I. INTRODUCTION

Satellite links, due to their extended capacity and wide coverage, are an ideal medium for the provision of a variety of services, areas where terrestrial networks are inadequate[1]. As a consequence, there is increasing commercial interest to use satellites in modern communications. However, these advantages are counterbalanced by the cost of the lease of satellite transponders and by the time-variation of satellite channels, especially near the bounds of the satellite footprint, which affects the performance of the whole system. The success of satellite communications is heavily dependent on new solutions that : (a) maximize the efficiency of satellite spectrum, which reduces the cost of satellite link per service or per user and (b) use adaptive channel coding techniques to compensate for the time variations of the satellite channel.

No complete and unified solution that maximizes the efficiency of the satellite transponder and compensates for time variations exists today. The problem has been –and is currently being– investigated in many layers (physical, network, services), but only partial solutions have been proposed so far; the solutions provide optimisation in special cases, where, for example, only one of the above layers is considered, or a static channel is assumed [2][3][4].

The EU-funded IST IMOSAN (Integrated Multi-layer Optimization in broadband DVB-S.2 SAtellite Networks) project [5], currently running under the 6th Framework Programme, addresses this issue by designing and implementing a closed-loop, cross-layer resource management mechanism and incorporating it in a DVB-S2/DVB-RCS interactive satellite network.

II. THE SRMS CLOSED-LOOP CONCEPT

Based on the aforementioned assumptions, the IMOSAN project proposes an integrated closed-loop control management mechanism that optimises the usage of the satellite spectrum. This management mechanism, under the name Satellite Resource Management System (SRMS), is located at the Satellite Provider site and performs real-time adaptation which spans across three layers: Physical, Network and Services. The Adaptive coding and modulation (ACM) feature of DVB-S2 standard is exploited, to provide optimization in time varying operating environments. The return channel is based on DVB-RCS technology.

An overview of the proposed SRMS closed-loop mechanism is depicted in Fig.1. Per-terminal measurements for the propagation conditions of the forward satellite channel, received through the return channel, are processed by the SRMS and appropriate actions are taken to optimize the satellite channel, by proper adaptations in the physical layer. These adaptations are always performed in conformance to the DVB-S2 standard and include:

- per-service change of modulation (QPSK, 8PSK, 16APSK, 32APSK)
- per-service change of the LDPC (Low-Density Parity Check) rate among the standard values: 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9 and 9/10

Thus, a closed-loop transmission control system is realised.

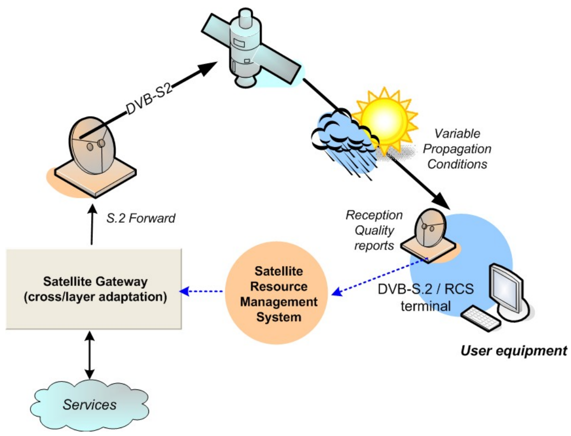

Figure 1. General concept of the SRMS closed-loop control system

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At the same time, since such a Physical-layer adaptation naturally causes fluctuations in the system useful downlink capacity, modification of the rate of the offered services must also be performed on i) the network layer for data services (dynamic bandwidth management per service, or per user, etc) and ii) the services layer for audiovisual broadcast services (bit rate, resolution, format, etc). Services-layer adaptation is undertaken by real-time A/V encoders, able to modify the rate of the produced stream on-the-fly. In this sense, the closed-loop control performs in a cross-layer approach. (Fig.2)

The SRMS system is designed, implemented and developed is currently being demonstrated and evaluated in a real satellite environment. In the frame of the IMOSAN project, an actual DVB-S2 satellite network is developed, demonstrated and validated to show the capabilities of the cross-layer management solution, for the provision of triple play services (digital TV programs, Internet access and telephone connections) under real conditions. A star-topology network is being implemented, among nodes in Toulouse (France), Athens (Greece), Paris (France), Heraklion (Greece) and Zalau (Romania). The finalisation of the experimental network will have taken place by June 2008.

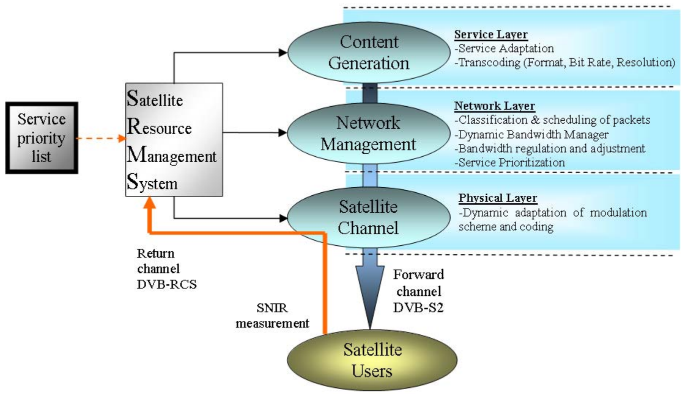

Figure 2. Cross-layer adaptation, as performed by the SRMS

The achievement of the SRMS functionality is threefold: i) link availability almost reaches 100% for all receiver sites due to link adaptation, ii) satellite capacity is fully exploited avoiding wasting of spectrum due to unnecessary over-coding when propagation conditions improve and iii) a service prioritisation scheme is satisfied, so that same streams (e.g. multicast TV) take precedence over others.

III. PERFORMANCE EVALUATION

Since long-term results regarding the efficiency of the system cannot obtainable during the field trials due to the limited transmission time, a software simulation environment has been set-up. This environment incorporates the algorithm and communication procedures of the SRMS. The aim of the simulation is to determine the expected long-term gain of the SRMS approach in terms of capacity and service availability, in comparison to static transmission schemes, such as DVB-S and DVB-S2 CCM. For each site, a channel fading model was developed in order to represent rain attenuation, in conformance to the empirical statistical model recommended by ITU-R P.618-8 [7]. Rain heights for each site were derived from [8]. Five different services were assumed, one for each site, having different priorities. The simulation parameters are shown in Table I.

TABLE I
SYSTEM PARAMETERS FOR PERFORMANCE EVALUATION

Satellite	**HellasSat II at 39^0 East**
Reception Sites	**Toulouse, Paris, Athens, Heraklion and Zalau**
Transponder Bandwidth	**36 MHz**
Transmission standard	**DVB-S, DVB-S2 CCM, DVB-S2 ACM/SRMS**
Downlink frequency	**14 GHz**
Polarisation	**Horizontal**
DVB-S2 mode	**normal frame, no pilots, roll-off = 0.2**
Clear sky C/N	**10 dB**
Rain fading model	**According to ITU-R P.618-8**
Rainfall rate	**Approximated in ITU-R P.837-4**
Elevation angle, rain path	**Calculated for each site**
Number of services	**5, one for each site**

For each scenario, various static configurations were considered (DVB-S, DVB-S2 CCM), for each of which the service outage time (in hours per year) and the overall capacity were derived. The latter was calculated as the average sum of all five services, at MPEG-2 TS level (i.e. including the IP-to-MPEG2 encapsulation overhead). Then, the SRMS approach was evaluated. SRMS received C/N reports from each site, in a round-robin scheme and, after each report processing, the Transmission Schemes for all services were calculated, and service rates were re-assigned, in relevance to their priorities. The average sum of service data rates was recorded, along with outage time due to very deep fades, below the lowest C/N threshold of the DVB-S2 system (i.e. -2.35 dB).

The results of performance evaluation is summarised in Table II.

From the comparative results it can be seen that, in the case of static configuration, a trade-off always exists between capacity and link availability. The adaptive SRMS approach overcomes this limitation, maximising at the same time capacity and availability. For high link availability requirements, the SRMS-enhanced system achieves an over 50% increase in capacity compared to a CCM transmission. This benefit will naturally be even higher, if the reception sites include regions with high rainfall rate and thus stronger signal quality fluctuations.

TABLE II

PERFORMANCE EVALUATION OF THE SRMS CLOSED-LOOP CONTROL MECHANISM, IN COMPARISON WITH STATIC CONFIGURATION, FOR THE PROVISION OF SATELLITE INTEGRATED SERVICES

Standard	*Modulation/ Coderate*	*C/N Operating Threshold (dB)*	*Link Outage (hrs/yr)*	*Link Availability*	*Average Capacity (Mbps)*
DVB-S	QPSK 7/8	7.2	14.0	99.84%	45.2
DVB-S	QPSK 3/4	5.5	6.1	99.93%	38.9
DVB-S	QPSK 2/3	4.3	4.4	99.95%	34.6
DVB-S2 CCM	16APSK 2/3	8.9	68.3	99.22%	78.1
DVB-S2 CCM	8PSK 3/4	7.9	23.7	99.73%	66.3
DVB-S2 CCM	QPSK 4/5	4.7	4.4	99.95%	47.4
DVB-S2/SRMS	**(adaptive)**	**-2.35**	**0.4**	**99.9954%**	**78.5**

IV. CONCLUSION

This paper presented the concept of a closed-loop Transmission Control mechanism using the ACM feature of DVB-S2. The mechanism, which is tailored for the provision of satellite triple-play services, is proposed and implemented of the EU-funded IST project IMOSAN. The project in integrating this mechanism (concentrated in a dedicated module – the SRMS) within a DVB-S2/DVB-RCS Network. The paper describes the functionality and operation of the SRMS and evaluates its gain in a simulation environment.

By maximising satellite resource efficiency, the closed-loop transmission control achieved by the SRMS achieves a significant innovation in satellite communications and accelerates the introduction of the DVB-S2 technology in the market. By increasing capacity and efficiency and reducing operational cost, the proposed solution is anticipated to assist the evolution of the satellite market, especially (but not only) addressing rural areas and developing countries and ultimately fulfil the needs of large groups of European citizens.

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