This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2007 proceedings.

A Statistical Bit Error Generator for Emulation of Complex Forward Error Correction Schemes

Reuben A. Farrugia and Carl J. Debono

Department of Communications and Computer Engineering
University of Malta
Msida MSD06, Malta
rrfarr@eng.um.edu.mt, cjdebo@eng.um.edu.mt

***Abstract*— Forward Error Correction (FEC) schemes are generally used in wireless communication systems to maintain an acceptable quality of service. Various models have been proposed in literature to predict the end-to-end quality of wireless video systems. However, most of these models utilize simplistic error generators which do not accurately represent any practical wireless channel. A more accurate way is to evaluate the quality of a video system using Monte Carlo techniques. However these necessitate huge computational times, making these methods unpractical.**

This paper proposes an alternative method that can be used in modeling of complex communications systems with minimal computational time. The proposed three random variable method was used to model two FEC schemes adopted by the Digital Video Broadcasting (DVB) standard. Simulation results confirm that this method closely matches the performance of the considered communication systems in both bit error rate (BER) and peak signal-to-noise ratio (PSNR).

***Index Terms*—System Modeling, Communication Systems Performance, Error Estimation, Video Coding**

I. INTRODUCTION

FIXED Satellite Services (FSS) such as multimedia and videoconferencing applications, are being pushed to higher frequency bands where larger bandwidths are available. This is achieved at the expense of an increase in attenuation, noise and interference which results in a significant increase in bit error rate (BER) and frame error rate (FER) [1]. These systems generally utilize robust forward error correction (FEC) schemes to minimize the power required in order to maintain an acceptable level of quality.

Although these systems generally operate in a quasi-error-free connection, they generally suffer under precipitation, where reduction in signal-to-noise ratio (SNR) of about 10 dB may be observed [2]. Moreover, minimizing the BER and the FER does not always result in improving the end-to-end quality of the videoconferencing system, since a single corrupted bit in the compressed video bitstream may propagate in both time and space, resulting in annoying visual impairments [3].

There are a number of video system models which are capable of modeling the end-to-end quality of a video system. Richardson [4] has evaluated the performance of a number of video formats assuming a simple two state Markov model to model the errors in an ATM network. Max Robert [5] has emulated the performance of convolutional codes, Reed Solomon codes and concatenated codes by considering the effect of bit errors which occur in bursts. Recently, a videoconferencing application was modeled to evaluate the performance of a practical videoconferencing system which adopts the Digital Video Broadcasting (DVB) FEC to protect the transmitted MPEG-2 TS frames [2], [6]. The accuracy of these simulators is mainly dependent on the accuracy of the error generator model. Moreover, it is desirable that the results of these simulators are delivered as fast as possible.

Any FEC scheme can be modeled using Monte Carlo techniques [7]. However, the Monte Carlo simulators require a large amount of resources when simulating complex communications systems [3]. This suggests that fast and accurate error models have to be used in modeling complex communication systems.

Hardware emulators were used in the past [8]-[10] to derive the performance of a communication system by implementing the channel and coding schemes on either Field Programmable Gate Arrays (FPGA) or Digital Signal Processor (DSP) boards. These emulators are accurate and can run up to 10^6 times faster than software emulators. However, hardware emulators are expensive, and cannot be extended to model the performance of other communication systems.

The software emulators [11]-[13] found in the literature utilize Markov models to generate error sequences similar to a reference error sequence produced by a real channel. The accuracy of these models depends on the number of states being used, and therefore increasing the accuracy results in a significant increase in complexity of the model. An alternative approach was presented in [3], where the author presented three fast error generators based on statistical probability distributions of the error burst arrival and the number of errors per error burst. However, this model was tailored for the effect of the error performance of convolutional codes on digital video streams.

This paper presents a fast bit error generator which is

The work presented was funded by the EU 6th Framework Program (FP6) project TWISTER.

capable of emulating the performance of two commonly used forward error correction schemes adopted by the Digital Video Broadcasting Standard (a) DVB-RCS Turbo Codes [14] and (b) DVB-S Concatenated Codes [15]. Both FEC schemes were modeled using Monte Carlo techniques [7] and were used as accurate reference models. These reference models were used to evaluate our solution, and in deriving the statistics required by the proposed error generator. The performance of the proposed model was compared to the reference Monte Carlo simulators in terms of both BER and PSNR. Results show that the proposed error generator provides a significant gain in computational time with minimal loss in accuracy.

The structure of this paper is as follows: The Monte Carlo techniques adopted by the reference simulators are described in Section II. The Forward Error Correction schemes considered in this work are described in the following two sections. The proposed error model is delivered in Section V. Section VI presents the simulated results while final comments and conclusion are provided in Section VII.

II. MONTE CARLO SIMULATOR

The simulations of both DVB-RCS and DVB-S communication systems were performed using the Monte Carlo technique with a uniform sampling of the search space [7]. The accuracy of the Monte Carlo simulation depends mainly on the sample size, where a fairly large number of samples will have to be simulated in order to obtain accurate estimates.

The accuracy of the results obtained by the Monte Carlo simulator is quantified by the confidence interval. A confidence interval is the most descriptive measure of the quality of an estimator because it quantifies the measure of the spread with an associated probability [7].

Ideally, the sample size of the simulation is infinite. However, in practice the simulator is stopped when the required confidence interval is achieved. The Monte Carlo simulator used in this work was stopped using the stopping condition provided in [16]:

$$\rho \ge Q^{-1}\left(\frac{1}{2}(1-\chi)\right)\frac{\hat{\sigma}}{\hat{\mu}} \qquad (1)$$

where Q(x) is the complementary error function, χ is the confidence interval, ρ is the tolerance and $\hat{\mu}$ and $\hat{\sigma}$ are respectively the mean and standard deviation of the population of results. Typically a confidence interval of 95% and a tolerance of 10% are found to be a good compromise between accuracy and complexity.

III. DVB-RCS TURBO CODE

The DVB-RCS Standard Turbo Code utilizes two identical double binary Circular Recursive Systematic Convolutional (CRSC) constituent encoders. The first encoder operates on the data in its natural order while the second encoder operates on the interleaved data blocks. Each block is executed twice by the CRSC encoder. During the first run it derives the circulation state while in the second pass it encodes the data block. A code rate of 6/7 is achieved through the puncturing of the parity bits.

The decoder employs a low complexity Soft Input Soft Output (SISO) Max-Log MAP algorithm which executes the decoding process in the logarithmic domain. This algorithm is less computational intensive and less sensitive to rounding errors. After the turbo decoder completes 6 iterations, a final decision on the bits is made.

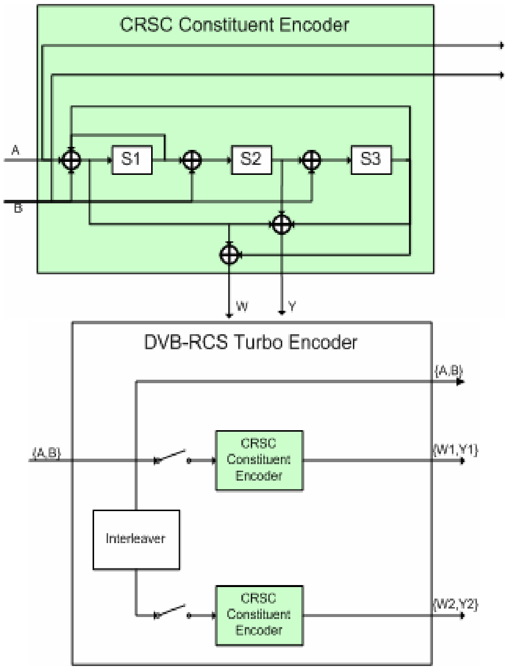


Fig. 1. DVB-RCS Turbo Encoder

IV. DVB-S CONCATENATED CODE

The DVB-S Concatenated Code illustrated in Fig. 2, utilizes a shortened outer Reed-Solomon (RS) (204, 188) code capable of correcting up to 8 corrupted bytes. An inner convolutional code with a constraint length of 7 is punctured to achieve the required code rate. An intermediate convolutional interleaver of depth 12, which utilizes Forney's approach, is placed between the inner and outer encoder.

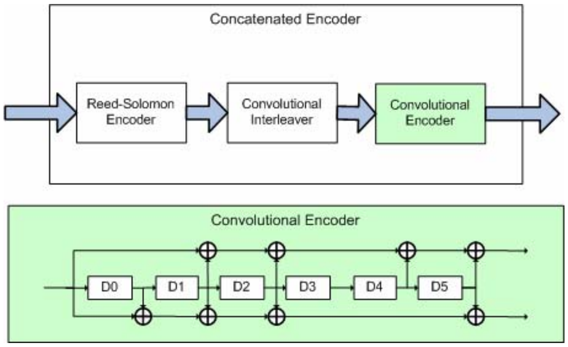


Fig.2. DVB-S Encoder

The Reed-Solomon decoder employs the Berlekamp-Massey algorithm, to derive the error location polynomial. The roots of the error location polynomial are derived according to Chien's search while the values of the errors are derived by Forney's algorithm. The resulting stream is de-interleaved and decoded by a soft-decision Viterbi Decoder.

V. PROPOSED ERROR GENERATOR MODEL

The DVB FEC schemes described in the previous sections where simulated using Monte Carlo techniques with a confidence interval of 95% and a tolerance of 10%. It was observed that a frame may be either corrupted or uncorrupted, and that each corrupted frame has a number of corrupted bits. This can be seen in Fig. 3 where a schematic representation of the proposed error generator model is presented. The following parameters were extracted from both Monte Carlo simulators:

- The Frame Error Separation (FES) which represents the distance between two consecutive corrupted frames.
- The Number of Errors per Corrupted Frame (NECF) which represent the number of corrupted bits present in each corrupted frame.
- The Error Location (EL) which represents the location of the each corrupted bit within each corrupted frame.

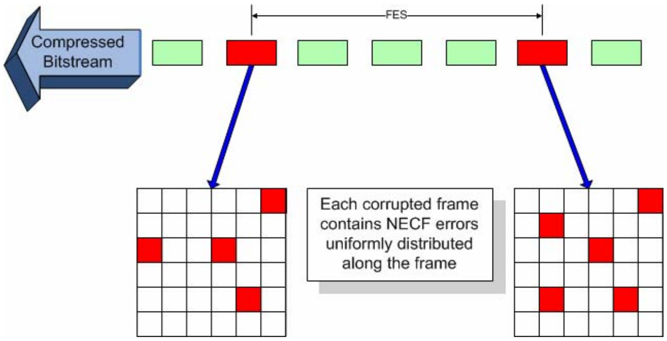
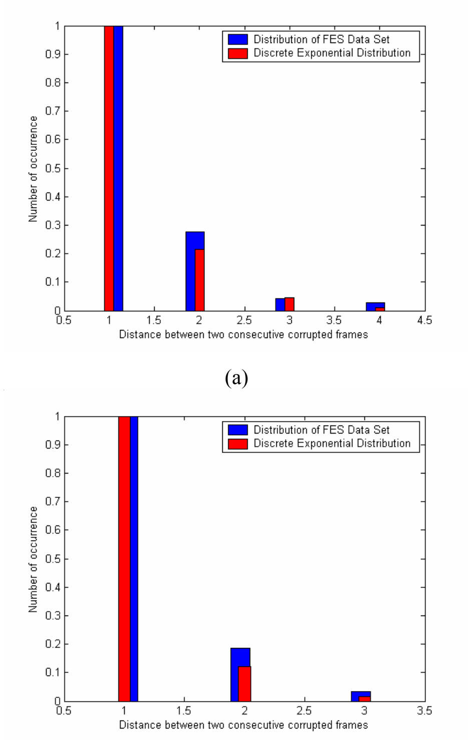


Fig.3. Proposed Error Generator Model

The mean μ_{FES} and μ_{NECF} and variance σ^2_{FES} and σ^2_{NECF} were respectively derived from the FES and NECF data set. These parameters were used to find a standard probability density function (PDF) which could be used to approximate the distribution of the FES and NECF distributions.

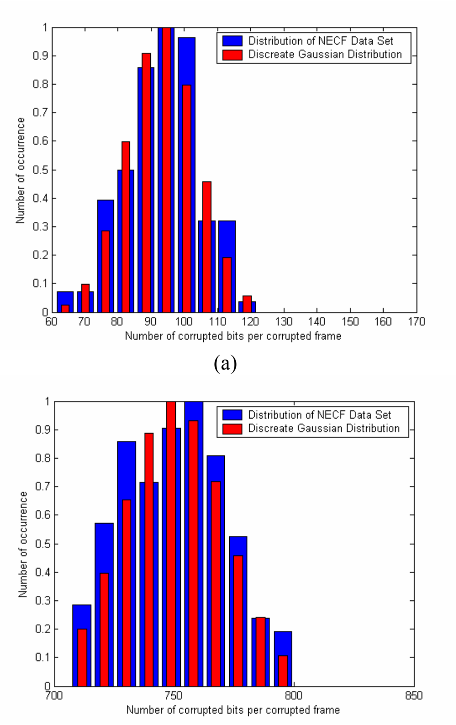
Both data sets were binned and the chi-square test was used to measure the difference between the binned distribution of the data set and the different standard distribution. From the chi-square statistical test, it was concluded that for both DVB FEC schemes, the FES can be approximated by a discrete exponential distributed, as illustrated in Fig. 4 with mean μ_{FES} and variance σ^2_{FES}, while the NECF can be approximated by a discrete Gaussian distribution, as illustrated in Fig. 5, with mean μ_{NECF} and variance σ^2_{NECF}. Both Monte Carlo simulators and the proposed error generator model were tested at different noise levels, and it was found that both the FEC and NECF follow similar standard probability density functions.



(a)

(b)

Fig.4. Normalized Histogram of the FES data set and the assumed discrete exponential distribution (a) DVB-RCS FEC at an Eb/N0 = 3dB (b) DVB-S FEC at an Eb/N0 = 2.5dB.



(a)

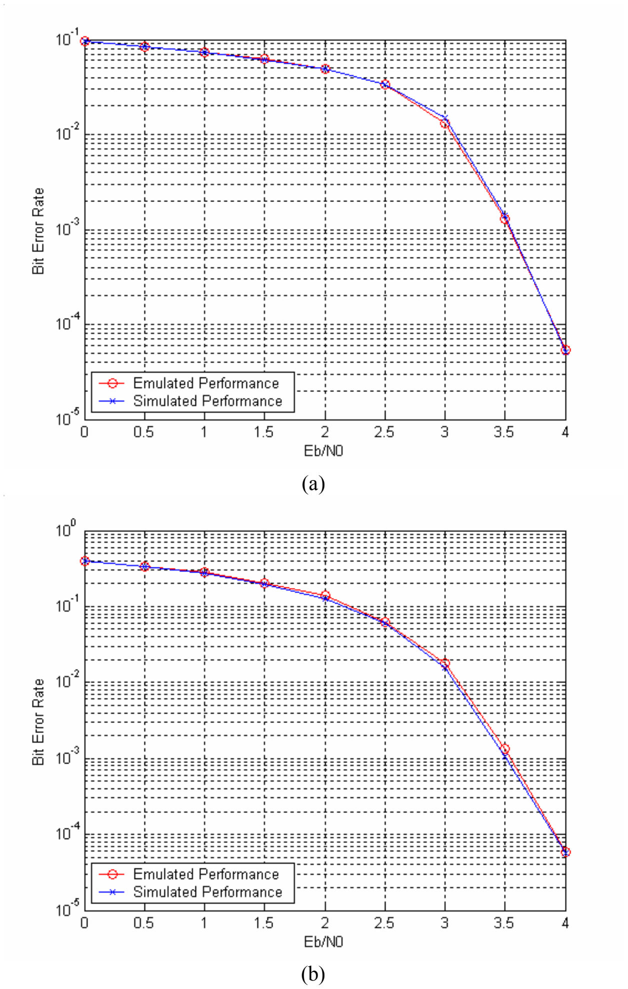
(b)

Fig.5. Normalized Histogram of the NECF data set and the assumed discrete Gaussian distribution (a) DVB-RCS FEC at an Eb/N0 = 1.5dB (b) DVB-S FEC at an Eb/N0 = 2.0dB.

In order to comply with ITU Radio Regulations and to ensure adequate binary transitions, serial data bitstreams are generally randomized [14]. Both DVB FEC schemes randomize the location of the errors, and therefore the EL distribution can be assumed to be uniformly distributed along the frame.

VI. SIMULATION RESULTS

The number of errors generated by the Monte Carlo simulator and the proposed three random variable bit error generator were compared by correlating the BER of two different FEC schemes described in the previous sections. This test was executed at different noise levels. Fig. 6 illustrates the correlation between the two Monte Carlo simulators and the corresponding proposed bit error generator model in terms of BER. From these results it is evident that the discrepancy between the two models can be considered to be negligible.



(a)

(b)

Fig.6. Comparison between the reference Monte Carlo Simulator and the proposed error generator in terms of BER (a) DVB-RCS FEC, (b) DVB-S FEC

When dealing with compressed video, evaluating the performance of the proposed error generator model based on the BER and FER is not enough. This is because the end-to-end quality of a video system is mainly dependent on the actual location of the corrupted bits. For example, if a variable length code (VLC) word is corrupted, the synchronization between the encoder and decoder is usually lost until the next synchronization marker. Therefore, even one corrupted bit may result in a burst of errors which will result in a significant loss in video quality.

Three different video sequences were considered in this simulation: (a) “Coastguard” - A boat moving at constant velocity, (b) “Erik” – head and shoulder video sequence, and (c) “Football” - an American football match. These video sequences are stored in YUV colour space at CIF resolution. The raw video was compressed using the standard H.263++ codec [17] which removes both spatial and temporal redundancy in order to achieve large compression ratios.

The compressed video sequence u was first corrupted by the proposed bit error generator e_P and then by the reference Monte Carlo simulator e_{MC} resulting in the corrupted compressed sequences $\hat{u}_{MC}$ and $\hat{u}_P$ respectively as illustrated in Fig. 7. The decoding process of both corrupted video streams produces two corrupted video files. The resulting video quality of both video files was evaluated objectively using the peak signal-to-noise ratio (PSNR) algorithm. Both DVB-RCS and DVB-S standard error correction schemes were simulated using this methodology.

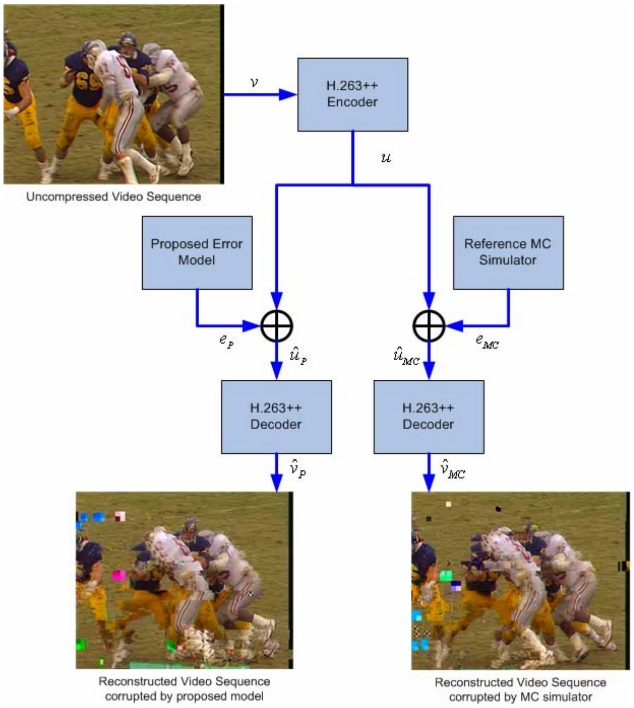


Fig.7. Methodology used to compare the performance of the proposed error model in terms of PSNR

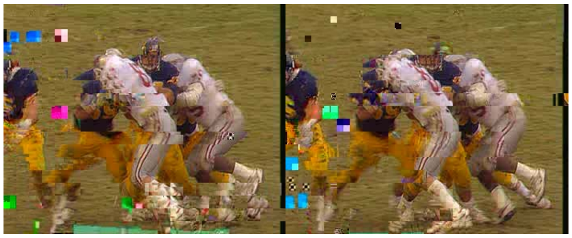
The three video sequences were corrupted at three different noise levels and the PSNR of the resulting reconstructed video are summarized in table I and II for the DVB-RCS and the DVB-S FEC scheme respectively. The performance of the proposed error model correlates relatively well with the reference error model in terms of PSNR. This becomes more evident when evaluating the video quality subjectively. Fig. 8 and Fig. 9 illustrate a number of reconstructed frames when corrupted by the reference and the proposed error model.

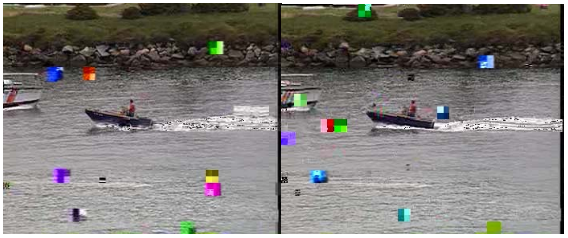
TABLE I
DVB-RCS VIDEO QUALITY EVALUATION

Sequence	Eb/N0	PSNR – Y (Proposed Model)	PSNR-Y (Reference Model)
Coast Guard	3.0	20.8902	21.6397
Erik	3.0	18.9288	18.1722
Football	3.0	16.4224	16.6405
Coast Guard	3.5	24.0058	24.2744
Erik	3.5	24.8352	25.5352
Football	3.5	22.2181	23.3352
Coast Guard	4.0	29.6491	28.9559
Erik	4.0	32.0581	31.3219
Football	4.0	28.3782	28.6851

TABLE II
DVB-S VIDEO QUALITY EVALUATION

Sequence	Eb/N0	PSNR – Y (Proposed Model)	PSNR-Y (Reference Model)
Coast Guard	3.0	24.0040	24.7726
Erik	3.0	21.8251	22.3453
Football	3.0	16.4111	16.5083
Coast Guard	3.5	25.2950	24.0077
Erik	3.5	24.7270	25.7871
Football	3.5	21.9582	22.0338
Coast Guard	4.0	29.5302	30.2286
Erik	4.0	31.6198	32.4961
Football	4.0	29.8183	30.5325


Frame 3 of the Football sequence


Frame 10 of the Coastguard sequence


Frame 10 of the Erik sequence

Fig.8. Reconstructed frames of the considered video sequences when adopting the DVB-RCS FEC scheme. The compressed video bitstream is corrupted by the proposed error mode (Left) and the reference MC simulator (Right).


Frame 9 of the Football sequence


Frame 11 of the Coastguard sequence


Frame 11 of the Erik sequence

Fig.9. Reconstructed frames of the considered video sequences when adopting the DVB-S FEC scheme. The compressed video bitstream is corrupted with the proposed error mode (Left) and the reference MC simulator (Right).

These results confirm that the proposed error generator provides an accurate error model which can emulate the performance of complex coding architectures, such as Turbo Codes and Concatenated codes. The advantage of this method is that it offers a significant increase in computational speed, and presents minimal loss in accuracy in both the number of errors and the end-to-end quality of a video system.

VII. COMMENTS AND CONCLUSION

The use of Monte Carlo simulators to evaluate the performance of complex coding architectures is accurate, but requires a huge amount of time to reach the required level of confidence. Such simulators are effective in developing reference models, however their utility is inadequate for network models where analyzes of the performance and end-to-end quality of the system must be done in a fast way.

This paper has presented a simple and flexible model, based on three random variables, which can be used to emulate the performance of complex coding architectures such as DVB-RCS turbo codes and the DVB-S concatenated codes in little time. Through observation of the simulation results, it was concluded that this has been successfully achieved with a minimal loss in both BER and PSNR values. Moreover, the complexity of the model is fixed and its accuracy is mainly dependent on the accuracy of the data set from which the distributions of the three random variables are derived.

REFERENCES

[1] R. A. Farrugia, C. J. Debono and P. Micallef, "Propagation Impairments Modeling and QoS Parameters Characterization in a Ka-band Videoconferencing System," in IEEE Proc. of EUROCON Conf., pp. 453-456, November 2005.

[2] R. A. Farrugia, C. J. Debono, and P. Micallef, "Channel Modeling and Simulation of a Ka-band Videoconferencing System," in IEEE Proc. of MELECON Conf., pp. 613-616, May 2006.

[3] P. M. Robert, A. M. Darwish and J. W. Reed, "Fast bit error generation for simulation of MPEG-2 transmission in wireless systems," in IEEE Proc. of WCNC Conf., vol. 1, pp. 324-328, September 1999.

[4] I. E. G. Richardson, "Video Coding for Reliable Communications," Ph.D. dissertation, Robert Gordon University, October 1999.

[5] P. M. Robert, A. M. Darwish and J. H. Reed, "MPEG video quality prediction in a wireless system," in IEEE Proc. of the Vehicular Technology Conf., vol. 2, pp. 1490-1495, July 1999.

[6] R. A. Farrugia, C. J. Debono, and P. Micallef, "Modeling the End-to-End Video Quality of a Practical Videoconferencing System," Proc. of OPNETWORK 2006, Washington, DC, USA, August 2006.

[7] M. C. Jeruchim, P. Balaban and K. S. Shanmugan, "Simulation of Communication Systems," 2nd ed. Plenum Press, New York, 2000, pp. 371-406.

[8] N. Celandroni, F. Davoli, E. Ferro, S. Vignola, S. Zappatore, A. Zinicola, "An experimental study on the quality of service of video encoded sequences over an emulated rain-faded satellite channel," in IEEE J. Selected Areas of Communications, vol. 22, pp. 229-237, February 2004.

[9] C. Chen, K. Kuusilinna, B. Richards, A. Chen, N. Chan, R. W. Brodersen and B. Nikolic, "Rapid design and analysis of communication systems using the BEE hardware emulation environment," in IEEE Int. Workshop on Rapid Systems Prototyping, pp. 148-154, June 2003.

[10] J. J. Olmos, A. Gelonch, F. J. Casadevall and G. Fermenias, "Design and implementation of a wide band real-time mobile channel emulator," in IEEE Trans. on Vehicular Technology, vol. 48, pp. 746-764, May 1999.

[11] C. Pimentel and I. F. Blake, "Modeling burst channels using partitioned Fritchman's Matkov models," in IEEE Trans. on Vehicular Technology, vol. 47, pp. 887-889, August 1998.

[12] A. Umbert and P. Diaz, "A generic channel emulator to evaluate higher layer protocols in a CDMA system," in IEEE Int. Symp. on PIMRC 2000, vol. 1, pp. 401-405, September 2000.

[13] D. Drajic, "On Channel Modelling for 3G (WCDMA) Systems Using Turbo-Coding", in IEEE Proc. of EUROCON Conf., pp. 1172-1175, November 2005.

[14] ETSI EN 301 790, "Digital Video Broadcasting (DVB); Interactive channel for satellite distribution systems", 2005.

[15] ETSI EN 300 421, "Digital Video Broadcasting (DVB) Framing structure, channel coding and modulation for 11/12 GHz satellite services," 1997.

[16] J. A. Briffa, "Interleavers for Turbo Codes," M. Phil dissertation, Dept. of Communications and Comp. Eng., Univ. of Malta, October 1999.

[17] ITU-T Recommendation H.263, "Video coding for low bit rate communication,", Series H: Audiovisual and Multimedia Systems Infrastructure of audiovisual services – Coding of moving video, 2005.