Using DVB-S2 Adaptive Coding and Modulation for the Provision of Satellite Triple Play Services

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ABSTRACT

The outstanding spectrum efficiency of DVB-S2 along with its adaptability and configurability makes it a very promising technology for next-generation satellite communications. This article discusses the application of the adaptive coding and modulation feature of DVB-S2 in the provision of satellite triple play services over an interactive DVB-S2/DVB-RCS network in order to compensate for fluctuations in propagation conditions. A cross-layer resource management system is proposed in order to adapt the system to such fluctuations and improve its overall efficiency. Based on area-specific attenuation models, an efficiency study is presented, showing considerable capacity gains over static transmission schemes (DVB-S and DVB-S2 CCM).

INTRODUCTION

Interactive satellite services provision via a broadcast system is not a new concept; it dates back almost a decade, when a terrestrial return channel was used for interaction in digital video broadcasting-satellite (DVB-S) networks, thus enabling for broadband satellite Internet access [1]. The standardization of DVB-return channel via satellite (DVB-RCS) [2] in 2000 introduced a pure satellite-based solution for interactive broadcasting. At the same time, in the terrestrial sector, the multiplexing of heterogeneous services — digital television, telephony, and Internet access, the so-called triple play — over the same channel opened new perspectives for the provision of integrated services via terrestrial networks like digital subscriber line (xDSL).

The synergy of the two worlds (i.e., the support of triple play services provision via a satellite platform) constitutes a very promising concept. Due to the high capacity and extended footprint of today's satellites, such an approach could make the provision of all-IP integrated services possible in cases where terrestrial networks prove inadequate, such as in isolated/low-population-density areas or long-range transportation media (ships, airplanes). Otherwise isolated end users are able to enjoy broadband digital television (DTV) content, telephony connectivity, and fast access to the Internet while being totally independent of terrestrial access networks. In this sense, such a satellite platform could contribute toward the fading of the so-called digital divide [3]. Recent statistics show that approximately 20 percent of the European population is not reachable by terrestrial broadband infrastructures, offering a large amount of potential customers to be targeted by satellite technologies. This also applies to developing countries, where the deployment of a space infrastructure (which does not rely on modern reliable local ground infrastructures) can be of considerable interest. Furthermore, it is important to note that satellite-based integrated services are more immune to catastrophes, natural disasters, and terrorist attacks, which usually cause the collapse of terrestrial communications.

There is, though, a critical issue in the economic viability and competitiveness of satellite access solutions, since the high transponder lease has a significant impact on user fees. This is why satellite service providers seek solutions to maximize spectrum efficiency, thus achieving optimum allocation of the transponder bandwidth. The introduction of DVB-S2 [4] constitutes a great step toward the optimum spectrum usage by achieving a less than 1 dB approach to the Shannon limit and providing per-service real-time adjustment of transmission parameters, a feature called adaptive coding and modulation (ACM). By exploiting ACM, the satellite provider can adjust in real time the transmission parameters for each service, in relation to the propagation conditions of the corresponding site. In this sense the satellite capacity can be optimally exploited, and subsequently the cost of services can be drastically reduced.

This article discusses the application of DVB-S2 ACM in satellite triple play, including technical issues involved in resource allocation, network design and deployment, and simulated system evaluation.

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Providing Triple Play over DVB-S2/DVB-RCS

Following the success and wide adoption of the DVB-S standard for digital satellite broadcasting, the DVB Forum came up with its successor, DVB-S2, a specification adopted by the European Telecommunications Standards Institute (ETSI) as a European Standard in March 2005 [4]. DVB-S2 defines the forward link transmission format for next-generation satellite services and has already generated significant industry activity, including technical trials and commercial deployment, as well as announcements of planned services by several providers.

The main features of the DVB-S2 specification include a flexible input stream adapter and multiplexer, supporting a multitude of baseband formats/heterogeneous services, a powerful forward error correction (FEC) system based on low density parity check (LDPC) codes concatenated with Bose-Chaudhuri-Hocquenghem (BCH) codes, allowing quasi-error-free operation at down to 0.7 dB from the Shannon limit, depending on the transmission mode and four constellations — quaternary phase shift keying (QPSK), 8-PSK, 16APSK, and 32APSK — optimized for operation over nonlinear transponders.

If all multiplexed services are transmitted under the same modulation constellation and coding rate (MODCOD in DVB-S2 terminology) scheme, as was the case with DVB-S, this is the simplest transmission scheme, called constant coding and modulation (CCM). Going a step further, modulation constellation and code rate can be applied separately on a per-service basis within the forward link time-division multiplex (TDM), thus realizing a variable coding and modulation (VCM) scheme. In this context each service undergoes a different error protection scheme and has differentiated robustness against signal degradation. In addition, if there is feedback from each client site regarding the reception quality, the per-service MODCOD — which directly affects the signal robustness — can also vary over time, in order to match the time-varying propagation conditions. This technique is called adaptive coding and modulation (ACM), and is inherently supported by the DVB-S2 specification, provided that a return link, such as DVB-RCS, exists in order to convey the reception quality reports.

Regarding interactivity, the DVB-S2 standard neither defines nor adopts a specific technology for the implementation of the return channel. Any wired or wireless terrestrial or satellite networking solution can be used. For satellite only access, though, the DVB-RCS system is the most appropriate, thus realizing a solution totally independent of terrestrial access networks.

Nowadays, DVB-S2 satellite networks are mostly used for either broadcasting or (in a very few cases) data (Internet) access solely. If triple play provision is desired, certain technical considerations regarding the network architecture must be taken into account.

Given that all services comprised in the triple play package are provided over IP, the core of the satellite network needs to be an IP-over-DVB forward channel chain, consisting of various stages for routing, policing, encapsulation, multiplexing, and, finally, encoding and modulation. All service streams (TV, Internet/data, and voice connections) are conveyed multiplexed over the common DVB-S2 channel utilizing either a single or multiple satellite transponder(s). User interactions are sent via the DVB-RCS return channel and concentrated in the DVB-RCS hub (Fig. 1).

At the user sites, interactive DVB-S2/RCS terminals receive, demultiplex, and present the various heterogeneous streams. Using appropriate interfaces, the terminals can play the role of head-end redistribution nodes, which offer connectivity to one or more local subnetworks of end users through other types of terrestrial access networks (LAN, WiFi, WiMAX, etc.).

Resource Optimization via ACM and Cross-Layer Management

In the simplest approach, the architecture referred to in the previous section can utilize CCM, providing all services to all user sites under a common modulation and coding (MODCOD) scheme.

However, as aforementioned, a critical issue in satellite transponder usage is the optimum exploitation of the available capacity. Satellite spectrum is quite costly, and is common for the entire footprint, without the ability to reuse it over a repetitive coverage scheme as is done in terrestrial cellular networks. It is therefore mandatory to ensure that transponder capacity is optimally used at any time. By using CCM, it is certain that a portion of the capacity is wasted in overcoding, which is unnecessary in clear sky conditions. The adaptive capabilities of DVB-S2 can greatly contribute to this goal. If the service provider is aware of the reception conditions of each site — quantified by a single parameter, like carrier-to-noise ratio (C/N) or E_s/N_o — transmission parameters can adapt in real time to the needs of each site. In this sense, ACM allows the reuse of the 4–8 dB of power (the so-called clear sky margin), which is typically wasted in CCM satellite links, thus considerably increasing the average satellite throughput and subsequently reducing the service costs [5].

ACM was initially designed for interactive services only (e.g., Internet access). In this work we extend its use to include the broadcast audiovisual streams included in a triple play package. Figure 2 depicts an example with 2 remote sites and 3 services, showing the ACM principle of operation.

When applying ACM, there is a critical issue to bear in mind: altering the transmission parameters leads to a change in the per-service spectral efficiency, and subsequently in the total overall capacity of the system.

This can be made clearer if we consider certain system parameters. Given that the overall downlink signal bandwidth (e.g., 36 MHz for occupying an entire satellite transponder) must be constant, the overall symbol rate S_T (in megasymbols per second) must also kept con-

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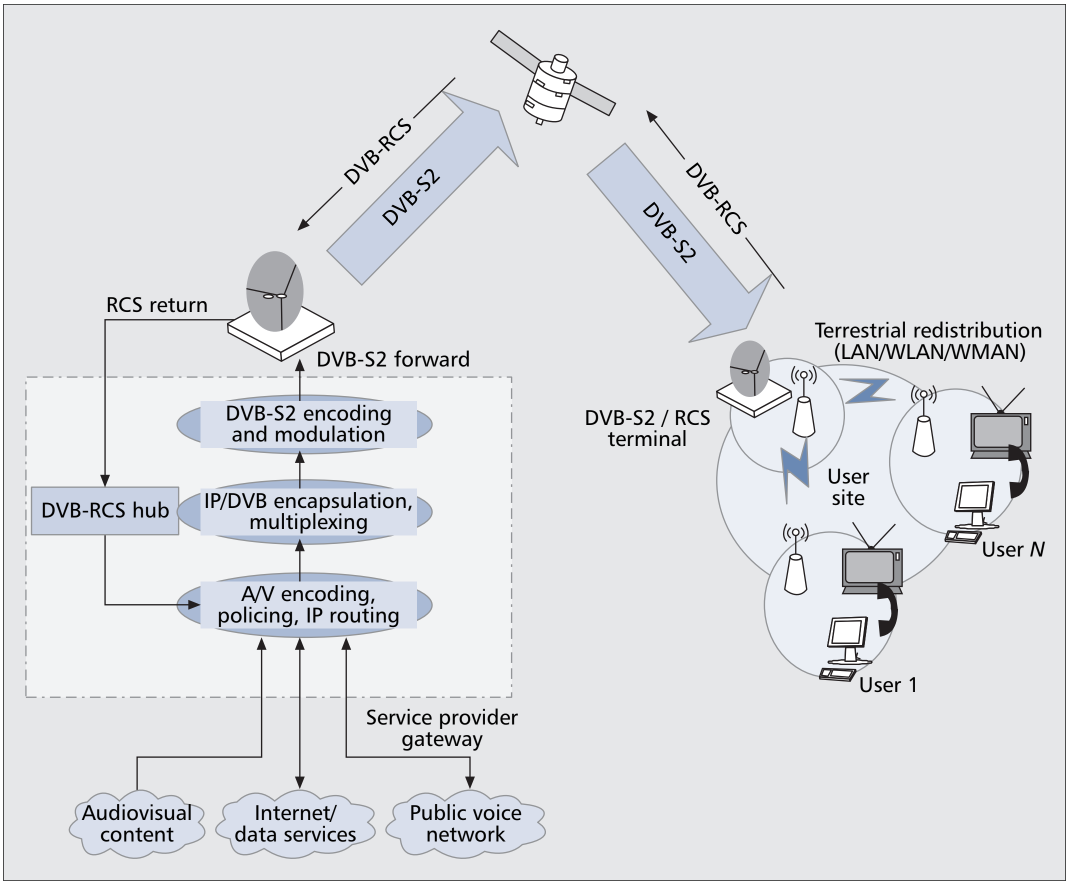
The goal of SRMS is to achieve optimum exploitation of the valuable satellite capacity for the provision of Triple Play services. It does not perform any adaptation process itself, but it decides what adaptations need to be applied and issues the appropriate commands to the corresponding modules.



■ **Figure 1.** *Generic architecture for providing triple play over DVB-S2.*

stant. Let us consider N services contained in the downlink multiplex, where a service can be defined as either a single data stream broadcast to multiple sites or a set of streams transmitted to a single site. For example, a service can be:

- An SDTV/HDTV program broadcast to all sites
- The set of all Internet data and voice connections from users at the same site (served via the same satellite terminal)

Each service is transmitted under a specific MODCOD because it needs to have a given robustness against channel impairments. The DVB-S2 standard offers a choice of 28 different MODCODs, each having a certain spectral efficiency e_i (in bits per symbol). For example, using 8PSK modulation with code rate 3/5 yields a spectral efficiency of 1.78 b/symbol.

If we assume that the kth service is transmitted under the MODCOD $i(k)$ and has an instantaneous bit rate of R_k, its symbol rate will be $S_k = R_k/e_{i(k)}$, where $e_{i(k)}$ is the spectral efficiency of MODCOD $i(k)$. At any time, the sum of symbol rates of all services must not exceed the overall symbol rate R_T of the system (i.e., $R_T \geq \sum S_k$). For this restriction to hold, upon any MODCOD change the service bit rates must be modified accordingly in real time. The rate of data services can be adjusted by proper IP-level rate restriction, queuing, and shaping (network-layer adaptation), while the rate of audiovisual services can be modified by dynamic modification of the audio/video encoding rate (service-layer adaptation).

It can thus be deduced that the employment of ACM for satellite triple play requires a central cross-layer management mechanism that performs real-time dynamic adaptation in multiple layers (physical, network, and service).

The EU-funded Information Science and Technology (IST) project Integrated Multilayer Optimization in Broadband DVB-S2 Satellite Networks (IMOSAN) [6] has designed and developed such a mechanism, the Satellite Resource Management System (SRMS), which has been integrated in a DVB-S2/RCS satellite network. Experimental transmissions are being carried out via the HellasSat II satellite.

SRMS (whose concept is depicted in Fig. 2) performs join real-time resource management spanning multiple layers. The goal of SRMS is to achieve optimum exploitation of the valuable satellite capacity for the provision of triple play services. It does not perform any adaptation process itself, but decides what adaptations need to be applied and issues the appropriate commands to the corresponding modules. Measurements for the condition of the forward satellite channel, received through the return channel, are exploited by the SRMS, which takes appropriate actions to optimize the satellite channel by adaptations in the:

- **Physical layer** (ACM commands to the DVB-S2 modulator: per-service modifications of MODCOD rate)
- **Network layer** (control of the IP policer and DVB encapsulator/multiplexer: dynamic bandwidth management per service)

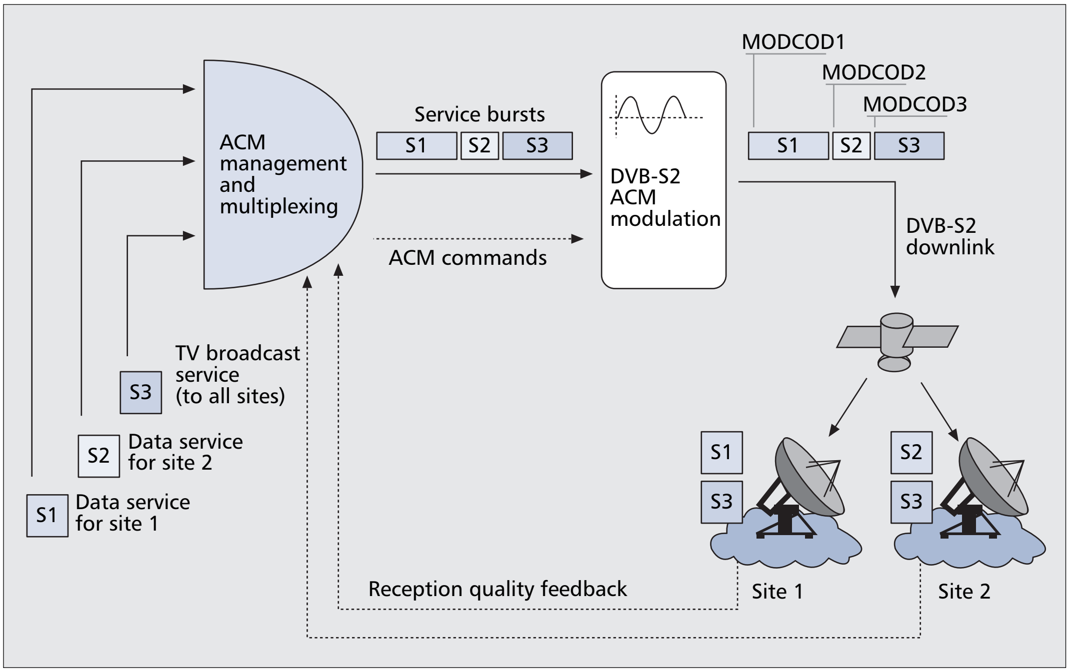


Figure 2. *ACM operation in the provision of satellite integrated services.*

- **Services layer** (commands to the audio/video encoding/transcoding modules: real-time adjustment of bit rate, resolution, and format)

The primary adaptation task is that of the physical layer, which depends on reception quality feedback. A simple representative metric for reception quality, mostly associated with additive white Gaussian noise (AWGN) degradation, is the C/N. A very likely reason for C/N degradation in a satellite setup is a change in weather conditions (e.g., clouds or heavy rain). By means of a fixed table correlating C/N with MODCOD settings, SRMS knows a priori which per-service settings are required to make the signal robust enough to compensate for the reported fading.

As shown in Fig. 3, the cross-layer management scheme does not depend on interactions among the different layers themselves (e.g., via cross-layer signaling and distributed management), but via the standalone SRMS, which supervises and manages all layers simultaneously. This centralized approach adds flexibility and eliminates the need to incorporate cross-layer signaling and also parts of the resource management algorithm into each module. Also, it is easier to configure and manage, since the cross-layer management and service priority list are concentrated in a single module.

As an example of the operation of SRMS, one can consider a scenario where a site receiving a certain service suffers from fading (e.g., due to rain) and reports a drop in C/N. In this case the SRMS decides to take appropriate action:

- In the physical layer, the DVB-S2 modulator is configured to offer extra protection to a certain service by increasing the coding redundancy or employing a sparser constellation (MODCOD change). Within the VCM-tagged multiplex sent to the modulator, the multiplexer marks the packets containing the service in order to be carried over a more robust MODCOD. The modulator extracts this in-band signaling and performs a per-PLFrame (physical layer frame, a basic component of the DVB-S2 downlink) variation of the MODCOD, according to the requirements of each service.
- In the network layer, rates of data services are restricted to fit in the new total capacity (which is decreased due to the stronger error protection). Each data service contains several discrete IP streams, multiplexed under , say, a weighted round-robin (WRR) or weighted fair queuing (WFQ) scheme. Each IP stream is served by a discrete first-in first-out (FIFO) buffer with — in a simple approach — drop-tail manage-

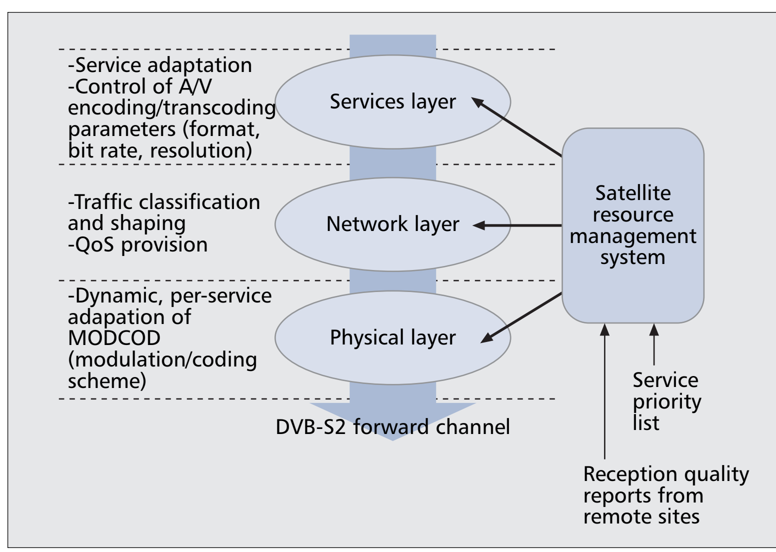


Figure 3. *Functionality of the SRMS cross-layer management.*

The SRMS concept constitutes a unified cross-layer solution that allows the application of ACM to satellite triple play services, maximizing the efficiency of a satellite transponder and compensating for time variations.

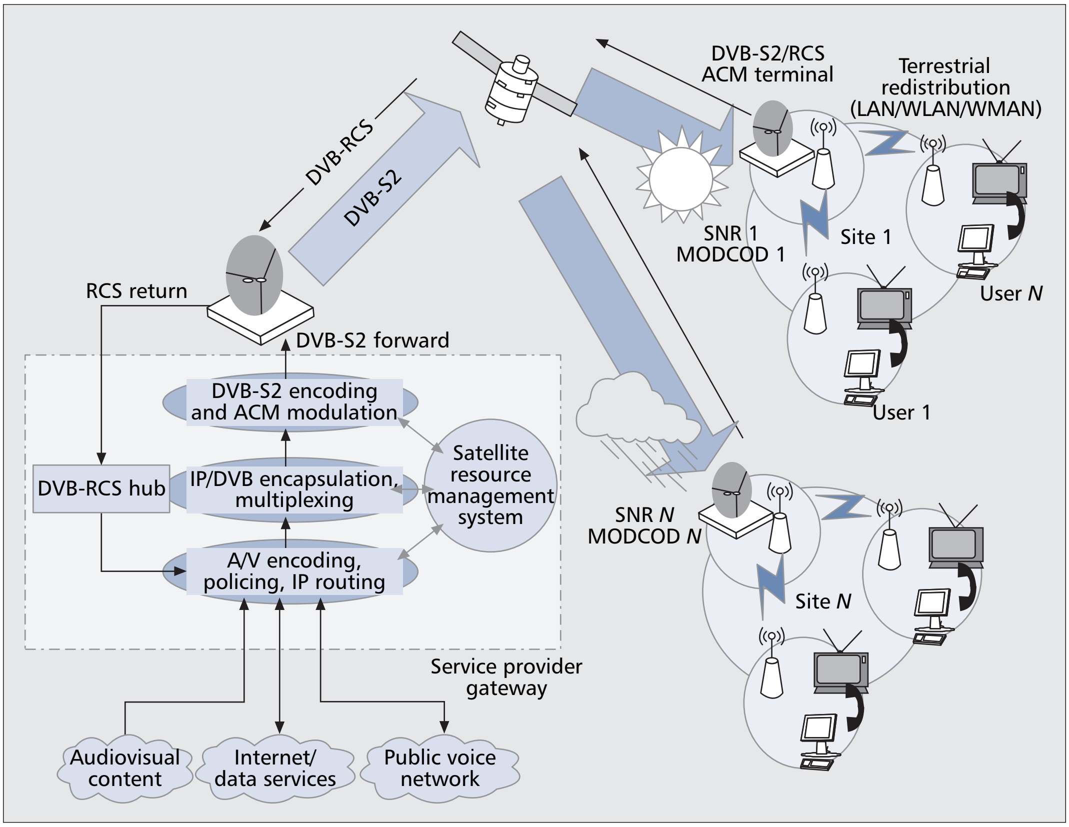


Figure 4. *Example of a DVB-S2 triple play network, employing ACM and SRMS*

ment. An ACM change triggering a bit rate reduction causes overflow of the IP stream buffers and loss of the last incoming packets. For TCP connections, TCP will naturally react by entering slow start mode and consequently reducing transmission rate.

- In the service layer, A/V services are transcoded in real time to lower bit rate in order to spare bandwidth. Picture quality is normally degraded, but this is preferable to not having any picture at all. Seamless adaptation ensures that the viewer observes no interruption in the playback of the audiovisual stream.

When the fading conditions cease, the SRMS will decide to revert the aforementioned actions. In any case, the symbol rate S_k of each service remains constant, according to its priority, as a portion of the overall symbol rate of the multiplex. Again, if we assume that the kth service is transmitted under the MODCOD $i(k)$ and the current spectral efficiency is $e_{i(k)}$, after each MODCOD change its maximum bit rate R_k is adjusted by the SRMS to $R_k = S_k/e_{i(k)}$.

The SRMS concept constitutes a unified cross-layer solution that allows the application of ACM to satellite triple play services, maximizing the efficiency of a satellite transponder and compensating for time variations. This issue has been and is currently being investigated in the physical, network, and service layers individually, but only partial solutions have been proposed so far; the solutions provide optimization in special cases, where, for example, only one of the above layers is considered or a static channel is assumed.

Efficiency Assessment

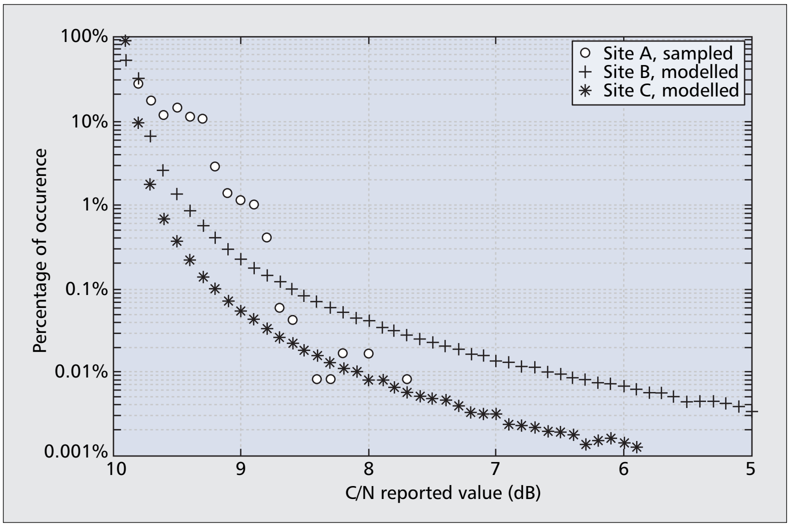
In this section we present a five-step procedure to assess the efficiency of the application of the DVB-S2 ACM feature, combined with cross-layer management, in satellite triple play, based on a five-step approach. This procedure can be applied at the design stage of any satellite network in order to determine the capacity gain of ACM over static transmission schemes (DVB-S or DVB-S2 CCM). A specific application scenario is adopted in order to illustrate the followed methodology.

a. At first, an overall network architecture and specification is needed: the satellite to be used, the bandwidth of the transponder and the radio frequency (RF) parameters, the location of the satellite hub-gateway and user sites, and the grouping of end users to sites. It is generally preferable for, if possible, each site to serve more than one end user. Users behind a satellite terminal are served via a wired or wireless terrestrial redistribution network. This grouping achieves reduction of the equipment cost (since the satellite infrastructure has fewer end nodes) and also simplifies the ACM management mechanism, since fewer sites and reception reports are considered. In order to have an example, let us consider a triple play provision network utilizing a 36 MHz transponder on the HellasSat II satellite at 39° east, with 10 remote sites distributed across a country (Greece), located in specific rural areas. At each site local end users are served via WiMAX networks. Figure 4 depicts the network architecture, featuring ACM transmission being managed by the SRMS module, as described in the previous section.

b. The second step is to determine the number and nature of services to be provided. In order that they can be handled and managed in a unified way, it is assumed that all services are provided over IP. Let us consider the provision of Internet connection and IP telephony to each user, along with three H.264 HDTV programs, also conveyed over IP and broadcast to all sites. For bandwidth management purposes, the set of interactive streams (data and voice) for each site is considered as a single service, which makes a total of 10 + 3 services. All of them are multiplexed in the common downlink, and each is transmitted under a specific MODCOD.

c. Afterward, the resource allocation strategy has to be defined (i.e., the algorithm that will process the ACM feedback reports and adjust the rate of each service) in order to conform to the restrictions mentioned in the previous section. Each MODCOD modification must be accompanied by an adjustment in the service rate. The ACM algorithm can be very complicated, taking in mind prioritization of services. In our example, let us consider a simplified yet fair approach in which each service is assigned a fixed symbol rate within the multiplex. As mentioned earlier, this approach was also followed by the SRMS. If we assume that the overall downlink capacity is 30 Msymbols/s, we can allocate, say, 2 Msamples/s for the data and voice service of each site, and 3.3 Msymbols/s for each HDTV program. With such a static allocation, the modification of a service's MODCOD affects only the bit rate of this service, leaving the others unaffected. Since each site serves many users, it can be statistically assumed that each service bandwidth will always be fully utilized, and the static allocation will not lead to waste of unused capacity. Upon the arrival of a reception quality report that makes a MODCOD change necessary for a specific site, the SRMS sends the corresponding MODCOD modification command to the modulator. At the same time, it commands the multiplexer to modify the rate of the service in order to keep the symbol rate constant. In the case of the HDTV services, these must be properly received by all sites. Therefore, their MODCOD has to comply with the site with the worst reception conditions. Their rate is modified by the SRMS, sending a rate modification command to the H.264 encoder.

d. A critical parameter for performance evaluation is the statistical modeling of the fluctuation of the reception quality for each site. Since satellite reception usually suffers from flat AWGN fading, a simple yet realistic approach is to consider the C/N ratio as the reception quality indicator. The C/N ratio is commonly reported by most commercial satellite receivers. In a time-varying environment, weather conditions affect the propagation loss of the satellite signal, with rain being the most important attenuation factor. The statistical processing of the signal fluctuation can be done via two approaches: sampling or modeling. The first approach involves sampling C/N values from the satellite receiver at a specific site during a sufficiently long period (e.g., three years). The statistical



■ **Figure 5.** *Probability of C/N values for three sites, assuming clear-sky C/N of 10 dB.*

data can be mapped to MODCOD requirements for each site. A simpler and quicker approach is modeling rain attenuation at each site. International Telecommunication Union (ITU) Recommendation P.618-8 [7] can be used for this purpose; it introduces a model for approximating the probability of a specific attenuation incident. Figure 5 shows the probability of occurrence for several attenuation incidents (in dB) which has been translated to C/N values, assuming a clear sky C/N of 10 dB. Both sampled and modeled values are shown. The sampled set is derived from an one-month per-minute recording of C/N values from a satellite receiver in Athens, Greece, during April 2008. The sampled values follow a trend line quite similar to the modeled ones, and would normally be much closer if the sampling were to take place through a whole year (or over several years).

In any case, as can be observed from Fig. 5, deep fading occurs only a small portion of the time and do not last enough to really affect the average C/N, which is practically the same for all sites and the standard deviation of which is quite restricted. What really differs is the magnitude of these fadings, for which the ACM mechanism is used to compensate. In order to determine this magnitude, the ITU model needs as input, apart from the site location and satellite/transmission parameters, an indicator of the rain intensity at the specific location. This indicator (labeled R0.01) represents the rain intensity value (in millimeters per hour) which is exceeded only in 0.01 percent of the time in a year. In our example we selected 10 rural locations (both dry and rainy) in Greece, as mentioned above, on which we applied the ITU model. The R0.01 value for each location was provided by the Hellenic National Meteorological Service and is shown in Table 1. The same table depicts the C/N0.01 estimation, which is the C/N value in dB below which reception falls only 0.01 percent of the entire year.

e. After the necessary data has been gathered, the last step is to conduct the simulation

After the necessary data has been gathered, the last step is to conduct the simulation procedure. During each iteration of the simulation, a C/N value is statistically produced for each site, and the data are processed by the modeled cross-layer management system.

Service	Site rainfall rate R0.01 (mm/h)	Site C/N0.01 (dB)	Average C/N compensated for (dB)	Service symbol rate (Mbaud)	Average service rate (Mb/s)
Site 1 data and voice	27.5	4.29	9.96	2.0	5.27
Site 2 data and voice	16.8	5.95	9.97	2.0	5.28
Site 3 data and voice	60.2	0.10	9.92	2.0	5.25
Site 4 data and voice	47.9	2.02	9.94	2.0	5.26
Site 5 data and voice	43.1	2.01	9.94	2.0	5.27
Site 6 data and voice	58.6	0.28	9.92	2.0	5.26
Site 7 data and voice	19.1	5.62	9.97	2.0	5.28
Site 8 data and voice	17.9	5.86	9.97	2.0	5.28
Site 9 data and voice	30.3	3.90	9.95	2.0	5.27
Site 10 data and voice	16.8	6.04	9.97	2.0	5.28
HDTV1	(all sites)	(all sites)	8.64	3.3	8.60
HDTV2	(all sites)	(all sites)	8.64	3.3	8.60
HDTV3	(all sites)	(all sites)	8.64	3.3	8.60
Overall average capacity					78.50

■ **Table 1.** *Attenuation parameters and performance evaluation results for the triple play satellite network under a specific application scenario.*

procedure. During each iteration of the simulation, a C/N value is statistically produced for each site, and the data are processed by the modeled cross-layer management system (SRMS), which selects the appropriate MODCOD for each service. For the HDTV services, the worst C/N report of all sites is taken into account, which explains why the average "C/N compensated for" is shown in Table 1 to be significantly lower in comparison to all sites. Then the (constant) service symbol rate is divided by the MODCOD spectral efficiency e_i (in bits per symbol) to derive the bit rate to be applied to the service. Our simulation involved 10^7 iterations, and the average rates derived are shown in Table 1.

It is derived that the average service rate of the broadcast HDTV programs is 8.6 Mb/s, sufficient for H.264 HD content. Also, the average rate of data and voice streams of each site is around 5.3 Mb/s. If we consider a commercial 1 Mb/s access service, using a typical contention ratio of 1:30, this means each site can serve 159 users, and the entire system can serve 1590 users.

At this point, the efficiency gain of the application of ACM can be estimated for the specific application scenario. Let us consider the same network setup, using DVB-S2 CCM transmission with no feedback and no cross-layer management. Without adaptive transmission, we have to set a desired link availability requirement (i.e., a percentage of time during which the services shall be available with sufficient C/N). Let us assume a typical desired link availability of 99.5 percent (i.e., 43.8 h/yr of outage due to fading). A statistical processing of the modeled C/N samples shows that for 99.5 percent of the year the C/N stays above 6.8 dB. Therefore, the satellite signal should be properly received at this C/N level.

This means that, according to the MODCOD-C/N threshold mapping, we have to select a constant modulation of 8PSK and code rate of 2/3, resulting in constant overall capacity of 57 Mb/s. If we keep 8.6 Mb/s for each HDTV service, the number of total users that can be served is 936. A comparison with DVB-S2 ACM shows that the latter offers a 70 percent gain in the number of users (accompanied by a reduction in service fees).

If we compare this to DVB-S, which is the case with most contemporary satellite access systems, using QPSK modulation, we have to select code rate of 3/4, resulting in 38.9 Mb/s, enough for 393 users. In this case the proposed DVB-S2 ACM mechanism offers a 304 percent gain.

The aforementioned gain figures are indicative yet realistic. They depend not so much on the cross-layer management algorithm, but mainly on the system setup (allocation of services and sites) and channel variability. It is evident that at sites with intense rainfall peaks (e.g., tropical regions), the importance of the adaptation mechanism and thus the gain from using ACM will be considerably greater. The application scenario illustrated is just indicative; the aforementioned procedure can be followed during the design of any satellite network, given that the network and services setup, ACM cross-layer management algorithm, and statistical fading data for each site are given or can be approximated.

CONCLUSIONS

The article discusses the application and exploitation of the ACM feature of DVB-S2 for the provision of satellite triple play services over DVB-S2/DVB-RCS networks. The architecture of the network is investigated, and a cross-layer management approach is proposed in order to adapt the system in capacity fluctuations caused by ACM.

A five-step efficiency assessment procedure is presented in order to determine, for any specific network and service deployment scenario, the expected capacity gain from the use of ACM and cross-layer management over static transmission schemes (DVB-S and DVB-S2 CCM). As an example, we used a typical setup, including three HD broadcast services and 1 Mb/s voice and data connections to 10 specific remote sites with modeled propagation/fading conditions. The increase in capacity was considerable over using DVB-S2 CCM and even higher compared to DVB-S. This gain results in more users being served and subsequently reduced service costs.

The proposed approach is very promising in the field of satellite integrated services provision and can accelerate the penetration of triple play in the satellite market. Transmission adaptability and efficient cross-layer resource management will result in affordable satellite triple play services, not only for the business but even for the home user. An attractive and viable solution for broadband triple play in rural, low-density, and underdeveloped areas is thus realized.

Transmission adaptability and efficient cross-layer resource management will result in affordable satellite triple play services, not only for the business but even for the home user. An attractive and viable solution for broadband triple play in rural, low-density and underdeveloped areas is thus realized.

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BIOGRAPHIES

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