A New DVB-RCS Satellite Channel Model Based on Discrete Time Markov Chain and Quality Degree

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Abstract— **DVB-RCS is an open satellite communications standard allowing a bi-directional communication via satellite. These characteristics certainly promoted its enormous diffusion in the commercial area and the academic research interest. In this context, it is very important to test DVB-RCS systems using an efficient satellite channel model. In the literature many channel models have been carried out, but most of them work at the bit level or they investigate only some aspects of channel interaction. In this work we provide a high level satellite channel model based on Discrete Time Markov Chain (DTMC) modeling, useful in every simulation context. Our model, called Quality Degree-DTMC (QD-DTMC), is based on the concept of Quality Degree (QD) of a given observation windows: the idea is not to analyze a single packet, but fixing an observation window and evaluating the QD of the link, computing the Packet Error Rate (PER) associated to the specific window. The effectiveness of the proposed idea has been evaluated through a deep campaign of simulations.**

Keywords- DVB-RCS, Channel Model, Satellite, Markov, DTMC, Log, Error Analysis, Fitting.

I. INTRODUCTION AND RELATED WORK

In the last years, Digital Video Broadcasting with Return channel Satellite (DVB-RCS) ([1],[2]) became one of the most used standard in the satellite communications system thanks to its open standard characteristic and efficiency. Mobility support has been also added in order to take care of mobile users, which want to perceive a certain quality for the requested services [3], [4] and other efforts have been made for aerial segment, like High Altitude Platforms [5]. DVB-RCS provides bi-directional communication via satellite and it offers many combination of services (reception of TV channels, data exchanges, etc.). In this context, it is very important to test DVB-RCS systems using an efficient satellite channel model, for guaranteeing an optimal level of QoS constraints, as shown in [6], [7] and [8]. In the literature many channel models have been proposed, but most of them work at the bit level or it investigates only few issues of channel interaction ([9],[10]), so they cannot be used in higher level simulators based for example on discrete time event simulation. The goal of this work is to provide a high level satellite channel model based on Discrete Time Markov Chain (DTMC) [11] modeling, very useful in every simulation context. In order to model DTMC, in accordance with ([12],[13]), we employ packet error log-file analysis, where, in our scenario, a packet is a sequence of bits. The log-file is a sequence containing information about whether a particular packet was transmitted correctly. In [13], the authors considered only two states, the Bad state, represented in the log file with a “1”, and the Good state (correctly transmitted packet), represented with a “0”, even if they extend the Bad state in more states if the stationary property is not satisfied. In this paper we propose a different model based on the observation of a fixed time-window instead of analyzing a single packet in order to evaluate the link quality degree, computing the Packet Error Rate (PER), on the basis of the analysis carried out in [14]. In this way, we construct a log file in which each state represents a specific quality/degree level. The proposed model can be also used in satellite Call Admission Control phase [15], [16], when the future channel conditions have to be taken into account. The model is based on the use of a DMTC, in which a chain state represents an accurate channel description. This model has been called Quality Degree based DTMC modeling (QD-DTMC). In the paper QD-DTMC has been compared with the classic Gilbert-Elliot (G-E) in order to proof the accuracy of the proposed model. The paper is organized as follows: section II gives a deep overview of the system architecture, section III proposes the new channel model, section IV shows simulations results, then section V concludes the paper.

II. SATELLITE SYSTEM ARCHITECTURE AND CHANNEL PHENOMENA

In this paper we considered a satellite system based on DVB-RCS architecture ([1],[2]). Generally, a satellite system is composed by terrestrial and space segments (see Fig. 1).

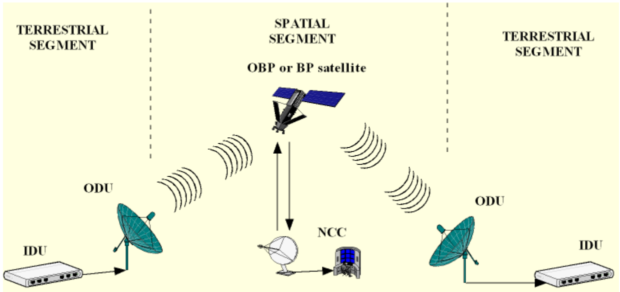

Figure 1. Satellite system architecture.

The terrestrial segment is formed by outdoor unit (ODU) and indoor unit (IDU), while the spatial segment is composed by satellite and Network Central Control (NCC). The parabolic antenna, the Block Up Converter (BUC) and the Low Noise Block Converter (LNB) compose the ODU, while the IDU section represents the Return Channel Satellite Terminal (RCST), that is the elements set fundamentals to encode/decode and modulate the users information. The NCC has to manage the access and allocate the band for all RCSTs. Besides, in our model we employed both the Bent-Pipe (BP) satellite (that is no regenerative) and the more performing On Board Processor (OBP) satellite (this satellite can regenerate the received signal and thus it can correct errors due to propagation phenomena). During transmission phase, user data are scrambled in order to ensure an adequate number of bit transitions to support clock recovery, then a first encoding phase is effectuated: MPEG packets are sent in a Reed-Solomon encoder that introduces redundant bits (in particular the packet size is increased to 204 bytes from 188 bytes). After, the encoded data are interleaved with a convolutional interleaver in order to disperse burst errors, therefore the interleaved packet is again encoded by a convolutional encoder. Finally the packets are Quaternary Phase Shift Keying (QPSK) modulated and sent to the ODU interface. While receiving data, instead, inverse operations are performed until original information are recovered. In this work, we considered the thermal noise due to temperature, the quantization noise and the background noise due to other communication system as a single input, modeled as zero mean and parametric variance Additive White Gaussian Noise (AWGN). Moreover, we considered an attenuation due to free space propagation, path loss, based on Friis's model [9]:

$$PL(d) = 20\log_{10}\left(\frac{4\cdot\pi\cdot d\cdot f_c}{c}\right), \qquad (1)$$

where f_c is the carrier frequency, c is the light speed and d is the covered distance. The distance d between a geostationary satellite and a earth terminal placed on equator line is 35.778 Km, however for terminal located on other latitude is necessary adding to d a further distance corrective term given for the northern hemisphere by [9]:

$$d_{correction} = 42643.7\cdot\sqrt{1-0.295577\cdot(\cos\phi\cos\delta)}, \qquad (2)$$

where ϕ is the earth station latitude, while δ is the difference between earth terminal longitude and satellite longitude. Moreover, in order to consider the atmosphere attenuation we introduced a corrective term both on the uplink and downlink channel as suggested in [9]. In order to take into account average climatic condition, also a rainfall attenuation term is considered in accordance with [9]. This term depends on earth station position (and so by elevation angle), therefore it depends on rain intensity in that particular zone (this information can be obtained from the rain climatic zone maps contained in [9]). Another important dependence is by central frequency: in fact attenuation due to rainfall is more significant for the high frequency (>10 GHz). Further detail can be found in [9]. In this work, we fix the Equivalent Isotropic Radiated Power (EIRP) of transmitter RCSTs to 40 dBW. Furthermore, we suppose that RCST sender and RCST receiver are located at geographic coordinates of Rome (this limitation is negligible for the purpose of our analysis) and the both geostationary satellites (BP and OBP) are located at 7° East longitude (such choice is made because at this coordinates are located real satellites). Besides, we consider a satellite EIRP of 53 dBW for both satellite and different climatic condition (clear sky or rain). Furthermore, we have also considered a variable noise contribution, so we carried out our simulation varying the total Carrier to Noise ratio (*C/No*) and fixing other configuration parameters. We remember that the total *C/No* depends on both uplink and downlink contributions, in particular we have:

$$\left(\frac{C}{No}\right)_{TOT}^{-1} = \left(\frac{C}{No}\right)_{up}^{-1} + \left(\frac{C}{No}\right)_{down}^{-1} \qquad (3)$$

For the OBP satellite scenario, it should be more correct consider Energy per Bit to Noise ratio (*Eb/No*) because also the satellite introduce a error correction phase. However it is not wrong to consider *C/No* also for OBP satellite, because the two ratio are correlated by the following formula:

$$\left(\frac{C}{No}\right) = \left(\frac{E_b}{No}\right)\cdot v \qquad (4)$$

where v is the bit rate.

III. SATELLITE DTMC MODEL

A DTMC is a discrete-time stochastic process assuming discrete values from a finite set $S=\{s_0,\ldots,s_{n-1}\}$ with $\|S\|=n$ depending only on the current state ([11],[12],[13]). As known, it means that:

$$t_{i,j}=P(X_k=s_j|X_{k-1}=s_i) \qquad (5)$$

where $t_{i,j}$ is the probability that the process X is in the state s_j at the time t_n if at the time t_{n-1} it has been in the state s_i. As stated in [11], all the probabilities (varying i and j from 0 to $n-1$) can be used to build the transition probability matrix T, for which:

$$\sum_{j=0}^{n-1} t_{i,j} = 1 \qquad i = 0,\ldots,n-1. \qquad (6)$$

It must be underlined that, as illustrated in [11], $t_{i,i}$ measures the constant trend to leave the state s_i, and state sojourn time of state s_i is exponentially distributed with a parameter $\mu=1/t_{i,i}$.

A) Model description

Following the approach of [13], satellite channel characterization can be well described using a packet error log-file where, clearly, a packet can be considered as a sequence of bits. Packets are correctly received if no errors are encountered in the reception phase, so a packet can be considered damaged if at least one bit is received wrong. Under these considerations, the log-file can be considered as a sequence of information about the correctness of a received packet. In addition to the contribution of [13], we extended the analysis by considering not only two states (Good or Bad), but taking into account the concept of Quality Degree (QD): starting from the log-file and fixing a time window *W* for the observation of the transmitted packets, link's QD can be analyzed by computing the PER belonging to *W*. This approach is repeated for the complete log-file, obtaining a new log-file (indicated with "secondary-log-file"), containing the sequence of PER, one for each observation window *W*. Each *W* has a length t_W, and if $t_W = 1$ the original log-file is obtained again (t_W is expressed in number of packets). Once the sequence is obtained, the admissible values of PER have to be discretized, in order to define a set of states for the DTMC: each DTMC state is associated to a particular range of PER.

Figure 2 shows the process of PER discretization after the secondary-log-file has been obtained. Each state s_j is associated to the PER range $[PER_{thrj-1}, PER_{thrj})$. At this point, the main problem in this type of approach is the determination of the number of PER ranges and, thus, the number of thresholds for PER discretization: a possible approach is to set the number of states $n=t_W+1$ and, if in a time window *W* the number of wrong packets is *j* (with $0 \leq j \leq t_W$) then the associated chain state is s_j.

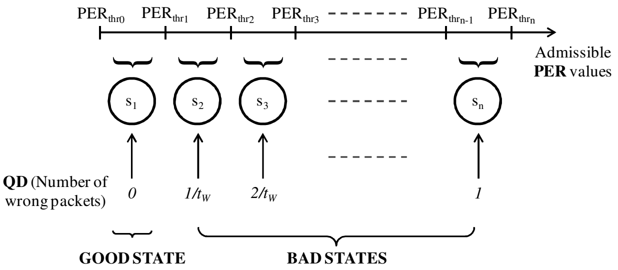

Figure 2. PER values discretization.

As it can be concluded from [11],[13],[17], in this kind of approach the addition of new states increases the precision of the model, until a "phantom" state $s_{phantom}$ is added. In our proposal, a generic $s_{phantom}$ is never reachable from any each other: $t_{i,phantom}=0 \;\; \forall s_i \in S$. So the value of t_W (thus the size of *W*) can be determined taking into account this observation. The stationarity property (independence of time) of the process has been also verified through the approach proposed in [18] by *Bendat-Piersol*: the secondary-log-file has been divided into time intervals of equal lengths, computing the mean value for each interval; then the number of runs of mean values above and below the median value of the series has been evaluated. The stationarity condition has been always verified due to the complete randomness of the considered AWGN process. The *Kolmogorov-Smirnov* (KS) test [19] has been employed to evaluate the correctness of an exponential approximation for the distributions of the state sojourn times: we indicate with st_i the sojourn time associated to $s_i \in S$. The last step in the proposed modeling is the computation of the elements of *T*. Once the secondary-log-file has been obtained, $t_{i,j}$ can be evaluated as follows:

$$t_{i,j} = \frac{tr_{s_i,s_j}}{tr_{s_i}} \qquad i,j = 0,1,\ldots,t_W \;\; s_i, s_j \in S \tag{7}$$

where $tr_{si,sj}$ is the number of transitions from state s_i to state s_j and tr_{si} is the total number of transitions from state s_i to any other state $s_k \in S$. At this point the model is completely defined.

B) *Model verification*

In the considered scenario, we employed for the transmission a BP satellite and a code rate of ¾. Furthermore we assume a rainfall climatic condition and an average *C/No* of 13 dB (RCSTs and satellites are always placed in the coordinates described in section 2). In this phase we do not consider the value of $t_W=1$ because, as earlier described, it will result in the Good-Bad (GB) model and the secondary-log-file will be the same as the original log-file. We started from $t_W=2$ and for $t_W=4$ a phantom state $s_{phantom}=s_4$ has been obtained. In addition, running the *Bendat-Piersol* test on the secondary-log-files (for the considered values of t_W) the stationarity property has been always verified. Using eq.7 the transition matrices illustrated in fig. 3 have been obtained (T_W indicates the obtained matrix considering a number of states equal to $n=t_W+1$).

$$T_2 = \begin{bmatrix} 0.7989 & 0.1879 & 0.0132 \\ 0.8154 & 0.1738 & 0.0108 \\ 0.7556 & 0.2222 & 0.0222 \end{bmatrix} \quad T_3 = \begin{bmatrix} 0.7125 & 0.2534 & 0.0329 & 0.0012 \\ 0.7345 & 0.2397 & 0.0241 & 0.0017 \\ 0.7027 & 0.2162 & 0.0676 & 0.0135 \\ 0.7500 & 0.2500 & 0 & 0 \end{bmatrix}$$

$$T_4 = \begin{bmatrix} 0.6236 & 0.3167 & 0.0562 & 0.0036 & 0 \\ 0.6819 & 0.2705 & 0.0419 & 0.0057 & 0 \\ 0.6170 & 0.2766 & 0.0851 & 0.0213 & 0 \\ 0.6667 & 0.2222 & 0.1111 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 3. The obtained T matrices for $t_W=2$, $t_W=3$ and $t_W=4$.

It is evident, from fig. 3, how s_4 in T_4 (5 states model) is a phantom state and it is not necessary to be considered in order to improve model precision.

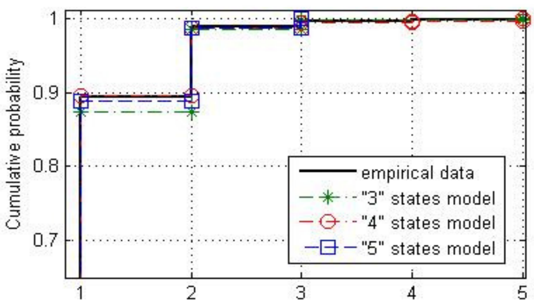

Figure 4. Data fit approximations for different values of t_W.

The last step is the verification of the exponential distributions of st_i.

We applied the KS test for all the states and fig. 5 shows the obtained results for s_0: the exponential distribution that minimizes standard error [17] is an exponential one with μ=9.43202, which introduces a standard error of 0.37.

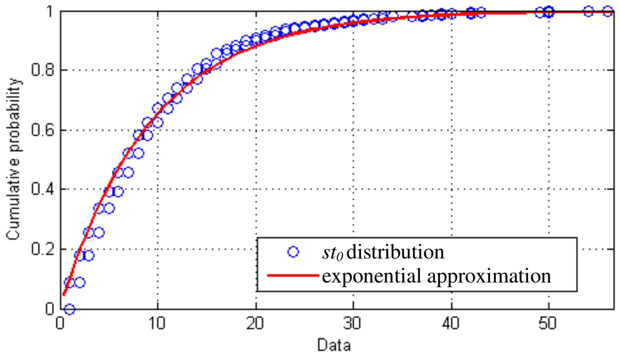

Figure 5. st_0 cdf for t_W=3 and its exponential approximation.

IV. PERFORMANCE EVALUATION

The effectiveness of the proposed idea is now illustrated, in order to compare the artificial log-file obtained by our model with the artificial log-file generated by the classical GB model, demonstrating how QD-DTMC better fits the experimental log-file.

First of all, we describe the procedure to generate an artificial log-file using DTMC statistics obtained by our model, assuming that the first state of the complete evolution is a good state (no-degradation), that is to say the generation starts always from s_0. If N and t_W are the number of packets to be generated and the windows size respectively, then the following steps are followed until all the packets are created:

- *If current state is s_i, then choose the next state s_j from the i-th row of T;*
- *Create a new window W of size t_W and randomly distribute the wrong packets, according to the QD of state s_i;*
- *Set the current state as s_j.*

It must be underlined that the assumption of s_0 to be the initial state is not restrictive, because the model dynamically evolves following transition probabilities, independently on the chosen initial state.

We generated an artificial log-file following the previous steps only for the considered scenario and using the best fitting QD-DTMC model and the GB one, proofing that QD-DTMC better approximates the experimental log-file trend.

Figure 6 shows the comparison of the correctly received packets for the generated log-file (experimental data), the QD-DTMC and the GB model and it can be seen how QD-DTMC outperforms the GB approach.

Figure 7 represents another confirmation of the goodness of the proposed model, depicting the distribution of the wrong received packets, obtained from artificial (both GB and QD-DTMC) and experimental log files.

Table I shows the obtained statistical parameters (mean μ and variance σ^2) for experimental data, GB and QD-DTMC models. It can be seen how $\mu_{QD\text{-}DTMC}$ and $\sigma^2_{QD\text{-}DTMC}$ are very close to $\mu_{Experimental}$ and $\sigma^2_{Experimental}$. In addition the standard error introduced by QD-DTMC is 0.00006, lower than the one introduced by GB equal to 0.0005.

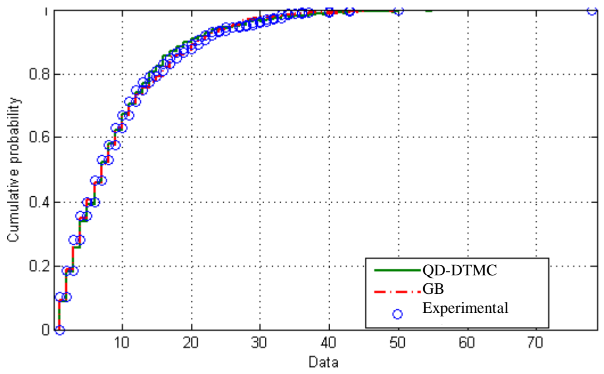

Figure 6. Correct packets distribution for artificial and experimental logs.

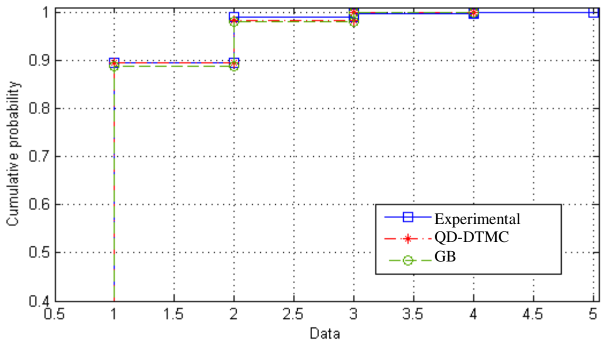

Figure 7. Wrong packets distribution for artificial and experimental logs.

TABLE I. ERROR TRACE STATISTICS

Trace type	**μ**	**σ^2**
Experimental	1.12121	1.25712
GB model	1.13242	1.28238
QD-DTMC	1.12217	1.25927

V. CONCLUSIONS

This paper presents a modeling of a AWGN DVB-RCS Satellite channel where different noise conditions (thermal noise, quantization noise and background noise due to other communications) are modeled as a single input. This model, differently by classical satellite channel models that work at bit level, provides a high level modeling based on DTMC degradation level. In order to consider a multi states channel, a log file based on packet error analysis has been studied. The proposed model has been tested generating artificial log files and comparing it with log files obtained by experimental simulation and with those obtained by classic Goob-Bad Markov chain model. The carried-out simulations have shown that the QD-DTMC model better fits experimental trace respects to the GB model as the standard error confirmed. Furthermore, we note that the number of additional states needed to obtain a better accuracy depends on the specific operative conditions and so on noise power level, satellite type, climatic condition and error correction rate.

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