Using DVB-S2 Adaptive Coding and Modulation (ACM) 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 (ACM) 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).

Keywords

DVB-S2 satellite networks, interactive broadcasting, cross-layer resource management, Triple Play services

1. Introduction

Interactive satellite services provision via a broadcasting system is not a new concept; it dates back to almost a decade ago, when a terrestrial return channel was used for interaction in DVB-S (Digital Video Broadcasting – Satellite) networks, thus enabling for broadband satellite Internet access [1]. The standardization of DVB-RCS (Digital Video Broadcasting – Return Channel via Satellite) [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 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 are proved inadequate, e.g. in isolated/low-population-density areas or in long-range transportation media (ships, airplanes). Otherwise isolated end users are able to enjoy broadband DTV (Digital Television) content, telephony connectivity and fast access to Internet, while being totally independent from terrestrial access networks. In this sense, such a satellite platform could contribute towards the fading of the so-called "digital divide" [3]. Recent statistics show that approximately 20% of European population is not reachable by terrestrial broadband infrastructures, offering a potential large amount of customers to be targeted by satellite technologies. This also applies to developing countries, where the deployment of a space infrastructure (that does not rely upon modern and 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, terrorist attacks, which usually cause the collapse of terrestrial communications.

There is, though, a critical issue, this of the economic viability and competitiveness of satellite access solutions, since the high transponder lease has a significant impact on the user fees. That is why satellite service providers seek solutions, which could maximize the spectrum efficiency, thus achieving an optimum allocation of the transponder bandwidth. The introduction of DVB-S2 [4] constitutes a great step towards the optimum spectrum usage by achieving a less-than-1-dB approach to the Shannon limit and by 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.

2. 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 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/heterogenous services, a powerful FEC (Forward Error Correction) system based on LDPC (Low Density Parity Check) codes concatenated with BCH (Bose-Chaudhuri-Hocquenghem) codes, allowing Quasi-Error-Free operation at down to 0.7dB from the Shannon limit, depending on the transmission mode and 4 constellations (QPSK, 8PSK, 16APSK, 32APSK), optimized for operation over non-linear transponders.

If all multiplexed services are transmitted under the same modulation constellation and coding rate ("MODCOD" in DVB-S2 terminology) scheme, as it 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 separately applied on a per-service basis within the forward-link TDM multiplex, 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 from terrestrial access networks.

Nowadays, DVB-S2 satellite networks are mostly used either for broadcasting or (in a very few cases) for 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 comprising 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 transponders. 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 a head-end redistribution node, which offer connectivity to one or more local sub-networks of end users, through other types of terrestrial access networks e.g. LAN, WiFi, WiMAX, etc.

3. Resource optimisation via Adaptive Coding and Modulation 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 coding and modulation (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 re-use it over a repetitive coverage scheme, as it happens 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 over-coding, which is unnecessary in clear-sky conditions. The adaptive capabilities of DVB-S2 can greatly contribute towards this goal. If the service provider is aware of the reception conditions of each site -quantified by a single parameter, like C/N or Es/No-, transmission parameters can in real-time adapted to the needs of each site. In this sense, ACM allows the reuse of the 4 to 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. Fig.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 be taken 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 MSymbols/sec) must also kept constant. Let us consider N services contained in the downlink multiplex, whereas 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:

- a SDTV/HDTV program, broadcast to all sites, or
- the set of all Internet data and voice connections from users in 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 20 different MODCODs, each one having a certain spectral efficiency e_i (in bits/symbol). For example, using 8PSK modulation with code rate 3/5 yields a spectral efficiency of 1.78 b/S.

If we assume that the k-th 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. $R_T \geq \Sigma S_k$. 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), whereas the rate of audiovisual services can be modified by dynamic modification of the audio/video encoding rate (Services-layer adaptation).

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

The EU-funded IST project IMOSAN (Integrated Multi-layer Optimisation in broadband DVB-S2 Satellite Networks) [6] has designed and developed such a mechanism, named 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 Figure 2) performs joint, real-time resource management spanning across 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 it 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 - modulation and code rate).

- **Network layer** (Control of the IP policer and DVB encapsulator/multiplexer: dynamic bandwidth management per service).

- **Services layer** (Commands to the Audio/Video encoding/transcoding modules: real-time adjustment of bit rate, resolution and format).

The primary adaptation task is this of the physical layer, which depends on reception quality feedback. A simple representative metric for reception quality, mostly associated with AWGN degradation, is the Carrier-to-Noise ratio (C/N). A very likely reason for a C/N degradation in a satellite set-up is a change in the 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 signalling and distributed management), but via the stand-alone SRMS, which supervises and manages all layers simultaneously. This centralised approach adds flexibility and eliminates the need to incorporate cross-layer signalling 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 the appropriate actions:

- In the Physical layer, the DVB-S2 modulator is configured to offer extra protection to the certain service, by increasing the coding redundancy or employing a sparser constellation (MODCOD change). Within the VCM (Variable Coding and Modulation)-tagged multiplex send to the modulator, the multiplexer marks the packets containing the certain service in order to be carried over a more robust MODCOD. The modulator extracts this in-band signalling and performs a per-PLFrame (Physical Layer Frame, 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 e.g. a WRR (weighted round robin) or WFQ (weighted fair queuing) scheme. Each IP stream is served by a discrete FIFO buffer with -at a simple approach- a drop-tail management. An ACM change triggering a bit rate reduction causes the overflow of the IP stream buffers, and loss of last incoming packets. For TCP connections, TCP will naturally react by entering slow start mode and consequently reducing transmission rate.

- In the Services 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 k-th 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 layer 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.

4. Efficiency assessment

In this section, we present a five-step procedure of assessing of 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. That is, the satellite to be used, the bandwidth of the transponder and the RF parameters, the location of the satellite hub-Gateway and the user sites and the grouping of end users to sites. It is generally preferable that, if possible, each site serves 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 less 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 utilising a 36MHz transponder on the HellasSat II satellite at 39 degrees East, with 10 remote sites distributed across a country (Greece), located in specific rural areas. In each site, local end users are served via WiMAX networks. Fig. 4 depicts the network architecture, featuring ACM transmission, which is 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 to be handled and managed in a unified way, it is assume 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 High-Definition TV programs, also conveyed over IP and broadcast to all sites. For bandwidth management purposes, the set of interactive streams (data&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 transmitted, each under a specific MODCOD.

c. Afterwards, the resource allocation strategy has to be defined, i.e. the algorithm which will process the ACM feedback reports and adjust the rate of each service, in order to conform to the restrictions mentioned to 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 prioritisation 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 aforementioned, this approach was also followed by the SRMS. If we assume that the overall downlink capacity is 30 MS/s, we can allocate e.g. 2MS/s for the data&voice service of each site, and 3.3 MS/s for each of the HDTV programs. With such a static allocation, the modification of a service's MODCOD affects only the bit rate of this service, leaving the other ones unaffected. Since each site serves many users, it can be statistically assumed that each service bandwidth will always be fully utilised, and that the static allocation will not lead to a waste of unused capacity. Upon the arrival of a reception quality report which 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 the sampling of C/N values from the satellite receiver in a specific site during a sufficiently long period, e.g. three years. The statistical data can be mapped to MODCOD requirements for each site. A simpler and quicker approach is the modeling of rain attenuation in each site. The ITU Rec. P.618-8 [7] can be used for this purpose, which introduces a model for approximating the probability for a specific attenuation incident. Fig.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 would take place throughout a whole year (or during several years).

In any case, as it can be observed from Fig.5, in any case, deep fadings occur only during 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 whose standard deviation is quite restricted. What really differs is the magnitude of these fadings, 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 the satellite/transmission parameters, an indicator of the rain intensity in the specific location. This indicator (labeled as R0.01) represents the rain intensity value (in mm/h) which is exceeded only in 0.01% of the time around a year. In our example, we selected ten rural locations (both dry and rainy) in Greece, as aforementioned, 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 during 0.01% of the entire year.

e. 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 (SRMS), which selects the appropriate MODCOD for each service. For the HDTV services, the worst C/N report of all sites is taken in mind, and that 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/symbol) in order to derive the bit rate to be applied to the service. Our simulation involved 10^7 iterations, and the average rates which were derived are shown in Table 1.

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 (Mbps)
Site 1 Data&Voice	27.5	4.29	9.96	2.0	5.27
Site 2 Data&Voice	16.8	5.95	9.97	2.0	5.28
Site 3 Data&Voice	60.2	0.10	9.92	2.0	5.25
Site 4 Data&Voice	47.9	2.02	9.94	2.0	5.26
Site 5 Data&Voice	43.1	2.01	9.94	2.0	5.27
Site 6 Data&Voice	58.6	0.28	9.92	2.0	5.26
Site 7 Data&Voice	19.1	5.62	9.97	2.0	5.28
Site 8 Data&Voice	17.9	5.86	9.97	2.0	5.28
Site 9 Data&Voice	30.3	3.90	9.95	2.0	5.27
Site 10 Data&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

It is derived that the average service rate of the broadcast HDTV programs is 8.6 Mbps, sufficient for H.264 HD content. Also, the average rate data&voice streams of each site is around 5.3 Mbps. If we consider a commercial "1Mbps access" service, using a typical contention ratio of 1:30, this means that 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 set-up, 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 the C/N being sufficient. Let us assume a typical desired link availability of 99.5% (i.e. 43.8 hours per year of outage due to fading). A statistical processing of the modeled C/N samples shows that, during 99.5% 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 on constant overall capacity of 57 Mbps. If we keep 8.6 Mbps for each HDTV service, the number of total users which can be served is 936. A comparison with DVB-S2 ACM shows that the latter offers an 70% gain in the number of users (accompanied by a reduction in service fees).

If we compare 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 Mbps, enough for 393 users. In this case, the proposed DVB-S2 ACM mechanism offers a 304% 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 set-up (allocation of services and sites) and also on the channel variability. It is evident that, in sites with intense rainfall peaks (such as in 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 set-up, the ACM cross-layer management algorithm and the statistical fading data for each site, are given or can be approximated.

5. Conclusions

The paper discussed the application and exploitation of the ACM (Adaptive Coding and Modulation) feature of DVB-S2 for the provision of satellite triple play services over DVB-S2/DVB-RCS networks. The architecture of the network was investigated, and a cross-layer management approach was proposed in order to adapt the system in capacity fluctuations caused by ACM.

An five-step efficiency assessment procedure was 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, in comparison to static transmission schemes (DVB-S and DVB-S2 CCM). As an example, we used a typical set-up, including three HD broadcast services and 1Mbps voice&data connections to ten specific remote sites with modeled propagation/fading conditions. The increase in capacity was considerable in comparison to using DVB-S2 CCM and even higher in comparison to DVB-S. This gain results in more users being served and subsequently in the reduction of 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.

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Authors' short bios

Dr. Georgios Gardikis received the Diploma and PhD in Electrical and Computer Engineering from the National Technical University of Athens. He is currently a Research Associate at NCSR "Demokritos", working in national and EU-funded ICT research projects. He has also collaborated with the University of the Aegean, conducting DVB-H-related research activities, and he has served as a consultant to the Ministry of Transport and Communications in digital switchover issues. He is a Member of the IEEE/Communications and Broadcast Technology Society.

Dr. Anastasios Kourtis received his BS degree in Physics in 1978 and his PhD degree in Telecommunications in 1984 from the University of Athens. Since 1986 he is a researcher in the Institute of Informatics and Telecommunications of the Greek National Center for Scientific Research “Demokritos”, currently ranking as Research Director. His current research activities include digital terrestrial interactive television, broadband wireless networks, perceived quality of video services and real time bandwidth management in satellite communications.

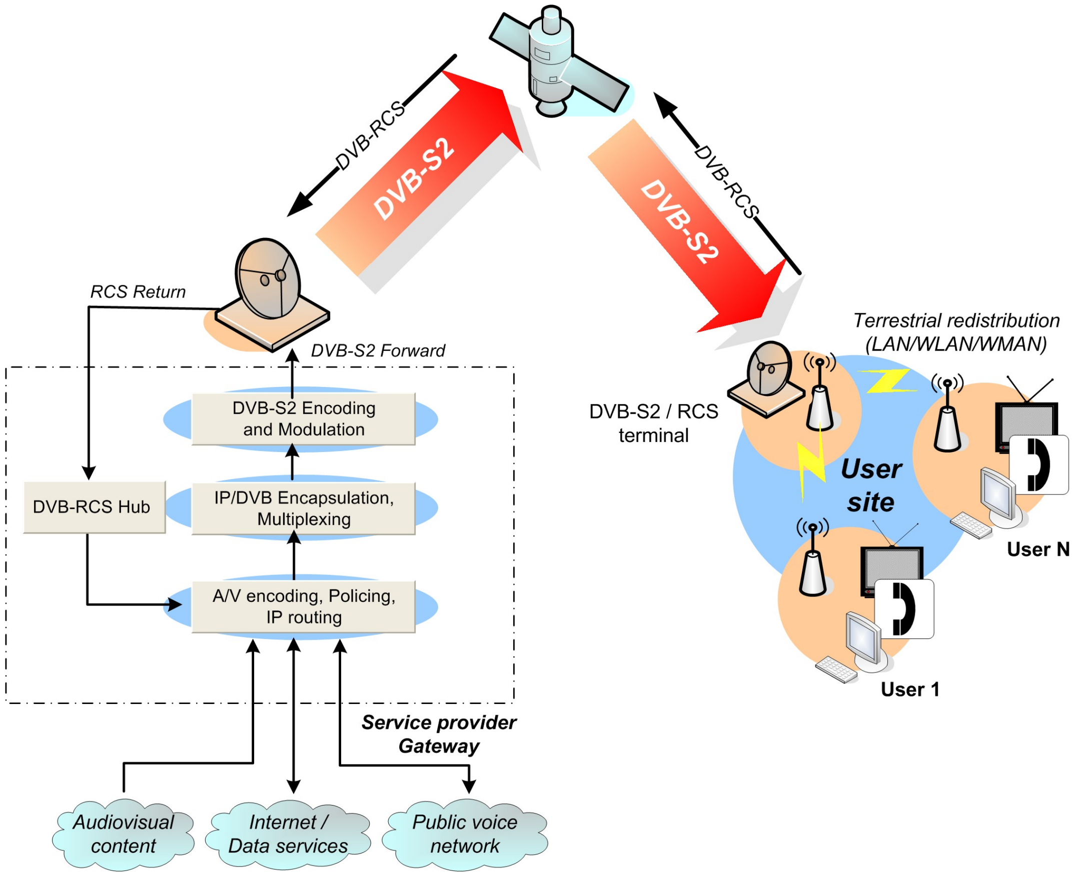

Fig.1. Generic architecture for providing Triple Play over DVB-S2

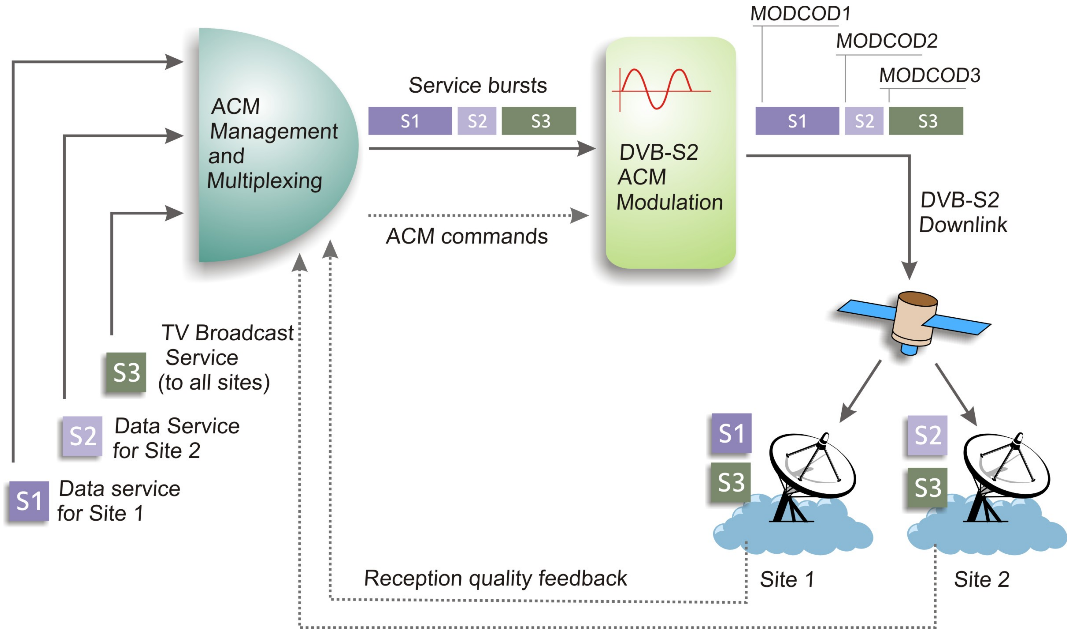

Fig.2. ACM operation in the provision of satellite integrated services

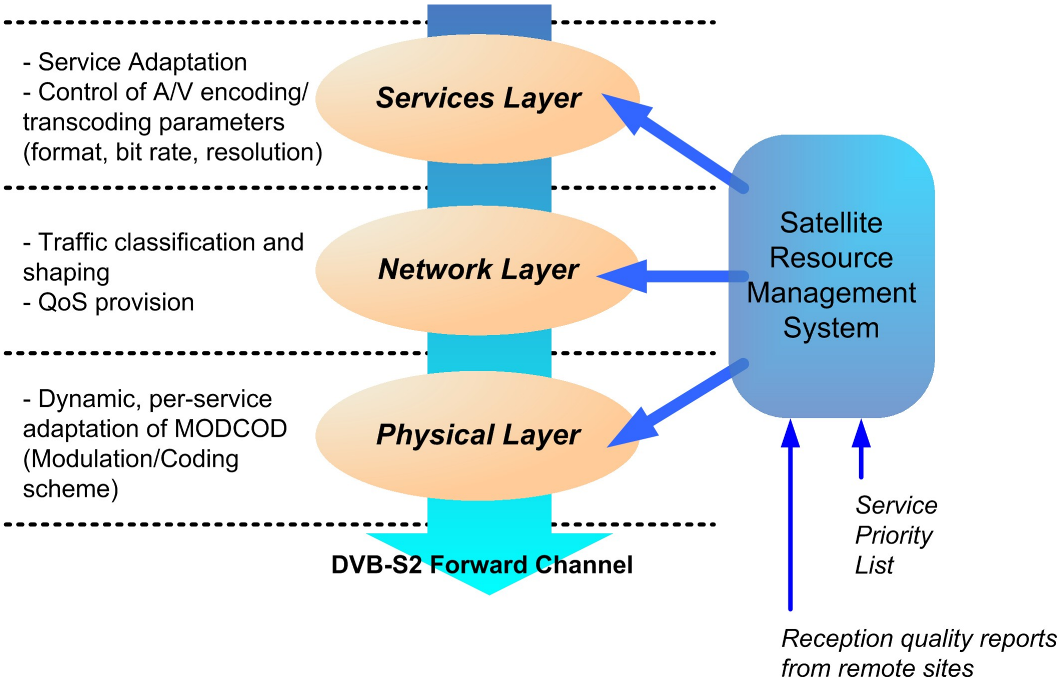

Fig.3 Functionality of the SRMS cross-layer management

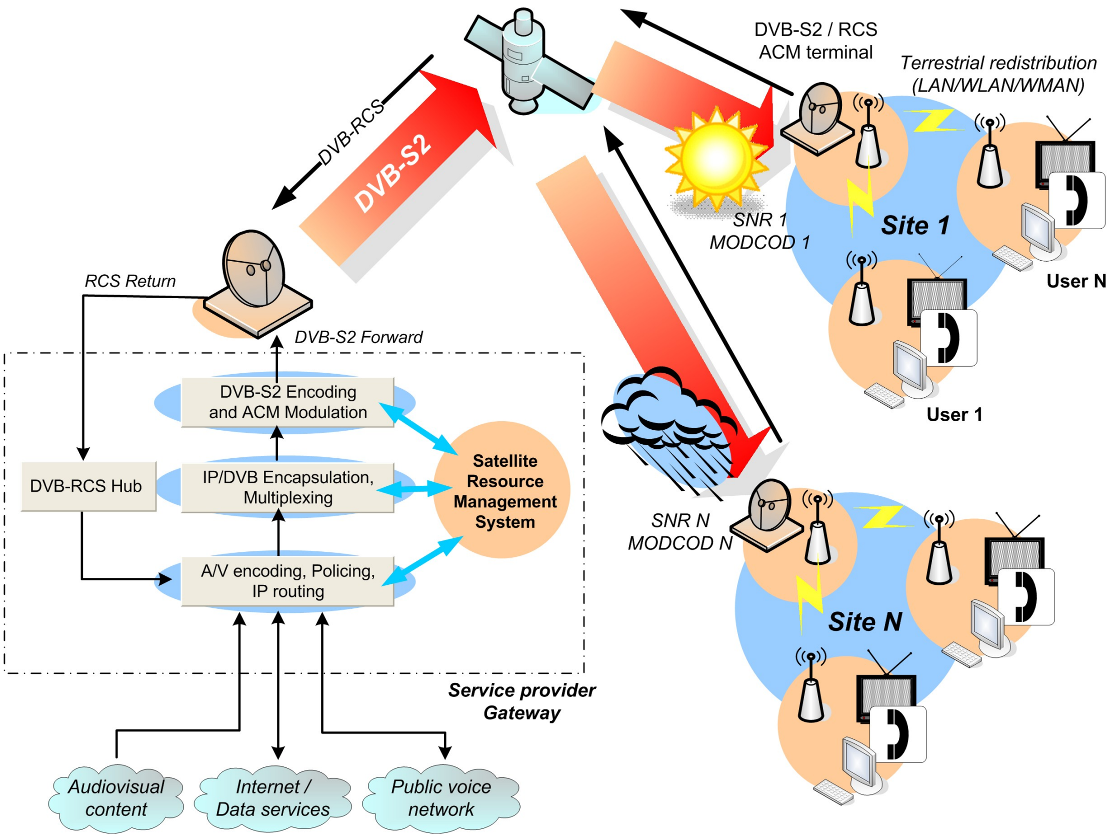

Fig.4. Example of a DVB-S2 triple play network, employing ACM and SRMS

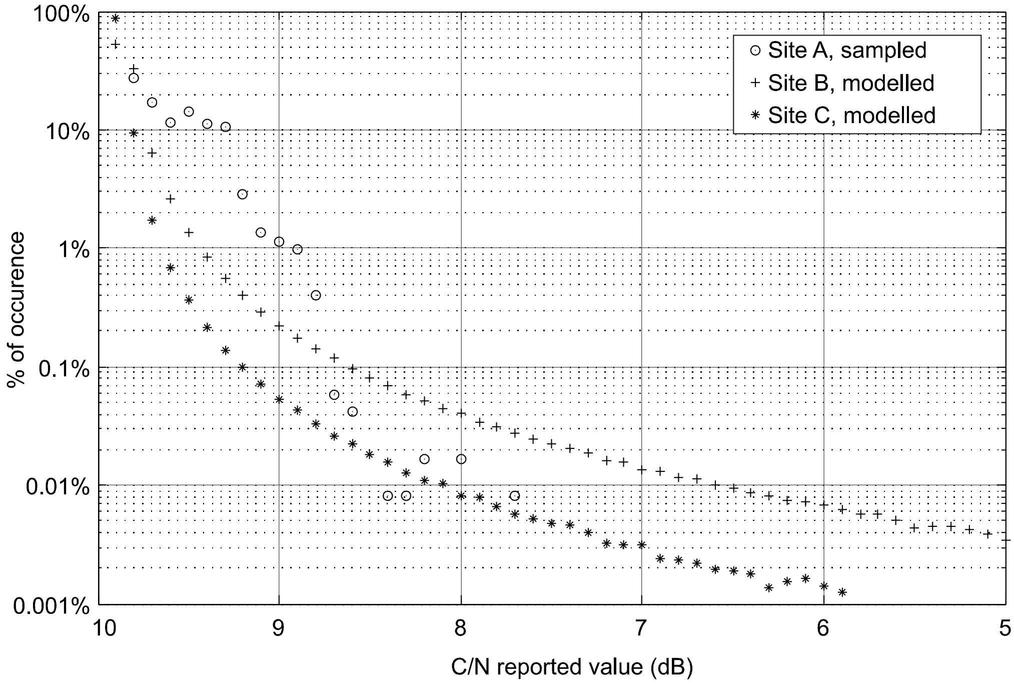

Fig.5. Probability of C/N values for three sites, assuming clear-sky C/N of 10 dB