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Research Letter

A Cross-Layer Rate Control Mechanism for Link-Adaptive Satellite Integrated Services

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This paper presents a mechanism for dynamic rate control of satellite integrated services, based on a cross-layer approach, utilising link quality feedback from the satellite terminals. The mechanism, namely, satellite resource management system (SRMS) relies on the adaptive coding and modulation (ACM) capabilities of DVB-S2 in order to perform real-time adjustments on the physical, network and services layer and optimise the usage of satellite spectrum. The functionality of the SRMS is discussed along with its implementation in the frame of the IST IMOSAN Project. Simulation results are presented, involving modelled rain fading and prioritised heterogeneous services, which illustrate the efficiency of the proposed solution against current static transmission schemes.

1. INTRODUCTION

Satellite platforms are the only medium for the provision of integrated/triple-play services in cases where terrestrial networks are inadequate, for example, in rural and underdeveloped regions or in long-range transportation media. However, their high-capacity and wide-coverage capabilities are in a sense counterbalanced by the high cost of the satellite spectrum, which has a direct impact on the end-user costs [1].

Therefore, solutions that optimise the efficiency of the usage of the satellite spectrum are not only valuable, but critical for the commercial viability of satellite integrated services. A significant step towards this optimisation has been the introduction of the DVB-S2 specification, featuring near-Shannon-limit performance along with adaptive coding and modulation (ACM) [2] to compensate for variations in satellite link quality, caused by several factors, such as attenuation due to rain and atmospheric gases, scintillation, depolarisation, and interference [3, 4].

Given that the available transponder bandwidth- and consequently the multiplex symbol rate—must remain constant, on-the-fly adjustments of the per-service modulation and coding naturally cause a fluctuation in the system overall capacity, since the spectrum efficiency changes. Thus, the available resources must be redistributed. Reference [5] proposes a tunable-fairness queuing algorithm, especially tailored for the DVB-S2 case, which, however, is applicable only to unicast data services. A triple-play service scenario requires simultaneous handling and adaptation of both unicast and multicast, interactive and streaming services. A cross-layer approach, extending to the services layer, is required as the one proposed in [6], but at this time including physical-layer adaptation. This is achieved by the proposed *satellite resource management system (SRMS)*, currently under development in the frame of the EU-funded IST IMOSAN (FP6-IST-027457) project.

2. SRMS: CONCEPT AND FUNCTIONALITY

The satellite resource management system is a separate and autonomous management entity, operating in the provider's satellite gateway. In the IMOSAN scenario, the latter is set up to provide triple-play services to end users, that is, multicast H.264-based TV, Internet access, and VoIP telephony.

The SRMS receives input from a service database, containing all multicast and unicast services, along with their relative priorities and associated terminals. It also collects and exploits reception quality reports which are periodically sent by certain satellite terminals back to the gateway via the interaction channel (e.g., DVB-RCS). Typically, reports contain the measured C/N ratio at the receiver, a value which can be degraded due to weather phenomena, mainly rain [7]. Whereas, in a static transmission scheme, a deep C/N fade below the threshold would cause the interruption of the service, an adaptive link as the one proposed adjusts in real time the signal robustness to match the channel state. Since C/N fluctuations in satellite reception are generally slow, the high satellite propagation delay has little impact on the responsiveness of the feedback loop.

Following this approach, the SRMS flow of operation is as follows. First, upon receiving an incoming C/N report by a terminal, SRMS reacts by selecting the appropriate transmission scheme (modulation constellation and code rate—MODCOD) for the specific service in order to match the reception conditions of the terminal(s) associated with this service. The appropriate command is sent to the DVB-S2 ACM modulator. A novelty introduced by the proposed approach is the support not only of unicast, but also of multicast services (e.g., a TV broadcast). In this case, distributed reference terminals are used, to report the measured C/N for a whole service area (e.g., a city).

As aforementioned, it is natural that changes in a transmission scheme cause capacity fluctuations. Let us assume n discrete services (A/V streams, data and voice connections) in the satellite multiplex, r_i the instantaneous rate of the ith service (in bits/s), and e_i its spectral efficiency (in bits/symbol) taking into account the coding overhead and the modulation constellation. In DVB-S2, e_i can vary from 0.49 up to 4.45, depending on the MODCOD used, as it has been calculated in [8]. The choice of a denser modulation constellation and less-redundant code rate increases the spectral efficiency but naturally reduces signal robustness. The symbol rate of each service R_i and the overall symbol rate R_S are given by

$$R_i = \frac{r_i}{e_i}, \qquad R_S = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \frac{r_i}{e_i}. \tag{1}$$

At any time, in order to avoid an overflow in the modulator, the following must be fulfilled:

$$R_S \leq R_{\text{mod}}, \tag{2}$$

where R_{mod} is the constant symbol rate of the modulator.

If, after an MODCOD adjustment, R_S exceeds R_{mod}, the rates of the services must be restricted so that (2) is fulfilled. SRMS takes the decision to restrict rates according to the priorities declared in the service database. In specific, if P_i is the priority of the ith service (a smaller value corresponds to a higher priority), then the new rate r'_i to be assigned is calculated as

$$r'_i = \frac{(\max_n\{P_j\} - P_i)\cdot B_i \cdot R_S \cdot e_i}{\sum_{k=1}^{n}(\max_n\{P_j\} - P_k)\cdot B_k}, \tag{3}$$

where B_i is an indicator of the instantaneous rate requirement for the ith service, derived from the occupancy of the buffer of the service in the multiplexer.

Once the new service rates are calculated, rate modification commands for interactive data services are sent to the bandwidth manager (BWM) which applies rate restrictions for each incoming service. Correspondingly, rate modification commands for multicast A/V services are sent to the real-time source encoders, in order to adapt in real time the encoding rate of the A/V stream. In the IMOSAN implementation, H.264 video encoders with on-the-fly rate adaptation capabilities have been developed and used. Here lies another novelty of the SRMS approach; unlike other cross-layer approaches which affect only the physical and the network layer, it expands its intervention also to the services layer, by directly controlling the encoding procedure of the multicast audiovisual services.

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.

3. PERFORMANCE EVALUATION

The aforementioned approach is being implemented into a complete DVB-S2/DVB-RCS functional system in the frame of the IST IMOSAN project. The satellite gateway is located in Toulouse, France, using the HellasSat II satellite, and the receiver sites are spread in five sites across Europe: Toulouse, Paris, France, Athens, Heraklion, Greece, and Zalau, Romania. Since long-term results regarding the efficiency of the system cannot be obtained 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 link 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 [9]. A long-term model for rain attenuation was used, instead of a dynamic one. Five different services were assumed, one for each site, having different priorities. The simulation parameters are shown in Table 1.

Three evaluation rounds were performed, assuming three different values of clear sky C/N, consistent for all sites. For each scenario, various static configurations were considered (DVB-S, DVB-S2 CCM). For each of these, the known operating threshold, as given in [8], was considered in addition to the statistical fading model, so as to derive the expected service outage time (in minutes per year). The overall capacity was also derived from [8].

Then, the SRMS approach was evaluated. In the simulation process, 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 reassigned, in relevance to their priorities,

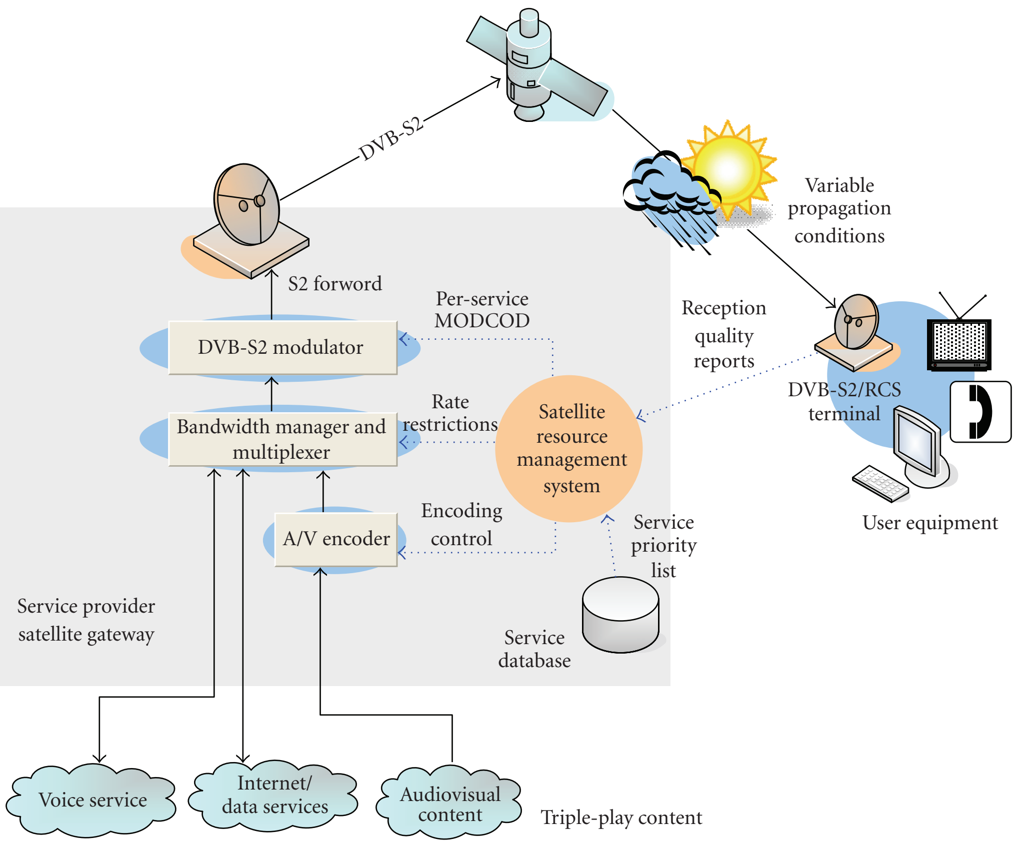

Figure 1: The SRMS in a triple-play-enabled interactive satellite network.

Table 1: System parameters for performance evaluation.

Satellite/Transponder BW	HellasSat II at 39° East/36 MHz
Reception Sites	Toulouse, Paris, Athens, Heraklion and Zalau
Transmission standard	DVB-S, DVB-S2 CCM, DVB-S2 ACM/SRMS
D/L frequency, polarisation	14 GHz, Horizontal
DVB-S2 mode	normal frame, no pilots, roll-off = 0.2
Clear sky C/N	7, 10 and 15 dB (three cases examined)
Rain fading model	According to ITU-R P.618-8
Rainfall rate	Approximated in ITU-R P.837-4

according to (3). In any case, restriction (2) was satisfied. The average overall capacity was calculated as the average sum of all five services, at MPEG-2 TS level (i.e., including the IP-to-MPEG2 encapsulation overhead). Also, the outage time was statistically calculated, which is 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 2.

From the comparative results, it can be seen that in the case of static configuration, a tradeoff always exists between capacity and service availability. The adaptive SRMS approach overcomes this limitation, maximising at the same time capacity and availability. For high availability requirements, the SRMS-enhanced system achieves 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.

4. CONCLUSION

This paper presented a cross-layer, link-adaptive rate control mechanism for satellite integrated services using DVB-S2. A new management entity, the satellite resource management system, was introduced in the provider's satellite gateway, processing in real-time signal quality reports from the satellite receivers and performing adjustments on the physical, network and services layer. Performance evaluation of the SRMS, carried out in a simulated environment, shows significant increase in both service availability and useful capacity, when compared with static transmission. In conclusion, the proposed approach offers much more optimised

Table 2: Performance evaluation of the SRMS adaptive mechanism, in comparison with static configuration, for the provision of satellite integrated services.

Performance evaluation results for clear sky C/N = 7 dB					
Standard	*Modulation/ Coderate*	*C/N Operating Threshold (dB)*	*Expected Outage (mins/yr)*	*Link Availability*	*Avg. Capacity (Mbps)*
DVB-S	QPSK 3/4	5.5	2418	99.54%	38.7
DVB-S	QPSK 1/2	2.6	366	99.93%	25.9
DVB-S2 CCM	QPSK 5/6	5.2	1842	99.65%	49.0
DVB-S2 CCM	QPSK 2/3	3.1	474	99.91%	39.6
DVB-S2 CCM	QPSK 1/2	1	210	99.96%	29.4
DVB-S2/SRMS	*(adaptive)*	*−2.35*	*48*	*99.9914%*	*58.8*
Performance evaluation results for clear sky C/N = 10 dB					
Standard	*Modulation/ Coderate*	*C/N Operating Threshold (dB)*	*Expected Outage (mins/yr)*	*Link Availability*	*Avg. Capacity (Mbps)*
DVB-S	QPSK 7/8	7.2	840	99.84%	45.2
DVB-S	QPSK 2/3	4.3	264	99.95%	34.6
DVB-S2 CCM	16APSK 2/3	8.9	4098	99.22%	78.1
DVB-S2 CCM	8PSK 3/4	7.9	1422	99.73%	66.3
DVB-S2 CCM	QPSK 4/5	4.7	264	99.95%	47.4
DVB-S2/SRMS	*(adaptive)*	*−2.35*	*24*	*99.9954%*	*78.5*
Performance evaluation results for clear sky C/N = 15 dB					
Standard	*Modulation/ Coderate*	*C/N Operating Threshold (dB)*	*Expected Outage (mins/yr)*	*Link Availability*	*Avg. Capacity (Mbps)*
DVB-S	QPSK 7/8	7.2	108	99.98%	45.4
DVB-S2 CCM	32APSK 4/5	13.6	2574	99.51%	117.3
DVB-S2 CCM	32APSK 3/4	12.73	1206	99.77%	110.4
DVB-S2 CCM	16APSK 4/5	11.1	474	99.91%	94.7
DVB-S2 CCM	16APSK 2/3	8.9	210	99.96%	79.2
DVB-S2/SRMS	*(adaptive)*	*−2.35*	*6*	*99.999%*	*122.49*

usage of the satellite spectrum with relatively minor modifications on the provider network, thus reducing service cost and increasing efficiency.

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