ISSN 2229-5518

Adaptive Rate Control for Low Rate Video Transmission over Wireless Network

Nasser N. Khamiss, Donya A. Khalid

Abstract— This paper investigates the visibility of using H.246 standard for transmitting videos over 3G mobile networks, it presents an optimal configuration for H.264 standard that support low bit rate. Rate control technique is applied based on the most effective H.264 encoding tools. Results to be compared with MPEG-2 compression standard. Coding improvements of H.264 in terms of PSNR is about 3-4 dB at compression ratio equal to 70:1 for main profile and 58:1 for baseline profile while MPEG-2 result in compression ratio equal to 32:1.

Index Terms—H.264 CODEC, Rate control, Buffering mechanism, 3G mobile network.

1 Introduction

WWireless video applications and services have undergone enormous development recently due to the continuing growth of wireless communication, especially the emergence of new generations of the wireless network. Examples of current video services are YouTube, multimedia messaging, video conferencing, and broadcasting.
However, wireless video streaming poses many challenges like the limited bandwidth in a wireless network and the digitized video produces vast amounts of data that it is necessary to represent the image content. This is a problem for both storage and transmission of video. The video has redundant data can be exploited by apply compression algorithms to minimize the amount of bits associated with the video contents [1],[2].

The demand for compatible video encoders and decoders has resulted in the development of different video compression standards. The "International Standards Organization/International Electrotechnical Commission" (ISO/IEC) and the "International Telecommunication Union" (ITU) had developed many compression standards like MPEG-1, MPEG-2, MPEG-4, H.261, H.263 and H.264 [3].

Within years a new coding standards had been released and developed starting with H.261 to H.265, each standards had a target point to represent the source video data in a more efficient way that can solve video storage and transmission problems. H.264/MPEG-4 Advanced Video Coding standard (H.264/AVC) is new video coding standard jointly developed by the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) [4].

- *Nasser N. Khamiss is a professor at Information and communicaton engineering colloge - Nahrain University, Iraq. E-mail: nasser_alani@yahoo.com*
- *Donya A. Khalid is M. Sc. student in Information and communicaton engineering - Nahrain University, Iraq. E-mail: donyaabbas5@gmail.com*

This standard provides significantly better compression effi ciency with good picture quality compared to previous video coding standards in terms of better peak signal to noise ratio and visual quality since this standard provides new compression tools to maximize quality and minimize bit rate, and are summarized as follows [5],[6]:

- Intra prediction technique,
- Variable block sizes for motion compensation,
- Multiple reference frames for motion compensation,
- Integer transform,
- Deblocking filter,
- Context Adaptive Variable Length Coding (CAVLC), and Context Adaptive Binary Arithmetic Coding (CABAC).

H.264/AVC achieved a significant improvement in compression performance compared to prior standards, and it provides a network-friendly representation of the video that addresses both conversational (video telephony) and non-conversational (storage, broadcast, or streaming) applications [7].

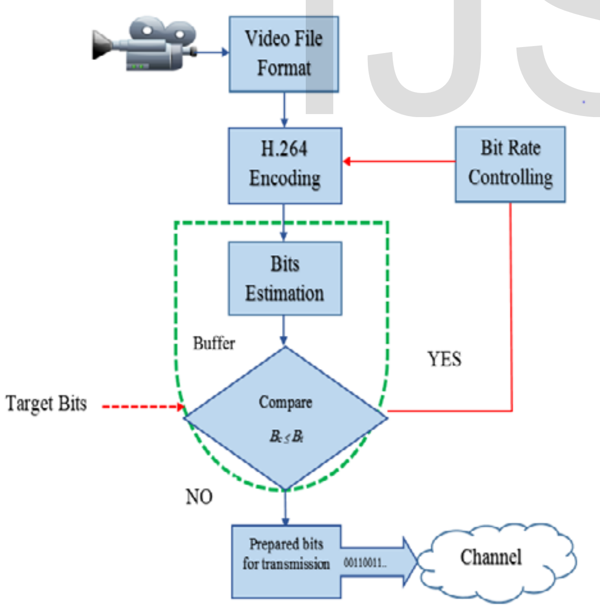
The rest of this paper is organized as follows. The proposed system idea is explained in section 2. The adopted compression standard configuration is illustrated in section 3. Buffering and rate rontorl mechanisms are discussed in section 4. Section 5 gives the experimental results. Section 6 concludes the paper.

2 Proposed System Work Flow

The flow chart for the propped system is shown in fig.1. Firstly the system includes formatting the tested video sequence, H.264 encoding standard is used to compress the input video sequence with initial QP, then a comparison will be held between the compressed bits (Bc) allocated to the video sequence and the target bits (Bt) available across channel. The following statement must be realized**,**

If $B_c \leq B_t$
Buffer is not overflow (allow successful transmission)
Else,
Buffer is over flow (apply rate control mechanism)

When the buffer is not overflowing the compressed bits will encapsulated in packet as a syntax and then send them through the channel. When the buffer is overflowing, rate control is held to reduce the number of bits, and then re-compress the video, comparison applied again to check buffer availability and so on.



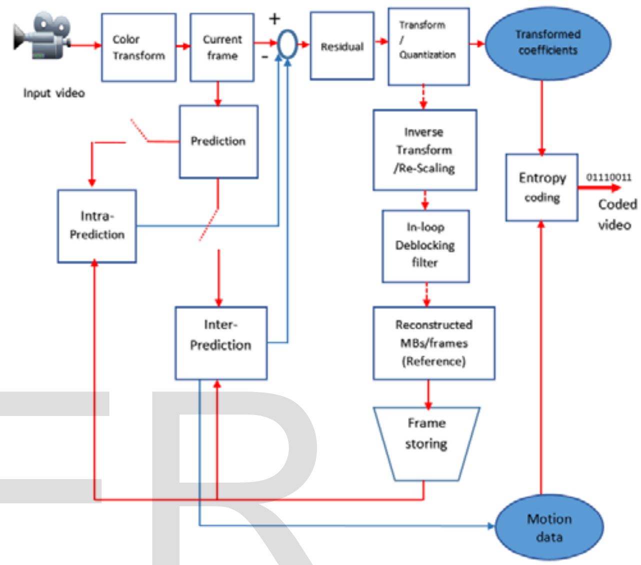
If $B_c \leq B_t$ ***Buffer is not*** ***Else, Buffer***

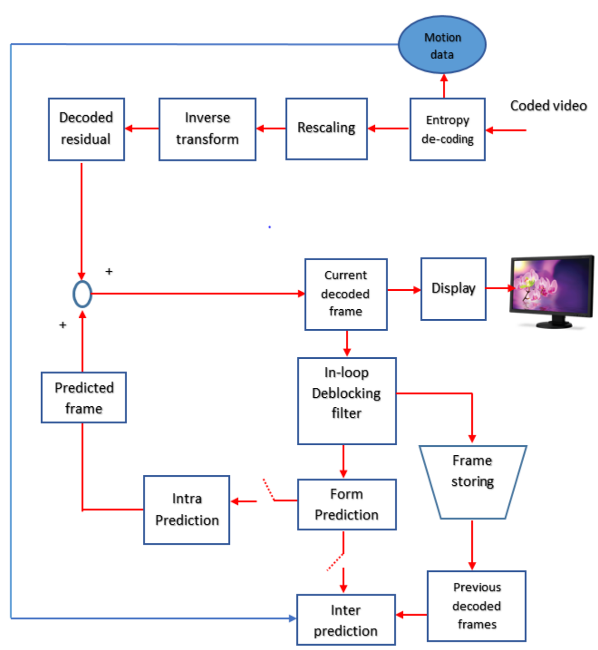
$\leq B_t$
Buffer is not overflow (
sion)
Else, Buffer over flow (
nism)

Fig. 1. Work

3 H.264 Configuration

A video sequence of (QCIF, CIF) formats used as input to the compression block in the proposed system as shown in fig.2, the input video sequence is divided into cycles, where the cycle start with Intra (I) frame and followed by a number of predicted (P) and/or bi-predicted (B) frames. Each frame is divided in to blocks; the encoder forms a prediction of the current block based on previously decoded data, either from the current frame using intra prediction or from other frames that have already been coded and transmitted using inter prediction. A residual error then produced by subtracts the prediction from the current block. This residual block is then transformed, quantized and finally encoded to be streamed over the channel.





(a)

ISSN 2229-5518

(b)

Fig. 2. H.264 CODEC (a) Encoder (b) Decoder

Many configuration scenarios are used for testing H.264 video compression standard based on:
-Baseline and main profiles that are adopted in this work to be used for video conferencing and video broadcasting over 3G mobile network which is dominated in our country since it is cosidered as low bitrae channle transmisoin.
-Two video formats are considered CIF (288×352), QCIF (144×176).
-Two videos differ in their contents (motion details) are tested.

After compressing the video sequence; a stream of bits are generated according to the selected profile either by using CAVLC for baseline profile or CABAC for main profile.
The proposed rate control scheme is based on the H.264 encoder parameters that influence on the bit rate of the encoded bit streams and output quality, these parameters are summarized as follows:

- Group of Picture Length
- Quantization parameter
- P reference frames
- MB droping
- Sub pixel motion estimation

4 Buffer Optimization and Rate control for Mobile Network

This work adopts video conferencing and video broadcasting applications over the 3G mobile channel, Mobile communication system is a constant bit rate (CBR) channel, and the encoded video data must be transmitted over the channel at a fixed bit rate. However, this makes a problem since encoded video data is variable bit rate. To map this varying data rate into a CBR channel, coded video data generated by the encoder is buffered before transmission by using encoder buffer, this buffer empties the data at X rate; where X equal to the transmission channel rate divided by frame rate, then the coded data are arrived from the channel and filled another buffer called decoder buffer at same X rate. The available 3G bit rates for multimedia services are as follows:

1- 144 Kbps: Outdoor at a high velocity.
2- 384 Kbps: From outdoor to indoor.
3- 2Mbps (Indoor).

Bitrate controlling system is needed to control the variable bitrate generated by the encoder over constant bitrate channel with aiding of buffering system. Rate control mechanism include two parts. First, the coded bit stream is buffered at the output of the encoder. If the buffer size is large enough and the encoded data rate is smaller than constrained channel rate the buffer empties data at constant rate. In case of the buffer size is limited and the encoded bitrate is larger than channel rate, the buffer cannot smooth the data. In this way some measures of the output bit rate is feedback to the encoder, this feedback is used to control the encoding process such that the output rate is modified to meet the constraints of the channel. Fig. 4 Shows rate control and buffering mechanism.

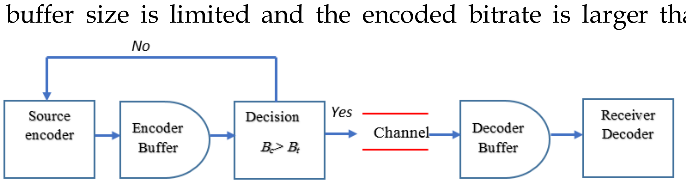


Fig. 3. Rate control and buffering mechanism

It is important now to make sure that the coded bits streams fit with the limitations of the buffering constrained by the specified level. Two levels are adopted in this work (1.1 and 2) based on the following:
1- Tested video formats which they are (CIF and QCIF).
2- Required bit rate according to channel type (Mobile).
Table 1 shows constrained specified by the selected profiles.

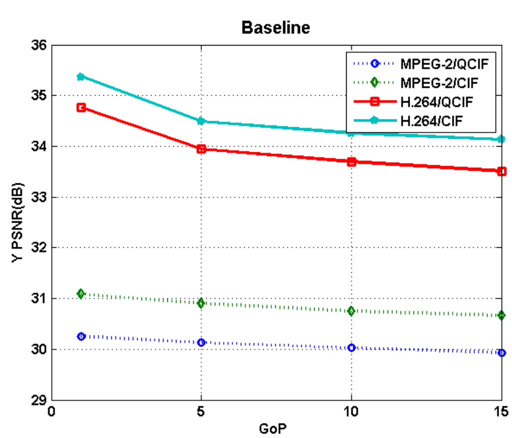
Table 1
Constrained specified by the selected profiles

Level	Tested video formats	Max CPB size (K bits)	Frame rate (fps)
1.1	QCIF	500	30
2	CIF	2000	30

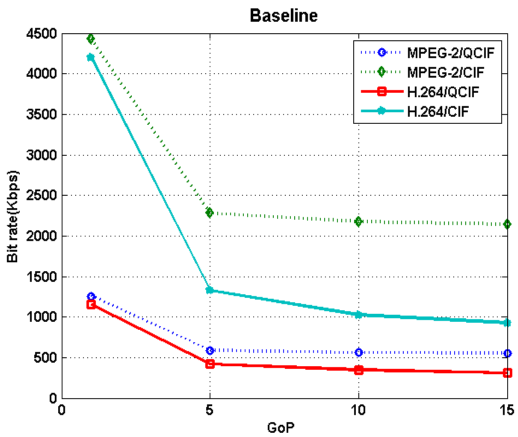
The most important thing to check out for buffer optimization is to prevent the encoder buffer from overflow/underflow to enable reliable transmission.
In addition, another goal can be achieved by rate control mechanism is to keep a more acceptable (consistent) video quality for the encoded video sequence.

5 Testing Results

The length of **GOP** means length between two consecutive I-frames. Generally, decreasing GOP length leads to decrease quality and number of bit.
As rate control scenario different GoP cycle length (GoP=1, 5, 10 and 15), is tested and the compression performance results of H.264 standard under baseline and main profiles are compared with MPEG-2 for both QCIF and CIF video formats.
Fig. 4 shows the impact of GoP length on the PSNR (a) and encoded bitrate (b) for high motion details "tennis" video with QCIF and CIF formats under the baseline profile. For main profile fig. 5 shows the impact of GoP length on the PSNR (a) and encoded bitrate (b) for the same video clip and formats.

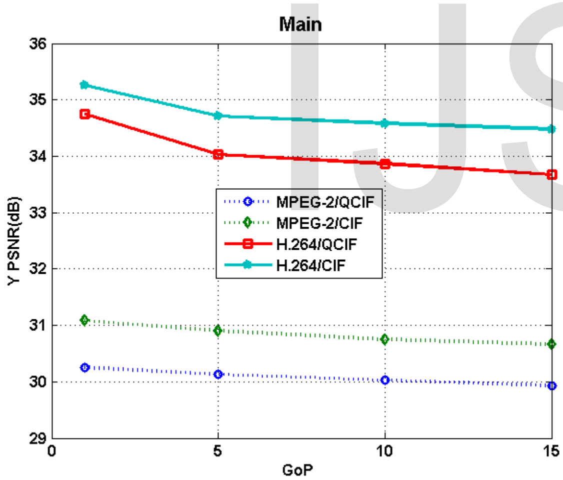


(a)

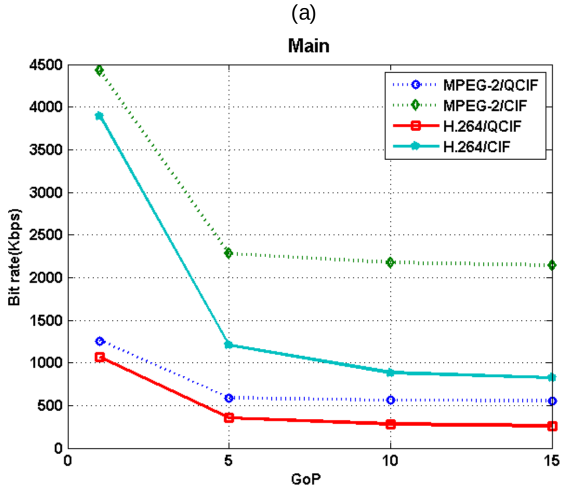


(b)

Fig. 4. Impact of changing GoP on H.264 baseline profile and MPEG-2 (a) PSNR (b) bitrate



(a)



(b)

Fig. 5. Impact of changing GoP on H.264 main profile and MPEG-2 (a) PSNR (b) bitrate

Table 2 summarizes the results for encoding two different video sequence differ in their statistics "Tennis", "Akiyo" at different GoP length with QCIF,CIF formats are encoded using H.246 baseline profile, while table 3 summarizes the results for H.264 main profile.

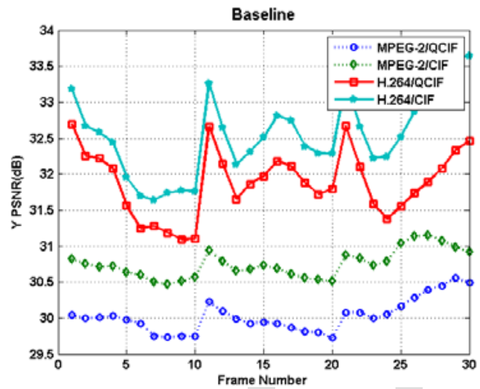
Table 2
Baseline profile performance at different GoP

Format	GoP	Video seq.	Y PSNR (dB)	Total Bit	Bit rate (Kbps)	CR
QCIF	1	Tennis	34.757	1152440	1152.44	15
	1	Akiyo	39.307	589832	589.83	30
	5	Tennis	33.89	403792	403.79	45
	5	Akiyo	38.999	129984	129.98	140
	10	Tennis	33.714	335056	354.55	54
	10	Akiyo	38.811	73536	73.54	248
	15	Tennis	33.509	309560	309.56	58
	15	Akiyo	38.692	54984	54.98	331
CIF	1	Tennis	35.363	4194984	4194.98	17
	1	Akiyo	40.741	1413072	1413.07	51
	5	Tennis	34.492	1330096	1330.1	54
	5	Akiyo	40.5	330200	330.2	221
	10	Tennis	34.258	1025344	1025.34	71
	10	Akiyo	40.325	196280	196.28	371
	15	Tennis	34.135	929312	929.31	78
	15	Akiyo	40.219	153576	153.58	475

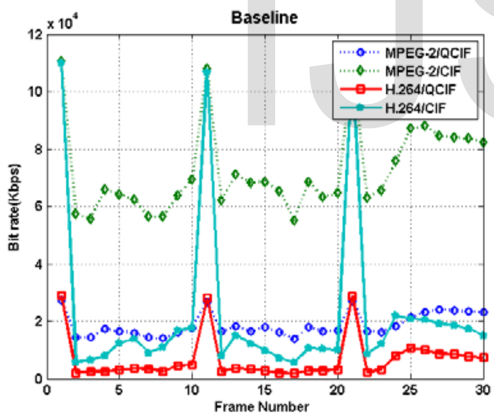
Table 3
Main profile performance at different GoP

Format	GoP	Video seq.	Y PSNR (dB)	Total Bit	Bit rate (Kbps)	CR
QCIF	1	Tennis	34.75	1062632	1062.6	17
	1	Akiyo	39.29	564808	564.81	32
	5	Tennis	34.03	354344	354.3	51
	5	Akiyo	38.94	128168	128.2	142
	10	Tennis	33.86	279912	279.9	65
	10	Akiyo	38.78	73480	73.5	248
	15	Tennis	33.675	259400	259.40	70
	15	Akiyo	38.55	58016	58	314
CIF	1	Tennis	35.27	3888904	3888.9	18
	1	Akiyo	40.75	1333464	1333.5	54
	5	Tennis	34.71	1205832	1205.8	60
	5	Akiyo	40.46	323752	323.8	225
	10	Tennis	34.58	885784	885.8	82
	10	Akiyo	40.28	195400	195.4	373
	15	Tennis	34.48	822608	822.6	88
	15	Akiyo	40.13	158112	158.1	461

The most important parameter that plays a massive role for rate control mechanism is the **quantization parameter (QP)**. The proposed system is executed using different quantization parameters (QP=1, 10, 20, 30, 40, and 50). Fig. 6 and Fig.7 show the comparison between H.264 under QP=20 and MPEG-2 under the standard scaling quantization matrix.
Fig. 6 shows the impact of QP on the PSNR (a) and encoded bitrate (b) for high motion details "tennis" video with QCIF and CIF formats under the baseline profile. For main profile fig. 7 shows the impact of QP length on the PSNR (a) and encoded bitrate (b) for the same video clip and formats.

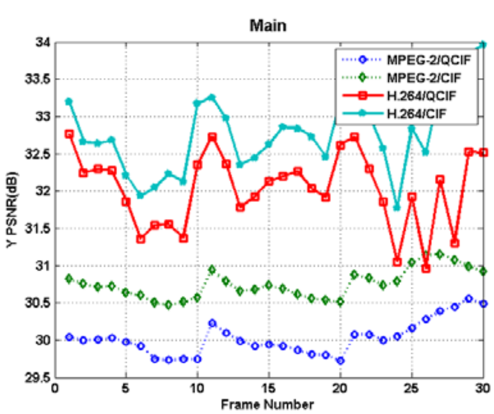


(a)

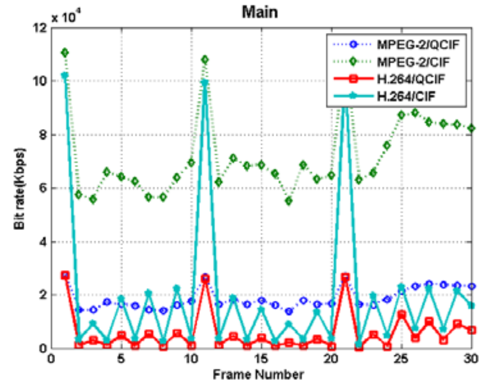


(b)

Fig. 6. Performance comparison for H.264 baseline profile and MPEG-2 standards: (a) PSNR (b) Bit per frame



(a)



(b)

Fig. 7. Performance comparison for H.264 main profile and MPEG-2: (a) PSNR (b) Bit per frame

Table 4 and table 5 present the compression performance for "tennis" and "akiyo" video clips at different quantization parameter values under baseline profile and main profile.

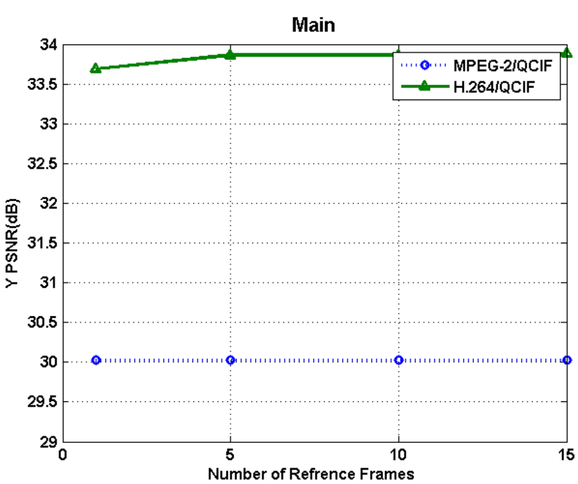
Table 4
H.264 baseline profile performance at different QP

Format	QP	Video seq.	Y PSNR (dB)	Total Bit Kb	Bit rate (Kbps)	CR
QCIF	1	Tennis	72.324	5051.1	5051.18	3
	1	Akiyo	68.847	1518.6	1518.66	12
	10	Tennis	51.898	2917	2917.02	6
	10	Akiyo	51.562	529.6	529.69	34
	20	Tennis	41.596	1092.9	1092.94	16
	20	Akiyo	44.533	171.4	171.4	106
	30	Tennis	31.883	205.8	205.82	88
	30	Akiyo	37.414	60.2	60.2	303
	40	Tennis	27.898	30	30.02	608
	40	Akiyo	30.738	24.4	24.46	747
	50	Tennis	24.309	12.7	12.73	1436
	50	Akiyo	25.141	11.3	11.26	1614
CIF	1	Tennis	69.91	18886.5	18886.5	3
	1	Akiyo	71.498	6653.8	6653.82	10
	10	Tennis	51.978	11209.1	11209.2	6
	10	Akiyo	52.189	2609.6	2609.64	27
	20	Tennis	41.934	3918.1	3918.1	18
	20	Akiyo	44.887	534.4	534.42	136
	30	Tennis	32.546	669.2	669.17	109
	30	Akiyo	39.092	156.9	156.92	465
	40	Tennis	27.534	94.2	94.27	774
	40	Akiyo	32.813	59	59	1237
	50	Tennis	25.194	34.2	34.19	2134
	50	Akiyo	26.802	24.9	24.97	2931

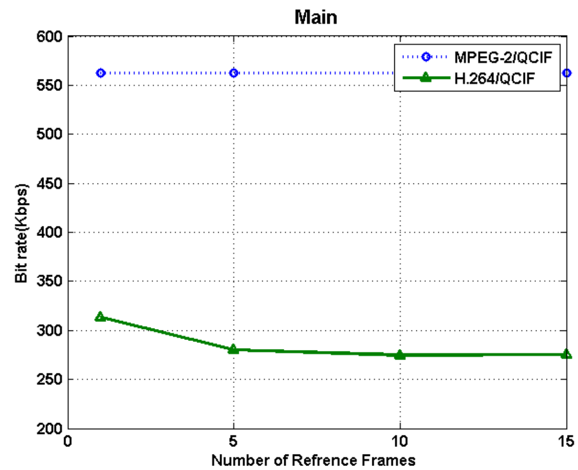
Table 5. H.264 main profile performance at different QP

Format	QP	Video seq.	Y PSNR (dB)	Total Bit (Kb)	Bit rate (Kbps)	CR
QCIF	1	Tennis	69.277	4834.1	4834.17	3
	1	Akiyo	67.863	1419.8	1419.83	12
	10	Tennis	51.825	2561.7	2561.77	7
	10	Akiyo	51.624	501.3	501.3	36
	20	Tennis	41.699	898.7	898.78	20
	20	Akiyo	44.666	167.7	167.78	108
	30	Tennis	32.03	175.8	175.86	103
	30	Akiyo	37.375	59.5	59.54	306
	40	Tennis	27.919	26.0	26.02	701
	40	Akiyo	30.729	21.9	21.99	833
	50	Tennis	24.471	10.8	10.82	1689
	50	Akiyo	25.164	10.3	10.32	1771
CIF	1	Tennis	69.838	18429.7	18429.7	3
	1	Akiyo	70.554	6159.0	6159.02	11
	10	Tennis	51.980	9956.1	9956.13	7
	10	Akiyo	52.152	2435.3	2435.3	29
	20	Tennis	41.888	3182.7	3182.78	22
	20	Akiyo	44.863	524.2	524.19	139
	30	Tennis	32.763	585.7	585.77	124
	30	Akiyo	38.95	152.7	152.77	478
	40	Tennis	27.58	77.7	77.76	939
	40	Akiyo	32.705	50.6	50.65	1442
	50	Tennis	25.232	26.2	26.2	2785
	50	Akiyo	26.744	19.8	19.89	3686

P-inter frame prediction process is achieved by making use of previous frames as a **reference frame** for prediction. H.264 encoding system is carried out at different reference frames for P-frame range (1, 5, 10, and15) under main profile only. The results is compared with MPEG-2 standard that configured only with one reference frame. Fig. 8 displays the performance for the tested scenario for H.264 main profile, in comparison with MPEG-2 compression standard.



(a)



(b)

Fig. 8. H264 Main profile performance for different reference frames number (a) PSNR, (b) Bit Rate

Table 6 summarizes the performance of H.264 main profile, for "tennis and akiyo" videos in QCIF and CIF formats at a different number of reference frames.

Table 6
Performance of H.264 main profile at different number of reference frames

Format	No. of Ref.	Video seq.	Y PSNR (dB)	Total Bits	Bit rate (Kbps)	CR
QCIF	1	Tennis	33.686	313160	313.16	58
	1	Akiyo	38.578	76584	76.58	238
	5	Tennis	33.865	279912	279.91	65
	5	Akiyo	38.779	73480	73.48	248
	10	Tennis	33.866	274688	274.69	66
	10	Akiyo	39.142	69272	69.27	263
	15	Tennis	33.883	275112	275.11	66
	15	Akiyo	39.142	69264	69.26	263
CIF	1	Tennis	34.317	1028728	1028.73	70
	1	Akiyo	40.339	183288	183.29	398
	5	Tennis	34.585	885784	885.78	82
	5	Akiyo	40.566	175888	175.89	414
	10	Tennis	34.604	866264	866.26	84
	10	Akiyo	40.564	175328	175.33	416
	15	Tennis	34.61	863344	863.34	84
	15	Akiyo	40.564	175160	175.16	416

The procedure of **MB dropping** is as follows:

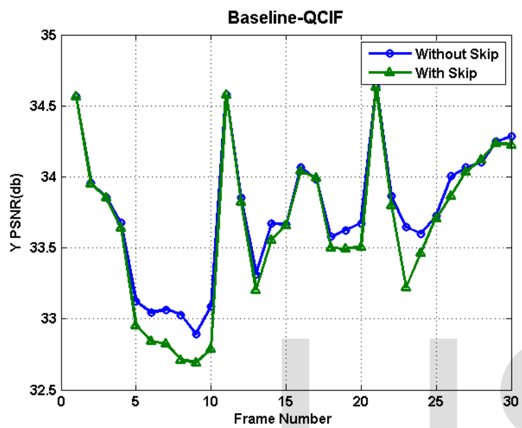
Step 1: Determine the similarity between the MB and previous one.

Step 2: If the current MB is very similar to the pervious MB, then it's dropped.

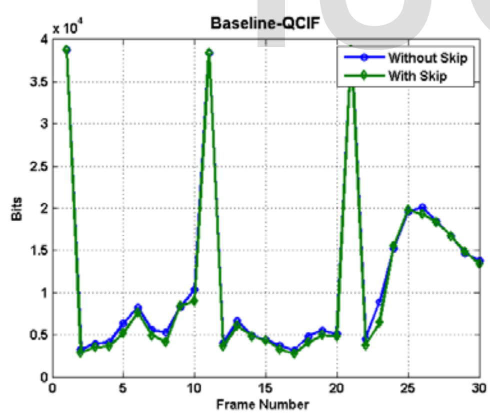
Step 3: The step 1 and 2 are repeated for all MBs in the frame.

This testing scenario consider two cases. First one encoding the system without using MB dropping the second case considers using it.

Fig. 9 and fig. 10 illustrate the effect of applying skip (drop) mode on the decoded frame quality and the number of encoded bits for two H.264 standard profiles (baseline and main).

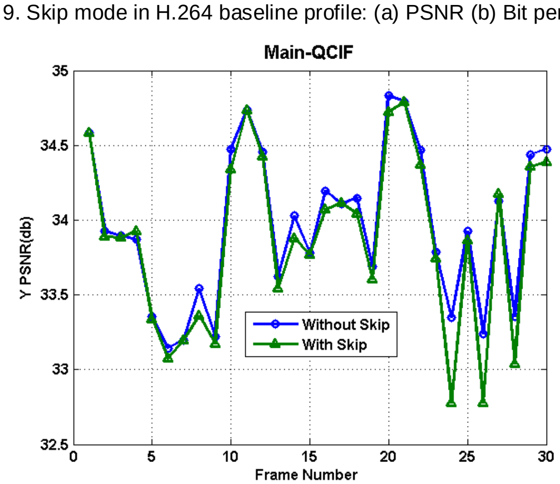


(a)

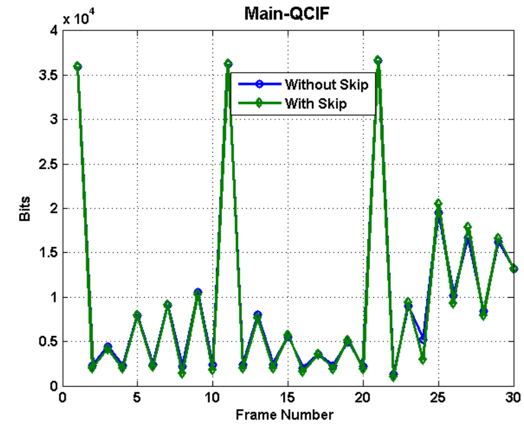


(b)

Fig. 9. Skip mode in H.264 baseline profile: (a) PSNR (b) Bit per frame



(a)



(b)

Fig. 10. Skip Mode in H.264 main profile: (a) PSNR (b) Bit per frame

Table7 for baseline profile, table 8 for main profile, compare the compression performance for two videos under without skip/with skip MB, for different video formats.

Table 7
H.264 baseline profile

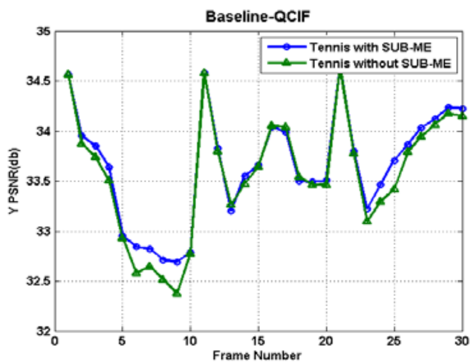
Format	Pred. Modes	Video seq.	Y PSNR (dB)	Total Bits	Bit rate (Kbps)	CR
QCIF	With	Tennis	33.65	332360	332.36	54
	With	Akiyo	38.811	73536	73.54	248
	Without	Tennis	33.749	345792	345.79	52
	Without	Akiyo	38.931	87040	87.04	209
CIF	With	Tennis	34.258	1025344	1025.3	71
	With	Akiyo	40.325	196280	196.28	371
	Without	Tennis	34.42	1088656	1088.7	67
	Without	Akiyo	40.482	251776	251.78	289

Table 8
H.264 main profile

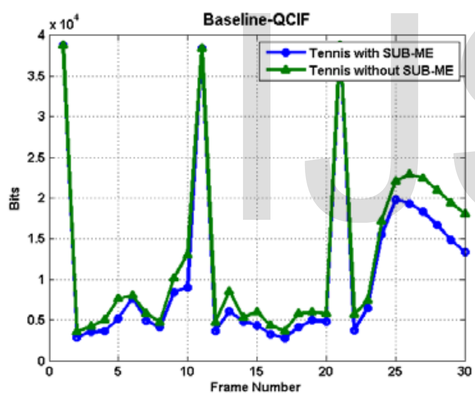
Format	Pred. Modes	Video seq.	Y PSNR (dB)	Total Bits (Kb)	Bit rate (Kbps)	CR
QCIF	With	Tennis	33.865	279.9	279.91	65
	With	Akiyo	39.133	69.3	69.34	263
	Without	Tennis	33.959	285.5	285.50	63
	Without	Akiyo	39.203	74.81	74.81	243
CIF	With	Tennis	34.585	885.8	885.78	82
	With	Akiyo	40.282	195.4	195.4	373
	Without	Tennis	34.671	928.6	928.66	78
	Without	Akiyo	40.671	196.7	196.77	371

ISSN 2229-5518

Fractional pixel motion estimation instead of full pixel resolution gives an optimal motion vector with high compression efficiency and good PSNR. This scenario considered two cases the first one of using fractional pixel resolution by implementing 1/4 pixel luma interpolation and 1/8 pixel chroma interpolation. The second case considered of using full pixel resolution instead of quadrature resolution. Fig. 11 and fig.12 show the effect of this technique on decoded video PSNR and bit rate of the encoded bit stream for the baseline profile and main profile.

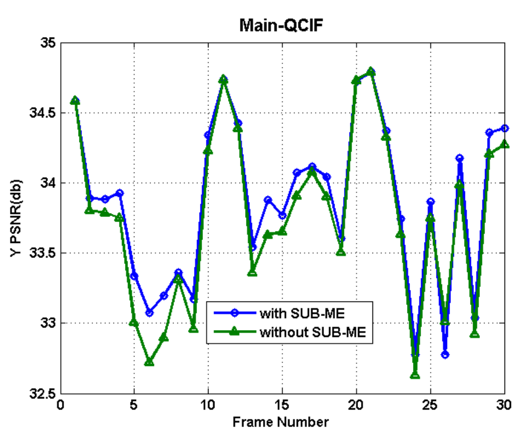


(a)

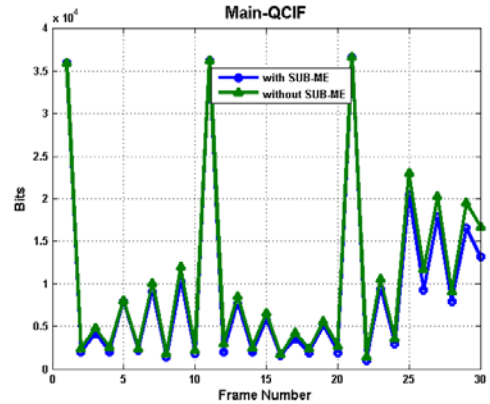


(b)

Fig. 11. Influence of Sub-Pixel Motion Estimation in H.264 baseline profile: (a) PSNR (b) Encoded bits per frame



(a)



(b)

Fig.12. Influence of Sub-Pixel Motion Estimation in H.264 main profile: (a) PSNR (b) Encoded bits per frame

Table 9 and 10 illustrate the results obtained with/without using sub-pixel motion estimation with both previously mentioned profiles.

Table 9
Influence of Sub-Pixel Motion Estimation in H.264 baseline profile

Format	Sub-pixel ME	Video seq.	Y PSNR (dB)	Total Bit (K)	Bit rate (Kbps)	CR
QCIF	With	Tennis	33.65	332.4	332.36	54
	With	Akiyo	38.811	73.5	73.54	248
	Without	Tennis	33.572	384.6	384.61	47
	Without	Akiyo	38.467	83.6	83.15	218
CIF	With	Tennis	34.258	1025.3	1025.3	71
	With	Akiyo	40.325	196.3	196.28	371
	Without	Tennis	34.088	1321.0	1321	55
	Without	Akiyo	39.988	235.6	235.66	309

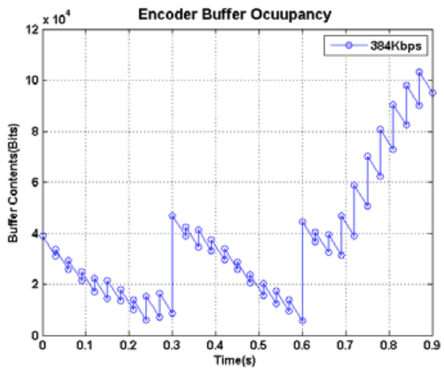
Table 10
Influence of Sub-Pixel Motion Estimation in H.264 main profile

Format	Sub-pixel ME	Video seq.	Y PSNR (dB)	Total Bit (K)	Bit rate (Kbps)	CR
QCIF	With	Tennis	33.865	279.9	279.91	65
	With	Akiyo	39.133	69.3	69.34	263
	Without	Tennis	33.75	307.9	307.94	59
	Without	Akiyo	38.779	73.5	73.48	248
CIF	With	Tennis	34.585	885.8	885.78	82
	With	Akiyo	40.282	195.4	195.4	373
	Without	Tennis	34.444	1071.4	1071.4	68
	Without	Akiyo	40.282	195.4	195.4	373

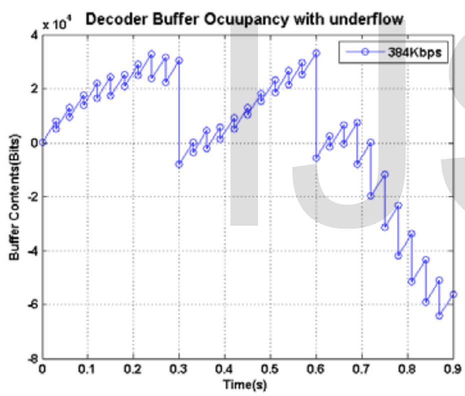
`**Buffering system** is designed at level 1.1 under 280 Kbps channel mobile bitrate with buffer size equal to 500

ISSN 2229-5518

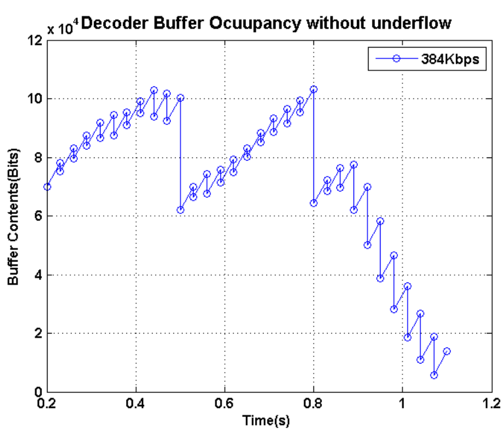
Kbits, results is illustrated for 30 frames at QP=28 and tested under 384 Kbps channel. At 30 fps, each frame has 0.03s interval time to remove from encoder side to the buffer and from buffer to decoder. Channel transmits and removes fixed bits equal to 9333 bits from the buffer in every frame period. Fig. 13 (a) shows the behavior of the encoder output buffer. Frame 0 is encoded and added to the buffer at time 0 and each subsequent frame is added at intervals of 0.03s. Fig. 13 (b) shows decoder behavior with buffer underflow, the problem is solved in fig. 13 (c) by adding initial removal delay equal to 0.2.



(a)



(b)



(c)

Figure 13. Buffer Occupancy (a) encoder (b) decoder with underflow (c) decoder without underflow

7 Conclusion

Most effected H.264 features can be configured to be used as a rate and quality control for the encoded video. The experimental results show that the encoded bit rate decreased with increasing the QP, that is due to quantization process that mapping a large set of values to smaller set values, so little bits are required to represent small quantized values. Increasing the number of reference frames from 1 to 15 (at fixed QP) in main profile leads to decrease the bitrate from 313.16 to 275.11 kbps with enhancement in decoded frame quality, this happens due to matching criteria between current block in the current frame and previous block in the N previous frames in the sequence, such matching leads to reduce a number of bits that needed to represent the current block in the current frame. Significant degradation in the bitrate from 345.79 to 336.32 kbps for baseline profile and from 285.50 to 279.91 for main profile when dealing with MB dropping. Fractional pixel motion estimation instead of full pixel resolution gives an optimal motion vector with good PSNR and high compression efficiency result in reduction in the bit rate from 332.36 to 384.61 kbps for baseline profile and form 307.94 to 279.91kbps for main profile.

Generally H.264 main profile provides lower bit rate due to the existence of B frames (bidirectional prediction) and efficient CABAC coding; it has less quality magnitude (PSNR) due to the existence of B-frames that has less decoded picture quality.

The overall compression performance of the H.264 is better compared to MPEG-2, result in PSNR gain about 4 dB, and bit rate saving for H.264 equal to 98% and 93% for MPEG-2, with compression ratio equals to70:1 for main-H.264, 58:1 for baseline-H.264 and 32:1 for MPEG-2.

8 References

[1] M. Jiang, "Adaptive Rate Control for Advanced Video," 2006.

[2] Q. Yun and H. Sun, "Image and Video Compression for multimedia engineering," *Potentials, IEEE*, 2000.

[3] Madhuri A. Joshi, Mehul S. Raval, Yogesh H. Dandawate, Kalyani R. Joshi, Shilpa P. Metkar, *Image and Video Compression Fundamentals, Techniques, and Applications*. 2015.

[4] K. N. Mamatha R., "Comparative Study of Video Compression Techniques-," *Int. J. Adv. Res. Comput. Sci. Softw. Eng. Res.*, vol. 4, no. 11, pp. 874–877, 2014.

[5] S. H. Bharathi, K. N. Raju, and S. Ramachandran, "Implementation of Intrapredictions , Transform , Quantization and CAVLC for H . 264 Video Encoder," vol. 4, no. 1, pp. 95–104, 2011.

[6] N. Manjanaik and R. Manjunath, "Selection of Intra Prediction Modes for Intra Frame Coding in Advanced Video Coding Standard," vol. 3, no. 2, pp. 192–196, 2013.

[7] T. Wiegand and G. J. Sullivan, "The H.264/AVC Video Coding Standard," *IEEE Signal Process. Mag.*, vol. 24, no. 2, pp. 148–153, 2007.