# DVB-S Air Interface over Railroad Satellite Channel: Performance and Extensions

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## ABSTRACT

In this paper the performance of the DVB-S air interface over the Railroad Satellite Channel (RSC) at Ku-band is investigated. Due to the peculiar channel impairments that characterize the satellite channel in the railway environment, some extensions to the DVB-S air interface as defined in [1] are proposed and analyzed in order to test the resulting link quality. The final aim is the design of a specific radio link capable to provide high quality internet and digital TV services to users travelling on high speed trains. This work is currently supported as part of the FIFTH project (Fast Internet for Fast Trains Hosts) by the European Commission under IST Contract Nr. 2001-39097 [2].

## I. INTRODUCTION

The possibility of using Ku-band satellites for mobile broadcast reception has recently attracted the interest of several operators and researchers of the satellite communications field, both in Europe [3], [4] and Japan [5], mainly due to the potential of a rather high number of existing Ku band transponders and to a large available bandwidth.

Furthermore, this represents an interesting opportunity to find a commercial reuse for those Ku-band satellites which are already close to their expected End-of-Life (EOL). These satellites cannot be used anymore to serve fixed terminals, since no strict orbital control of its position can be ensured due to low residual fuel availability. However, most of them are still in good technical state and their time of life could be significantly increased by restricting the stationkeeping to the east-west direction (to avoid interfering with neighbour satellites) and let them drift in the north-south direction, slightly falling into an inclined orbit. This does not represent a major problem for mobile systems, where antenna tracking capabilities are in any case required.

Among the different classes of mobile users, public transportation and especially fast trains are an interesting market, also taking into account that the special limitations and the aesthetic constraints are less strict than for the private car market. On the other hand, the railroad environment features some peculiar fading events that have to be taken into account when designing the system. In this context, the FIFTH Project has been devised with the ultimate goal to provide satellite based communication services to the passengers.

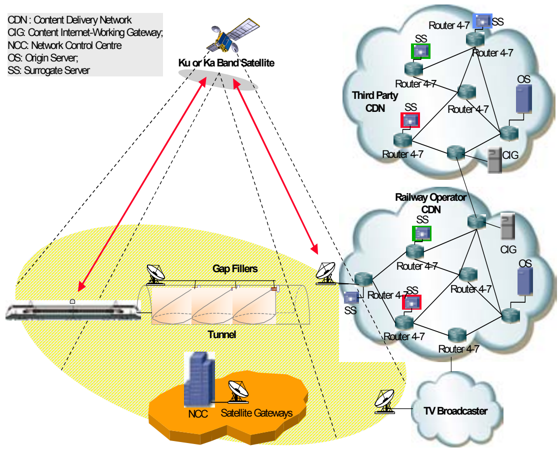


**Figure 1. FIFTH System Architecture**

The network infrastructure supporting the distribution of contents consists of an *access portion* and a *fixed terrestrial portion*. Digital TV services are provided by TV broadcasters directly exploiting the satellite connectivity. On the other hand, Internet access is realised by adopting a hub-centric configuration (i.e. only one point of access to the Internet network is considered) based on a Content Delivery Network (CDN) [6] architecture, in order to provide an efficient delivery of contents to the end-users and to support different levels of Quality of Service (QoS), e.g. a *basic Internet access* and a *QoS Internet access* for top class passengers. This is depicted in Figure 1 for the short-term scenario of the FIFTH system deployment, where the access portion is characterised by the usage of a geostationary transparent satellite operating at Ku (or eventually Ka) band. A DVB-S/DVB-RCS compliant data format (see [1] and [7]) is envisaged, with an enhanced air-interface to implement the specific solutions necessary to counteract the periodic fading of the satellite link due to the obstacles along the railway routes. The main advantage of this short-term scenario is the reduction of the time-to-market of the system, which could be made operative in a short time frame.

The medium/long-term scenario will involve geostationary Ka or Ku band regenerative satellite payload, which implements on-board switching/ routing and capacity assignment functionality so that full meshed connectivity and a dynamic bandwidth assignment mechanism for the satellite channels can be guaranteed. An overall architecture based on a full-meshed configuration among a given population of satellite gateways is adopted in this case: each gateway supports Internet traffic over both forward and return link, i.e. the system is characterised by several points of access to the Internet network. As in the short-term scenario, it is assumed that other gateway stations, under the control of TV broadcasters, are used to support TV channels distribution. This scenario has to be considered as an evolutionary version of the former, allowing a more efficient exploitation of the CDN procedures to cleverly route requests and to efficiently distribute contents. This results in improved system performances especially in terms of time reduction to access the contents and fair sharing of the traffic load among the servers.

In both scenarios, the satellite connectivity is bridged in areas where the satellite coverage is not available (e.g. within tunnels, at the railway stations etc.) by means of suitable wireless terrestrial technologies. Several solutions may be adopted to implement these gap fillers: i) wireless LAN (W-LAN) based on the IEEE 802.11 standard or ii) satellite local repeaters. More in details, two main scenarios have been identified in the railway environment, namely Scenario A and B, whereas B can be further divided into three sub-scenarios:

- Scenario A - Open/rural and suburban areas: the train will be travelling at a speed of up to 300 km/h and the connectivity is provided to the train terminal by the satellite system.
- Scenario B.1 - Urban areas: this scenario is characterised by low train speeds and is only a limited portion of the train trip. The connectivity is provided to the train terminal by the extended segment (e.g. local repeaters)
- Scenario B.2 - Railway tunnels: the train would be travelling at a maximum speed of 300 km/h. As in the Scenario B.1, the connectivity is provided to the train terminal by the extended segment (e.g. local repeaters)
- Scenario B.3 – Railway Stations: the train is stationary at the station and the connectivity may be provided to the train terminal by a W-LAN "hot spot" segment and/or an extended segment.

The main difference between scenario B.1 and scenario B.2 consists in the substantial difference in the propagation conditions: the latter scenario faces the challenging issue of providing coverage into railway tunnels, for which several solutions are under study and a dedicated measurement campaign is being setup at the time of writing. Concerning the scenario B.3, different configurations may be devised. One of them envisages that the train station is provided with one bridging segment to extend the satellite connectivity and one W-LAN "hot-spot" segment. In this case the end-users access the Internet network by means of the extended segment (i.e. bridging segment + satellite connection) while the hot-spot W-LAN is used both to refresh the contents of the server on-board the train and to support the exchange of fleet management information between the train and the station. End-users are unaware of the presence of this direct connection.

Finally, more details about other important features of the FIFTH system such as IP mobility support and the distribution of the signal inside the train via W-LAN can be found in [8] and [9] respectively.

The rest of the paper is organized as follows: Section II is dedicated to introduce the model used to characterize the behaviour of the RSC (Railroad Satellite Channel) for what concern the Scenario A. Based on the outcomes of the channel analysis, the envisaged air interface is presented in Section III. Its performance has been assessed via an extensive simulation campaign whose results will be presented in Section IV. Finally our conclusion will be presented.

## II. MODELLING AND ANALYZING THE RAILROAD SATELLITE CHANNEL

Although the behaviour of the LMSC (Land Mobile Satellite Channel) has been deeply studied for a wide range of frequencies up to 30 GHz and recently new ongoing studies are willing to investigate even higher frequencies, for the special case of the RSC, the only dedicated measurement found in the literature was performed more than 10 years ago in the north of Spain over an itinerary of roughly 300 km. The results presented in [10] are an important reference even if no channel model is proposed.

At a first qualitative analysis, the RSC appears to differ substantially with respect to the scenarios normally considered when modelling the LMSC. In addition to the presence of obstacles such as bridges, trees and small building that may appear along both rail and normal roads, one has to consider the presence of frequent tunnels, whose duration can easily reach several kilometres, and the presence of approximately equally spaced metallic structures to supply power to the train, as depicted in Figure 2. According to the results already presented in [11], where a knife-edge diffraction model has been used to analyze the effect of the power supply structures on the received signal level at Ku-band, this may result in a nearly periodic fading of short duration (approximately 0.5 m), with depth down to -15 dB as can be seen in Figure 3.

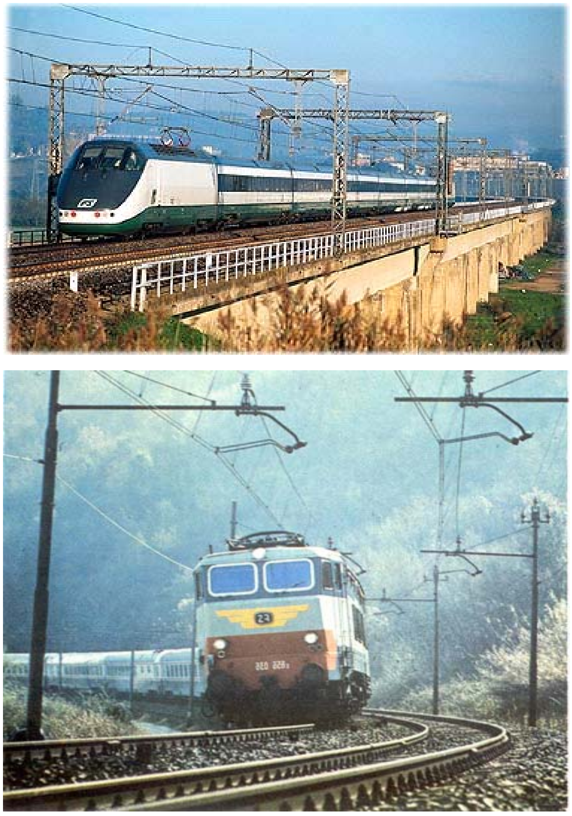

**Figure 2. Electrical Bridges (Trellises) and Posts**

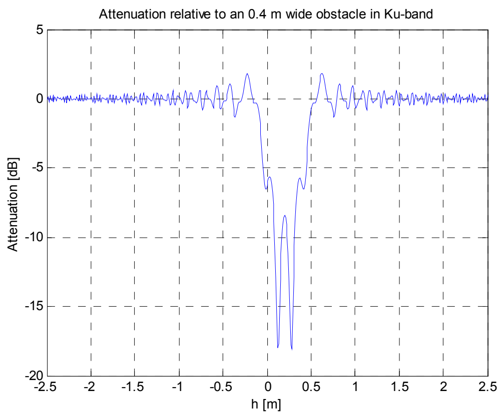


**Figure 3. Attenuation Due to an Electrical Bridge**

For these reasons, and in absence of direct measurements, a specific channel model has been developed by combining together three components:

- a Markov-chain based model of the LMSC at Ku-band, accounting for unpredictable non-periodic fading events due to trees, bridges and small buildings that may appear along the railroad. The channel model has been extracted from direct measurements performed in the highway environment in winter 2001 in southern Germany [12];
- the periodic fading due to the electrical bridge, seen in Figure 3, which is always a deterministic function of the motion of the train;
- the presence of long tunnels, modelled by means of two random variables representing the tunnel length and the inter-tunnels distance and following a Probability Density Function (PDF) obtained by processing the data provided by Trenitalia (the main Italian railway operator, partner of the FIFTH project) concerning the railway path between Bologna and Naples.

Using the model presented above, an extensive set of simulations has been executed to estimate the link performance in presence of the following fading countermeasures [11]:

- Space Diversity:
  - Two antennas located on the same coach (separation 15 m)
  - Two antennas located at the beginning and at the end of the train (separation 300 m)
- Time Diversity:
  - One retransmission after 5 minutes
  - One retransmission after 10 minutes
  - Two retransmissions after 5 and 10 minutes respectively

The main outcomes can be summarized as follows:

1. 15 m space diversity can completely compensate the fading due to the power supply structures while 300 m space diversity can only partially compensate it. The reason is that whenever the train enters /exits a tunnel, the back/front antenna suffers the power supply arches fading. On the other hand, 300 m space diversity performs better against longer fading. Both solutions are however not effective against long tunnels, since the maximal separation between the two antennas is limited by the length of the train.

2. Time diversity technique leads to higher improvements in the overall link performance although it does not compensate the fading effect of the power supply structures. No significant improvements are obtained by increasing the retransmission period from 5 to 10 minutes, as a consequence of the frequent occurrence of long tunnels. On the other hand, two retransmissions after 5 and 10 minutes lead to appreciable benefits even against long tunnels. This technique, however, is only suitable for non-delay sensitive applications such as broadcast services.

## III. SATELLITE RADIO LINK DESIGN

As already pointed out in the introduction, in the first phase of the FIFTH system deployment the utilization of transparent satellites operating at Ku/Ka band is foreseen. The train terminal antenna, depicted in Figure 4, in agreement with the basic requirements for the implementation of the FIFTH demonstrator available to date, is a motor driven elliptical reflector with axes of 104.8 cm and 45 cm, featuring an EIRP (Equivalent Isotropic Radiated Power) higher than 42.8 dBW and a G/T of 11.5 dB/K.

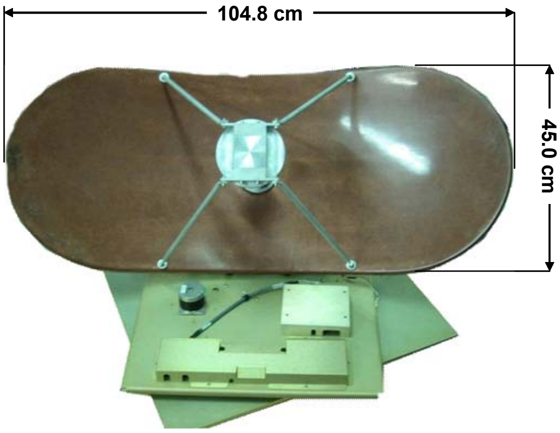


**Figure 4. The FIFTH Terminal Antenna**

Concerning the Hub, a 2.4 m motor driven circular parabolic reflector antenna is envisaged, capable of radiating up to more than 66 dBW EIRP (corresponding to a maximum power amplifier output of 100 W) and featuring a G/T performance better than 25 dB/K.

For the forward link (from the Hub to the train), a TDM (Time Division Multiplex) access technique is envisaged, where as for the return link (from the train to the Hub) a SCPC (Single Channel per Carrier) access technique shall be adopted, assuming a nominal bitrate of 500 kbps per channel. Although this approach could be modified for the long term scenario (phase 2), in favour of a multiple access scheme allowing more efficient utilization of the available resources for the return link, it has to be pointed out that the SCPC strategy allows an extremely fast access to the medium, even after a long fading, in contrast to the normal DVB-RCS procedure [7].

To counteract the fading due to the power supply structures, the introduction in the DVB-S/DVB-RCS air interface of a channel interleaver having length in the range of some hundreds ms (see Figure 5) seems an adequate and relatively easy-to-implement solution. Although commercial DVB-S receivers and DVB-RCS transceivers may no longer be used, most of the internal components are still be usable, hence permitting to take advantage of the low-cost and widely available DVB-S/DVB-RCS standard receiver technology.

QEF (Quasi Error Free) link type, according to the DVB-S standard is assumed, leading to a BER (Bit Error Rate) in the order of $10^{-10}$. The cumulative link availability (percentage of time in which QEF conditions are guaranteed) has been assumed equal to 99.7%, which means roughly a cumulative 26 hours of average link downtime per year per train. All coding rates and coding schemes reported in [1] and [3] shall be supported, allowing the specified additional gain in case of bad link conditions (e.g. hard rain) or alternatively to increase the datarate correspondently in case of favourable link conditions. This is especially true for the return link, where the adopted code rate could be negotiated between each train terminal and the Hub station during the first logon.

Finally, for broadcast services only, i.e. digital TV, 5 minutes time diversity shall be supported to reduce the number of signal loss appreciable by the travellers. Each video stream is hence sent twice using different PIDs (Packet Identifiers) which are merged together in the receiver.

## IV. SIMULATION RESULTS

An extensive set of simulations have been executed to asses the performance of the above described satellite radio link. The main parameters and assumptions, if not otherwise stated, are:

- Packet Size of 188 bytes according to MPEG2-TS format
- FEC made of parallel concatenation of RS(204,188, 8) and a rate ½ Convolutional Code according to [1].
- Info datarate of 2 Mbit/s
- QPSK Modulation
- Nominal $E_b/N_0$ in LOS condition 3 dB, roughly 1 dB less than the necessary value to have QEF conditions
- Perfect synchronization

Furthermore, two different implementations for the channel interleaver in Figure 5 have been used:

- convolutional interleaver with $M$ branches, where each of them consists of a shift register of length $kJ$, $k = 0, 1, \ldots, M - 1$.
- block interleaver with $M$ columns and $N$ rows.

The overall end-to-end delay expressed in seconds introduced by such devices is respectively equal to $\Delta_c = M(M\text{-}1)J / R_s$ and $\Delta_b = 2MN / R_s$ [s], being $R_s$ is the symbol rate [13].

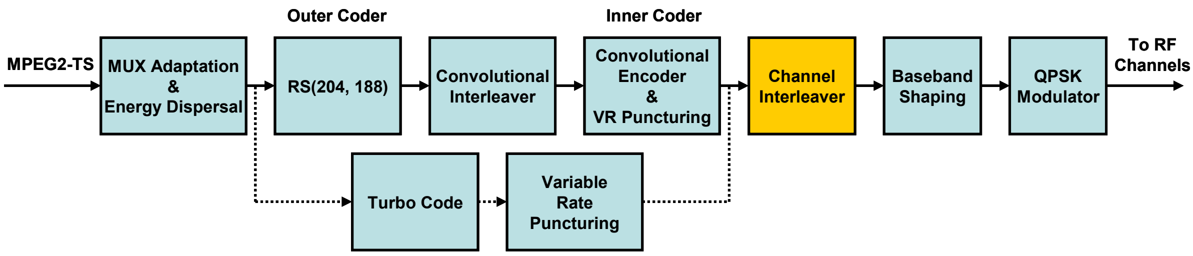


**Figure 5. Modified DVB-S/DVB-RCS Based Air-Interface for the FIFTH System**

Concerning the channel model described in the previous section, the correspondent channel parameters for the stochastic part are given in Table 1. The fast fading has been modelled via a Rice distribution with Rice factor $c$ in LOS and via a Rayleigh distribution with average mean power obeying a Lognormal PDF with mean $\mu$ and variance $\sigma$ in the shadowed state. No parameters are available for the blocked state, whose received power level was below the noise floor of the measurement equipment (approx. 20 dB). Power line arches have been assumed 0.4 m wide (worst case scenario) with a constant separation of 53 m.

**Table 1. Channel Model Parameters.**

| State | LOS | Shadowed | Blocked |
|---|---|---|---|
| Time Share | 90% | 7% | 3% |
| PDF | Rice | Lognormal + Rayleigh | - |
| Parameters | $c$ = 17 dB | $\mu$ = -8 dB $\sigma$ = 1.5 dB | - |

The effect of the electrical bridges is clearly visible in Figure 6 (upper plot), where no channel interleaver is applied. On the other hand, in the lower plot, a convolutional interleaver with $M$ = 5 branches and introducing an end-to-end delay of 150 ms has been considered. As it can be seen, the errors per MPEG2-TS cell at the output of the Viterbi decoder are always below the error correction capabilities of the RS decoder (8 bytes).

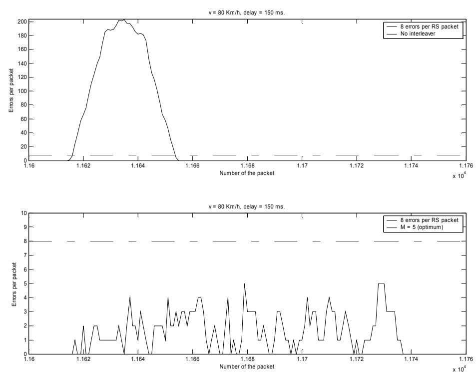

**Figure 6. Numbers of Errors per Packet When Crossing an Electrical Bridge**

Given a fixed end-to-end delay Δ, only one degree of freedom is then available in the design of the interleaver: Figure 7 reports the Packet Error Rate (PER) as a function of the train speed for different choices of M compared to the case of no interleaver. The optimum choice turned out to be $M$ = 5. In any case, the performance is significantly degraded below 80 km/h. On the other hand, to achieve good performance for a train speed of 30 km/h, and depending on the choice of $M$, the results in Figure 8 show that the minimum end-to-end delay is equal to 0.4 seconds.

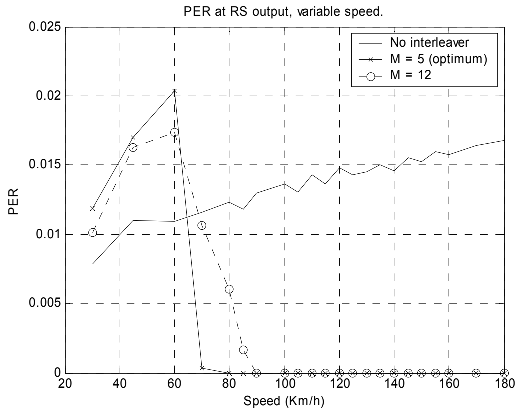


**Figure 7. PER for Different Convolutional Interleavers**

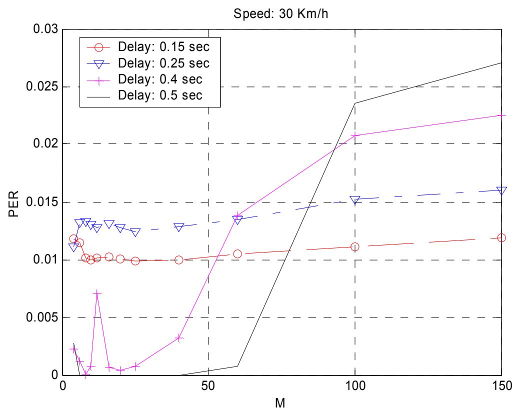


**Figure 8. PER for Different Delays and Low Train Speed**

Finally, Figure 9 shows the outcome of a simulation relevant to a percentage outage (ratio between "errored window" and distance between two errored windows) slightly lower than 1%; periodic occurrence of outage is assumed. The curves show the bit error rate (BER) averaged on MPEG cells and refer to: I) upper curve: errors due to link impairments without the effect of coding, II) median curve: residual errors after the decoder without implementing the interleaving/deinterleaving and III) bottom curve: residual errors after the decoder when block interleaving/deinterleaving are implemented (Δ = 320 ms), as it can be seen all the errors are removed.

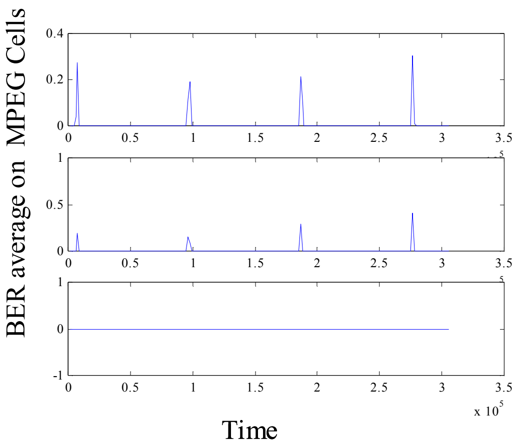


**Figure 9. Average BER with and without Block Channel Int.. $v$ = 120 km/h, $SNR > SNR_{QEF}$**

## V. CONCLUSION

The performance of an enhanced DVB-S air interface especially designed for the Railroad Satellite Channel has been assessed via a large simulation campaign.

The obtained results permitted to optimize the design of the channel interleaver in order to compensate for the presence of nearly periodic short deep fading introduces by electrical bridges.

Moreover, it has been proved how this simple countermeasure can significantly increase the link performance. This is especially true for non-delay sensitive applications, such as digital TV, where the interleaver length could be further increased to improve its effect in the low-speed regions, and where the effect of short but frequent interruptions would result in an unacceptable degradation of the provided service.

Further study will deal with the analysis of the synchronisation related aspects, in order to guarantee robust synchronization and fast re-synchronization also at high speed such as 300 km/h.

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