Unequal Error Protection of H.264/AVC Video Bitstreams based on the Motion Energy Estimation for Group of Pictures

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Abstract— A multi-level error protection technique for H.264/AVC video bitstreams is proposed. Error protection levels for video frames are determined based on frames' motion activities and the importance of the Group of Pictures (GOP) containing the considered frames. The motion activity of a frame is evaluated by the majority of macroblocks having high motion energy, which is defined as the energy necessary for macroblocks movement between two consecutive frames. Then, the importance of a GOP is determined based on the estimation of motion energy of previous GOPs. Simulation results show that the proposed technique provides better video quality compared to other GOPbased Unequal Error Protection (UEP) techniques.

Index Terms— Group of Pictures (GOP), Motion Energy, Macroblock Importance, Unequal Error Protection.

I. INTRODUCTION

With the growth of multimedia communication systems, applications of compressed videos transmitted over wireless networks have been increased. The protection of video data over the wireless networks is still a challenging task due to its sensitivity to the channel noise. As video frames are related to each other, a single error in a video frame can propagate to other frames of the video bitstreams [1]. This will result a significant deterioration on the video quality.

A variety of error resilient methods were proposed in order to protect the video bitstreams from transmission errors. In H.264/AVC standard, Group of Pictures (GOP) is an effective tool for preventing the error propagation in consecutive frames [2]. A GOP include one Intra-coded (I) frame and some other inter-coded frames. As the I frame is the first frame of a GOP and independently decoded by itself, errors occurred in previous GOPs are not transmitted to the current one. It is recognized that errors occur in earlier frames will affect the following frames of a GOP. As a result, earlier frames are more important than latter ones in a GOP. In an UEP technique, higher protection levels are applied for earlier frames of a GOP [3]. In addition, frames of a GOP are divided into different slices. Each slice contains macroblocks having the same importance determined by their positions in a video frame (MB POS). It is also concluded that macroblocks closely located to the beginning of a video frame are more important than others. As synchronization information of a video frame is inserted to the macroblocks positioned at the beginning of the frame, errors occur in these macroblocks will cause the loss of synchronization. In this case, decoding is stopped until the next video frame is received. In this technique, division of slices in a frame reduces the coding efficiency of the video bitstreams as added slice headers will significantly

increase the number of transmission bits. Another method for determining the importance of macroblocks in a GOP is done by analyzing the error propagation of macroblocks. Macroblocks having high contribution to the distortion of a GOP are highly protected [4]. This method requires a delay equal to the length of one GOP in order to calculate the error propagation of macroblocks.

In another GOP-based UEP technique, macroblocks in a frame with high motion activities are protected more than others [5]. An algorithm is constructed to determine high motion-activity macroblocks. First, macroblocks containing different sub-macroblocks are considered as candidates for high motion-activity macroblocks, since they contain more details of movements than other macroblocks. Then, Motion Vector Magnitudes (MV_MAG) of these macroblocks are calculated and compared with the average motion vector magnitude of all macroblocks of a frame. If MV_MAG value is larger than the calculated average value, the macroblock is determined as a high importance macroblock. Otherwise, they are evaluated as low importance ones. In addition, the importance of a frame in a GOP is determined based on the estimation of distortion of the GOP, when error occurs in the relevant frame. As a result, multi-level protection for different macroblocks in a GOP is constructed based on motion levels of macroblocks and importance of frames [5].

Alternatively, UEP is formed by the importance of different slices in a GOP. A priority model for evaluating slices' importance was proposed [6]. It takes into account the effect of slice types, positions of slices and headers of slices on the distortion of video sequences. Different protection levels are assigned for slices depending on their calculated priority values. Another technique for preventing error propagation in a GOP is proposed based on a modified Reed-Solomon (RS) code, which is applied for real time video streaming applications [7]. RS parity packets of the current frame are generated by using the information of the current and all previous frames of the GOP. At the decoder, these parity packets will help to recover the lost macroblocks of the current and previous frames. As macroblocks in previous frames are corrected, errors from these frames are not propagated to the current frame. However, the processing time for recovering latter frames is increased, when a higher number of previous frames are considered.

The determination of error protection levels for frames or macroblocks inside a GOP proposed in previous papers either requires a delay of one GOP or high complexity in calculation. In this paper, the importance of a frame is determined according to the majority of macroblocks having high motion energy, which is the energy necessary for macroblocks movement between two consecutive frames [8], [9]. Despite other methods, the importance of the current GOP is obtained on the basis of its estimated motion energy, which is calculated as the weighted average of motion energy of previous GOPs. The motion energy of each previous GOP is assigned a weight, which determines its importance contributing to the average calculation. Weights are decided with respect to the temporal distances between previous and current GOPs [10]. The importance of a GOP is evaluated by comparing its estimated motion energy with the motion energy of the immediately previous GOP. This forms a multi-level error protection for different video frames. Simulation results confirm that the proposed method provides better video quality than other GOP-based UEP methods, while no delay is required for estimating the importance of GOPs.

The rest of the paper is organized as follows. Section II introduces the estimation method for determining the importance of frames and GOPs based on motion energy. Section III presents the simulation results of the proposed method. Section IV concludes the paper.

II. DETERMINATION OF IMPORTANCE OF FRAMES AND GROUP OF PICTURES (GOP)

The motion activity of a sub-macroblock can be evaluated by motion energy, which quantifies the movement of a submacroblock between two consecutive frames [6]. It is defined as the product of motion vector magnitude and the size of sub-macroblock, which is given as follows:

$$ME_t \triangleq S_{BLCK_t}.MV_t \tag{1}$$

where S_{BLCK_t} and MV_t are the size and the motion vector magnitude of the t^{th} sub-macroblock, respectively. Motion energy of a macroblock is calculated as the total motion energy of its sub-macroblocks. The importance of a macroblock is determined based on its motion energy. In two-level error protection, a macroblock is more important, when its motion energy is greater than the threshold value. The threshold value is estimated as the average motion energy of neighboring areas of the considered macroblock [11]. The importance of a video frame is evaluated by the majority of macroblocks having the same importance level in a video frame [11].

As GOP prevents the error propagation between frames, UEP technique for the video frames encoded by GOP structure will be promising to achieve a high video quality. To determine the importance of a GOP, the definition of motion energy for video frames is extended. Motion energy of a GOP is the total motion energy of frames inside the GOP. Conventionally, motion energy of the i^{th} GOP is estimated as the average motion energy of previous GOPs (AVG_EST). It is given by:

$$\widehat{ME}_{GOP_i} = \frac{\sum_{k=1}^{M} ME_{GOP_{i-k}}}{M}$$
(2)



Fig. 1. Temporal distances between GOPs.

where i > M. M is a constant value and represents the number of consecutive GOPs, which are positioned before the i^{th} GOP¹.

It is recognized that the correlation between the current and previous GOPs is reduced by increasing the temporal distance [10]. Hence, previous GOPs positioned closer to the current one are more important than others in the abovementioned equation. An estimation of motion energy of a GOP is proposed based on the weighted average ($WAVG_EST$), which considers the contribution of previous GOPs to the average of motion energy calculation based on their positions. It is represented by:

$$\widehat{ME}_{GOP_i} = \frac{\sum_{k=1}^{M} w_k . ME_{GOP_{i-k}}}{\sum_{k=1}^{M} w_k}$$
(3)

In this equation, w_k is the weight of motion energy of GOP_{i-k} , which is inversely proportional to the temporal distance T_k [10]. That is:

$$w_k = \frac{\lambda}{T_k} \tag{4}$$

where λ is a constant value. Figure 1 shows the temporal distance T between two consecutive GOPs. The temporal distance between the i^{th} and $(i - k)^{th}$ GOPs is given by:

$$T_k = kT \tag{5}$$

This concludes:

$$w_k = \frac{\lambda}{kT} \tag{6}$$

Applying Equations (6) and (3), the estimated motion energy of a GOP is obtained by:

$$\widehat{ME}_{GOP_{i}} = \frac{\sum_{k=1}^{M} \frac{\lambda}{kT} \cdot ME_{GOP_{i-k}}}{\sum_{k=1}^{M} \frac{\lambda}{kT}}$$
$$= \frac{\sum_{k=1}^{M} \frac{1}{k} \cdot ME_{GOP_{i-k}}}{\sum_{k=1}^{M} \frac{1}{k}}$$
(7)

¹For $i \leq M$, GOPs are categorized as high importance ones.



Fig. 2. Normalized correlation of previous GOPs of CIF Stefan sequence.

In Equation (7), a normalized value of the weight w_k is introduced as Ω_k , where $\Omega_k = \frac{1}{k}$.

The relationship between correlation and the normalized weights of previous GOPs will be verified below. The correlation between the l^{th} frames positioned at two different GOPs is calculated by [12]:

$$C_{(i,i-k)}^{l} = \frac{\sum_{x=0}^{H} \sum_{y=0}^{W} I_{i}^{l}(x,y) I_{i-k}^{l}(x,y)}{\sum_{x=0}^{H} \sum_{y=0}^{W} [I_{i}^{l}(x,y)]^{2}}$$
(8)

where $I_i^l(x, y)$ and $I_{i-k}^l(x, y)$ are the luminance values of the pixel located in position (x, y) of the l^{th} video frame at the i^{th} and $(i-k)^{th}$ GOPs, respectively. H and W are the height and width of the video frame. As a result, the correlation between GOPs is the total correlation of their correspondent frames. This is given by:

$$\mathcal{C}_{(i,i-k)} = \sum_{l=1}^{L} \mathcal{C}_{(i,i-k)}^{l} \tag{9}$$

where L is the total number of frames inside one GOP. For M consecutive previous GOPs, the first one, i.e. $(i - 1)^{th}$ GOP, has the highest correlation with the i^{th} GOP since correlation values are reduced with the temporal distance [10]. This means:

$$\mathcal{C}_{(i,i-1)} \ge \mathcal{C}_{(i,i-2)} \ge \dots \ge \mathcal{C}_{(i,i-M)} \tag{10}$$

A normalized correlation between the i^{th} and $(i - k)^{th}$ GOPs $(1 \le k \le M)$, can be expressed by:

$$\widetilde{\mathcal{C}}_{(i,i-k)} = \frac{\mathcal{C}_{(i,i-k)}}{\mathcal{C}_{(i,i-1)}} \tag{11}$$



Fig. 3. Normalized correlation of previous GOPs of QCIF Foreman sequence.

The average value of normalized correlations given by Equation 11 is calculated as follows:

$$\overline{\mathcal{C}}_{(i,i-k)} = \frac{\sum_{i'=M+1}^{N} \widetilde{\mathcal{C}}_{(i',i'-k)}}{N-M}$$
(12)

where N is the total number of GOPs utilized for measuring the average value.

Figures 2 and 3 show the normalized correlation $C_{(i,i-k)}$ between the i^{th} and $(i-k)^{th}$ GOPs of CIF Stefan and QCIF Foreman video sequences (k = 2, 3, 4). The GOP structure is formed as "IPPPP". Three hundred frames of QCIF Foreman and CIF Stefan video sequences are used in the analysis, which are equivalent to 60 GOPs. From these analysis, it is concluded that $\overline{C}_{(i,i-k)}$ is almost equal to the normalized weight of motion energy of the (i-k) GOP, i.e. the value of Ω_k^2 . This is expressed by:

$$\bar{\mathcal{C}}_{(i,i-k)} \approx \Omega_k \tag{13}$$

Table I shows the result of estimated motion energy by different methods for QCIF Foreman video sequence. Motion energies of GOPs are obtained by $WAVG_EST$, AVG_EST and MAX_EST techniques³. This table also gives the Mean Squared Error (MSE) [2] values between these estimated motion energies and the exact one, which is achieved from the motion activities of the frames positioned in the relevant GOP. It can be seen that $WAVG_EST$ provides the lowest MSE value. This means that the proposed method gives the best estimation of motion energy for the considered GOP compared to the other methods. As motion energy is estimated from

 ${}^{3}MAX_EST$ considers maximum motion energy of M previous GOPs as the estimated motion energy of the current GOP.

 $^{^{2}\}Omega_{1}=1, \Omega_{2}=0.5, \Omega_{3}=0.33, \Omega_{4}=0.25.$

GOP No.	AVG_EST	MAX_EST	WAVG_EST	Real value
5	3752.02	3098	3005.07	3063
6	3985.1	4256	3845.78	3800
7	4120.7	3978	3678.92	3661
8	4356.65	5974	4500.68	4477
9	2894.24	4203	4891.05	3914
10	4022.08	4254	4251.74	4212
11	2998.93	2789	2415.22	2668
12	3158.72	4569	3899.78	3887
13	3561.81	3475	2925.54	2939
14	3614.56	3896	3295.34	3251
15	4002.64	4285	4103.22	4115
16	2589.22	2897	2764.46	2780
17	3984.46	3815	3777.94	3768
18	2905.58	3208	3277.85	3117
19	4206.15	4159	3845.81	3815
20	3356.72	3997	3743.29	3755
21	5310.44	5877	4156.13	4954
22	3158.57	3568	3466.59	3453
23	4432.46	4725	4189.19	4098
24	2358.82	3861	3098.48	3125
MSE	216,780.38	292,449.4	85,099.31	0

 TABLE I

 Comparison of different estimation methods for GOPs' motion

 Energy

previous GOPs, the proposed method does not produce any delay for determining the importance of GOPs.

The estimated motion energy obtained from the analysis of GOPs is utilized to determine the importance of the next GOP, which is based on the changing rate between its estimated motion energy and the motion energy of the former GOP. It is given by:

$$\Delta_{ME} = \frac{\dot{M}\dot{E}_{G(i)} - ME_{G(i-1)}}{ME_{G(i-1)}}$$
(14)

 Δ_{ME} is then compared with threshold values to determine the importance of GOPs. Threshold values are obtained by trial and error so as to optimize the video quality in terms of the overall code rate used in FEC coding technique. In this case, the optimal threshold value will be achieved by simulations. Let $\mathcal{L}(i)$ as the importance level of the GOP_i , where $0 \leq \mathcal{L}(i) \leq \mathcal{L}_{\max}$. \mathcal{L}_{\max} is the highest protection level for GOPs. Based on a positive value set as the threshold value (TH), an algorithm for determination of the importance of the i^{th} GOP is formed as follows:

- 1) Calculate Δ_{ME} value for the i^{th} GOP from Equation (14).
- 2) Compare Δ_{ME} with the threshold values and decide the importance level of GOP based on the following rules:
 - a) If $-TH \leq \Delta_{ME} \leq TH$, $\mathcal{L}(i) = \mathcal{L}(i-1)$
 - b) If $\Delta_{ME} > TH$, $\mathcal{L}(i) = min\{\mathcal{L}(i-1)+1; \mathcal{L}_{max}\}$

 TABLE II

 Code rate setting for different video frames

	GOP importance level $(\mathcal{L}(i))$				
Frame importance	P frame		I frame		
	0	1	0	1	
High	0.42	0.37	0.36	0.334	
Low	0.45	0.4	0.36	0.334	

c) If
$$\Delta_{ME} < -TH$$
, $\mathcal{L}(i) = max\{\mathcal{L}(i-1) - 1; 0\}$

A protection level for the l^{th} frame in the i^{th} GOP is formed based on the importance of the frame itself and the importance level $\mathcal{L}(i)$ of the i^{th} GOP. Specific FEC code rates for frames having different protection levels will be applied to form a multi-level unequal error protection for GOPs of the H.264/AVC video sequences.

III. SIMULATION RESULTS

The performance of GOPs in H.264/AVC video sequences is verified by different motion energy estimation methods including AVG_EST , MAX_EST , and $WAVG_EST$. They are compared with other motion-based UEP techniques introduced in [3] and [5] (MB_POS and MV_MAG). Different video sequence are encoded with GOP structure of "IPPPP" format and the rate of 30 frames per second. JM 18.0 Reference Software is applied in encoding and decoding of the H.264/AVC video bitstream [13].

The unequal error protection technique is applied in the physical layer, where channel coding is used for protecting video signals from noise [14]. Additive White Gaussian Noise (AWGN) model is implemented in simulation of random noise for video bitstreams modulated by Binary Phase Shift Keying (BPSK) technique. Different headers are added to frames, when they pass through different layers. At the physical layer, a frame is mapped into a packet recognized by its header added to the Network Abstraction Layer (NAL) Unit [2]. The protection for different frames are accomplished by product codes constituted by two cyclic Euclidean Geometry Low Density Parity Check (EG-LDPC) (63,37) codes with length L = 1369 [14]. Puncturing is conducted on the full-rate of product code, i.e the rate of 0.334, to unequally protect frames with different importance. Table II shows the punctured EG-LDPC product code rates for different video frame types and GOPs. Two importance levels for GOPs (0 and 1) are constructed in simulations. As a result, four different code rates are applied for P frames based on the importance of frames and GOPs. Code rates for I frames only depend on the importance levels of GOPs, as motion vectors utilized in determining the importance of frames based on motion energy cannot be extracted from I frames. Zero padding is applied on frames to construct bitstreams with the length required for the cyclic EG-LDPC codes [14]. For EEP technique, the code rate is set to the average rate of $UEPs^4$. Iterative decoding of

 $^{^{4}}$ For whole simulations, the code rate of EEP is set to 0.385.



Fig. 4. PSNR result of CIF Stefan video with different thresholds.



Fig. 5. PSNR result of QCIF Foreman video with different thresholds.

cyclic EG codes with maximum 100 iterations is implemented by Sum-Product Algorithm (SPA) [14].

Various video sequences with different frame sizes and motion activities are considered in simulations. Three hundred (300) frames of each video sequence are used in the loop of 200 simulations in order to compute the average PSNR for different video sequences.

In order to determine the optimal threshold value of the proposed method, a simulation for $WAVG_EST$ method with different TH values from 0.04 to 0.2 is conducted. Figures 4 and 5 show PSNR results of Stefan and Foreman sequences. It can be seen that when TH is set between 0.08 and 0.12, the code rate is changed by $\pm 2\%$. For TH < 0.08, the code rate is rapidly increased by $\pm 9\%$. However, PSNR of video sequences are not improved accordingly. For $0.12 < TH \le 0.2$, PSNRs are lower than the range of 0.08 to 0.12. As a result, TH from 0.08 to 0.12 are selected. Similarly, simulations are conducted to determine the optimum value of number of previous GOPs,



Fig. 6. PSNR result of 4CIF Crew video sequence.



Fig. 7. PSNR result of 4CIF Harbour video sequence.

i.e the value of M. This will provide the best estimation of motion energy for the current GOP. It is concluded that the value of M = 5 provides the best video quality for different video sequences.

To compare the performance of different GOP-based UEP techniques, TH = 0.1 and M = 5 are considered. Figures 6, 7, and 8 illustrate video performance of different methods based on different Energy per Bit to Noise ratio (E_b/N_0) values. In 4CIF Crew video sequence, $WAVG_EST$ outperforms other methods, which provides 0.52 dB, 0.64 dB, 1.36 dB, 1.8 dB, and 3.4 dB better than MAX_EST , AVG_EST , MB_POS , MV_MAG , and EEP methods, respectively. Similar results are obtained for 4CIF Harbour video sequence, where $WAVG_EST$ provides 0.48 dB to 3.62 dB higher than other methods. For Pedestrian Area video sequence, the PSNR provided by $WAVG_EST$ is also higher than the others. These Figures conclude that $WAVG_EST$ extracts high-importance frames and GOPs



Fig. 8. PSNR result of 1080p Pedestrian_area video sequence.

better than MAX_EST and AVG_EST methods.

Table III shows the performance of various video sequences with different bit rates. Again, it is shown that $WAVG_EST$ outperforms other methods in all video sequences.

IV. CONCLUSIONS

A multi-level error protection technique based on the motion activities of frames and GOPs was proposed. An improved estimation method was applied for predicting the motion energy of different GOPs. This method can be applied for real time video transmission, since it minimizes processing time for determining the importance of GOPs. Conducted analysis and simulation results confirm that the proposed method provides better estimation of motion energy for a GOP. This was led to a suitable protection for different frames of the video bitstreams. Simulation results also showed that a higher video quality is achieved by the newly proposed technique, while it maintains a similar overall code rate in comparison to other GOP-based UEP techniques.

REFERENCES

- S. Wenger, "H.264/AVC over IP," Circuits and Systems for Video Technology, IEEE Transactions on, vol. 13, no. 7, pp. 645–656, 2003.
- [2] Advanced Video Coding for Generic Audio Visual services. Telecommunication Standardization Sector of ITU, 2011.
- [3] Y. C. Chang, S.-W. Lee, and R. Komyia, "A fast forward error correction allocation algorithm for unequal error protection of video transmission over wireless channels," *Consumer Electronics, IEEE Transactions on*, vol. 54, no. 3, pp. 1066–1073, 2008.
- [4] C. Lin, T. Tillo, Y. Zhao, and B. Jeon, "Multiple Description Coding for H.264/AVC With Redundancy Allocation at Macro Block Level," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 21, no. 5, pp. 589–600, 2011.
- [5] H. Ha, J. Park, S. Lee, and A. Bovik, "Perceptually unequal packet loss protection by weighting saliency and error propagation," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 20, no. 9, pp. 1187–1199, 2010.
- [6] P. Perez and N. Garcia, "Lightweight multimedia packet prioritization model for unequal error protection," *Consumer Electronics, IEEE Transactions on*, vol. 57, no. 1, pp. 132–138, 2011.

TABLE III PSNR results of different video sequences.

Video Sea	Mathad	bit rate (kbps)			
video seq.	Method	500	1000	2000	3000
	WAVG_EST	37.2	39.18	42.02	42.96
	AVG_EST	36.31	38.23	41.45	42.18
QUIF Foreman	MB_POS	35.24	36.62	40.17	41.85
	MV_MAG	34.76	36.09	40.03	41.59
	WAVG_EST	35.1	37.12	38.94	40.22
CIE Stafan	AVG_EST	34.6	36.72	38.47	39.62
CIT Stelan	MB_POS	34.48	35.91	37.64	38.11
	MV_MAG	34.33	35.54	37.22	37.73
	WAVG_EST	33.76	35.74	38.82	39.81
CIE Dorio	AVG_EST	33.40	35.24	38.07	39.21
CIFFAIIS	MB_POS	33.09	34.83	36.91	38.17
	MV_MAG	33.01	34.20	36.36	37.79
	WAVG_EST	36.2	38.45	41.85	42.23
CIF Hall	AVG_EST	35.85	37.78	40.97	41.84
monitor	MB_POS	34.69	36.21	39.14	40.28
	MV_MAG	34.42	35.97	38.56	40.07
	WAVG_EST	34.84	36.42	38.18	39.02
ACIE Crew	AVG_EST	34.64	36.07	37.91	38.84
4CIF Clew	MB_POS	33.70	35.04	36.62	37.24
	MV_MAG	33.42	34.81	36.26	36.97
	WAVG_EST	34.07	35.67	38.22	38.86
ACIE Harbour	AVG_EST	33.49	35.22	37.14	38.01
4CIF Halboul	MB_POS	33.47	34.53	36.04	37.26
	MV_MAG	33.14	34.35	35.84	36.13
	WAVG_EST	32.56	34.71	36.94	38.02
1080p Pedestrian	AVG_EST	32.14	34.25	36.47	37.61
area	MB_POS	32.08	33.65	35.29	36.14
	MV_MAG	32.04	33.25	35.07	35.84

- [7] J. Xiao, T. Tillo, and Y. Zhao, "Real-time video streaming using randomized expanding reed-solomon code," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. PP, no. 99, pp. 1–12, 2013.
- [8] H. Pham and S. Vafi, "Motion Energy Based Unequal Error Protection of H.264/AVC Video Bitstreams (submitted)," *IET Image Processing Journal*, April 2013.
- [9] H. Pham and S. Vafi, "An Adaptive Unequal Error Protection based on Motion Energy of H.264/AVC Video Frames (accepted)," in Wireless Communications and Networking Conference, IEEE WCNC, April 2013.
- [10] Z. Wang, H. Li, Q. Ling, and W. Li, "Robust temporal-spatial decomposition and its applications in video processing," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 23, no. 3, pp. 387–400, 2013.
- [11] H. Pham and S. Vafi, "A Multi-Level Error Protection Technique Based on Macroblocks Importance of the H.264/AVC Video Frames (submitted)," in Asia-Pacific Conference on Communications Conference, APCC, May 2013.
- [12] R. Haralick, "Statistical and structural approaches to texture," *Proceedings of the IEEE*, vol. 67, no. 5, pp. 786 804, May 1979.
- [13] K. Suehring, "H.264/AVC JM reference software," http://iphome.hhi.de/suehring/tml/download/, Retrieved Feb. 2, 2012.
- [14] S.Lin and D.Costello, *Error Control Coding, Second Edition*. Prentice Hall, 2004.