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Review of Multimedia Communication Quality Assessment Techniques

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Abstract

Communication pattern is drifting from conventional audio to multimedia applications, streaming live and on-demand digital video contents over telecommunications and broadcasting networks. Currently, some businesses deploy video in promoting products in a far more enriching, entertainment and informative approach than typical traditional audio would allow. However, users of multimedia applications are interested in paying for a good acceptable video quality. Thus, this paper reviews methods used in Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Metric (SSIM) and Video Quality Metric (VQM) with the objective of providing useful information to wireless video services providers in assessing and monitoring of quality of multimedia services delivered to users. Experimental comparison of PSNR, SSIM and VQM assessment methods to examine their performances in evaluation of multimedia applications has been performed. Comparing the quality performance of PSNR, SSIM and VQM metrics for Akiyo and Crew standard test sequences, it has been observed that the quality performance of the metrics improves when the bitrates allocation increase. For the test of consistency and quality performance of the metrics, observation shows that for a given bitrates of 3.84Mb/s, under CABA test configuration, Akiyo test sequence, experienced better quality performance of 46.63dB (PSNR), 99.10% (SSIM) and 11.00% (VQM) compared to lower quality performance of 36.18dB (PSNR), 90.40% (SSIM) and 22.00% (VQM) experienced by Crew test sequence. Experimental results of the media quality metrics for Akiyo and Crew standard test sequences with different temporal activity levels show that the quality performance of media content also depends on the temporal activity of the media content. The experimental results further show consistency in quality performance of PSNR, SSIM and VQM metrics for CABA and UBA test configurations. Thus, the objective metrics can be harnessed for evaluation of quality performance of multimedia applications at different channel conditions.

Keywords: Bitrates, multimedia communication, objective video quality systems, quality performance, temporal activity.

1.0 INTRODUCTION

Multimedia is a composite of video, text, sound, graphics, images and animation. A video sequence consists of a sequence of video frames or images. Video is the dominant component and mostly affected by channel errors. Video requires significant amount of resources for efficient communication. The two common methods for generating analogue video signals are progressive and interlaced scanning. Conversion of analogue video to digital signal involves filtering of noise (unwanted signal), transformation, sampling and quantization. Digital video is more tolerant to channel noise, flexible in editing and video processing than analogue video signal. Digital video applications are found in broadcasting, educational field and telecommunication fields. The generated video signal contains high bitrates, thus requires video coding to technically reduce the high bit rates without losing much quality such that it will be possible to efficiently transmit the video signal over communication networks without causing network congestion and delays. Transmission of raw video signal requires significant bandwidth, large storage facilities (servers) and large amount of transmit power resources, which may not be possible in reality to satisfy reasonable amount of video users in a resource-constrained system such as wireless channel.

Therefore video coding is necessary for representation of visual information with fewer bits (less bandwidth requirements) and efficient transmission. Video coding plays significant role in the world of multimedia communication where bandwidth and transmits resources are limited. A reversible process, decoding is employed at the decoder to reconstruct the compressed multimedia data. Various principles are employed to achieve multimedia coding such as exploiting human visual system, spatial and temporal redundancies. This paper reviews multimedia communication technology and quality assessment system by comparing the performances of Video Quality Metric (VQM), Structural Similarity Index Metric (SSIM) and Peak Signal to Noise Ratio (PSNR) quality assessment systems. Experimental tests were carried out to complement

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the conducted review. The experiments were performed using standard test multimedia samples, VQM, SSIM and PSNR softwares. The experimental results show that multimedia quality performance with PSNR, SSIM and VQM systems improves in the quality performance as the bitrates increases. The useful information obtained from the experiment can be useful in development of advanced multimedia networking system for quality assessment of multimedia applications.

2.0 REVIEW OF MULTIMEDIA CODING TECHNOLOGIES

International Telecommunication Union (ITU-T) and ISO/IEC Moving Picture Expert Group (MPEG) jointly developed and improved the video coding standards. The aim of the standardization is to facilitate global compatibility and internetworking of media contents. The Moving Picture Experts Group is a working Group of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). The Video Coding Expert Group (VCEG) is a working group of the International Telecommunications Union Telecommunication Standardization Sector (ITU-T). ITU-T develops/recommends standards for telecommunication. Subgroup 16 of ITU-T is responsible for standards related to video multimedia services, systems, terminals, video communication over telecommunication networks and computer network. MPEG-1 was standardized in 1993, it focused on compression, storage and retrieval of multimedia information on compact disc. In 1994, MPEG-2 was standardized; it is designed for compression of video signal for television broadcasting applications. Progressive developments evolve H.264/Advanced Video Coding (H.264/AVC) which was standardized in 2004. High Efficient Coding Standard (HEVC), H.265 video coding standard [1] is one of the video coding standards from ITU. Its advantages include good compression performance and provision of a "network-friendly" video representation for storage, video streaming, terrestrial broadcasting and satellite broadcasting applications [2-4]. Versatile Video Coding (VVC), H.266, supports a wide range of applications including features to support computer-generated screen content. H.266 yields coding gain of over 35% bit-rate reduction compared to its predecessor H.265 [5, 6]. Video creates much impact in the field of communication because it carries the visual and action parts of information which the users find it more interesting. Video communication involves capturing of natural scene by video camera, encoding and transmission processes. The encoding block performs the function of video compression by exploiting redundancies in video sequence and application of various algorithms to enhance robustness of the media streams. The robustness of compressed media stream over noisy channel such as wireless channel is affected by the dynamic characteristics of the transmission channel and high channel bit error rate [7, 8]. It is possible to mitigate the impact of channel errors when the resources are unlimited, for example by applying lower channel coding rate and robust modulation scheme. However, such situation (unlimited resources) hardly exists in wireless system. When a compressed multimedia stream is transmitted over wireless channel, it is susceptible to the impact of channel errors which result in poor received quality performance.

2.1 Multimedia Quality Assessment

Communication trend has shifted from predominantly audio to video inclusion. Digital video communication applications include, videoconferencing, digital video streaming over the internet, Video on-Demand (VoD), Internet Protocol Television (IPTV) and digital video content over wireless channels and broadcasting networks. The wireless channels have limited capacity to guarantee acceptable video quality due large bandwidth requirements. Factors affecting received video quality performance include source compression algorithm, viewing condition, receiving device, artifacts and transmission errors. Video transmission errors, commonly experience in wireless networks introduce artifacts into a video signal and packet losses which result in poor received video quality degradation. A large number of businesses now employ video in promoting products in a far more enriching, entertainment and informative approach than typical audio would allow. However, viewers are interested in paying for a good acceptable video quality. This research work reviews performance of widely used video quality metric systems to provide insight on the challenge facing video vendors and wireless video services providers in assessing quality of multimedia services delivered to viewers. The two methods widely applied in assessment of multimedia quality performance are the objective and subjective approaches. Subjective method involves evaluation of multimedia quality by group of experts. The viewers watch and rate quality of a set of video sequence. Results of subjective measurements for each video sequence are expressed in mean opinion score given as an average for all observers. The International Telecommunications Union recommendation approach for subjective video quality assessment are available in the literature [9]. However, the subjective quality assessment experiments are time consuming since it requires a group of experts to participate in the video quality assessment, expensive and unsuitable for real-time applications. Alternatively, it is significant to employ objective video quality metric in the video quality performance. Objective video quality assessment is a statistical approach for evaluating the quality of digital video performance. It is cost and time effective, more reliable in terms of consistency, flexibility and capability of carrying out repetitive assessments at ease compared with subjective assessments. One of the most popular objective digital video measurement methods is the Peak Signal-to-Noise Ratio.

2.2 Peak Signal-to-Noise-Ratio

Peak Signal-to-Noise Ratio (PSNR) measures video quality by correlating the maximum possible value of the luminance and the mean squared error (MSE). Peak-Signal-to-Noise Ratio (PSNR) video quality performance assessment is obtained by comparing the reference and the degraded video signal, objectively. The average PSNR values across the video signal is recorded. Practically, PSNR [10] can be calculated using equation (1) and (2):

$$PSNR_{dB} = 20.log_{10}\left(\frac{2^X - 1}{\sqrt{MSE}}\right) \quad (1)$$

$$MSE = \frac{\sum_{i=1}^{M} \sum_{i=1}^{N}[A(i,j) - B(i,j)]^2}{\mathrm{M.N}} \quad (2)$$

where A(i,j) and B(i,j) are the values of the original and reconstructed pixels. *M* and *N* represent the frame resolution (height and width), while ***X*** represents the number of bits in the picture (for e.g. an 8-bit resolution = $2^8 - 1 = 255$). The overall video quality performance is obtained by averaging the PSNR values throughout the video sequence. Higher PSNR values indicate better quality.

2.3 Structural Similarity Index Metric

Structural Similarity Index Metric (SSIM) is objective metric system for measuring received multimedia quality performance. SSIM concept is based on the fact that Human Visual System is highly adapted for extracting structural information from a scene. SSIM exploits important perceptual factors including luminance, contrast and structural information in the metric system. The system measures signals information in terms of luminance, contrast and structural perspectives. The three components produce an overall similarity weigh [11];

$$S(a,b) = f\{L(a,b), C(a,b), S(a,b)\} \quad (3)$$

where, L(a,b), C(a,b) and S(a,b) represent the Luminance, Contrast and Structural components respectively. The luminance comparison is defined by:

$$L(a,b) = \frac{2\mu_a\mu_b + C_1}{\mu_a^2 + \mu_b^2 + C_1} \quad (4)$$

where μ_a and μ_b are the mean intensities of ***a*** and ***b*** representing pixels in the original and test samples. The constant $\boldsymbol{C_1}$ is expressed as:

$$C_1 = (K_1 L)^2 \quad (5)$$

where $\boldsymbol{K_1}$ = 0.01 and ***L*** represents the dynamic range of the pixels values, given by;

$$L = (x^2 - 1) \quad (6)$$

The contrast comparison is defined by:

$$C(a,b) = \frac{2\sigma_a\sigma_b + C_2}{\sigma_a^2 + \sigma_b^2 + C_2} \quad (7)$$

where the parameters σ_a and σ_b are the variance of ***a*** and variance of ***b***. The constant C_2 is given by:

$$C_2 = (K_2 L)^2 \quad and \quad K_2 = 0.03 \quad (8)$$

The structural comparison is computed after luminance subtraction and variance normalization, defined by:

$$S(a,b) = \frac{\sigma_{ab} + C_3}{\sigma_a\sigma_b + C_3} \quad (9)$$

Where σ_{ab} is the covariance of ***a*** and ***b***, respectively.
The combination of luminance, contrast and structural comparisons of equations (4), (7) and (9) form the Structural Similarity (SSIM) index between signals ***a*** and ***b***:

$$SSIM(a,b) = [L(a,b)]^{\propto} \times [C(a,b)]^{\beta} \times [L(a,b)]^{\gamma} \quad (10)$$

Where $\alpha > 0$, $\beta > 0$ and $\gamma > 0$ are modifying parameters for luminance, contrast and structural components. For simplified expression, $\alpha = \beta = \gamma = 1$ and $C_3 = C_2/2$. Thus, SSIM index can be simplified:

$$SSIM\,(a,b) = \frac{(2\mu_a\mu_b + C_1)(2\sigma_{ab} + C_2)}{(\mu_a^2 + \mu_b^2 + C_1)(\sigma_a^2 + \sigma_b^2 + C_2)} \quad (11)$$

In this research, the average mean value of the SSIM estimation across the test video sequence is used in the evaluation of the overall test video quality performance. More details on SSIM are found in the literature [12, 13].

2.4 *Video Quality Metric*

Video Quality Metric (VQM) is another objective tools for measurement of video quality performance. It measures the perceptual effects of multimedia impairments and combines them into a single metric, which forms a strong correlation with the subjective opinion score. VQM uses the full-frame technique which is based on the full availability of the reference information. VQM scores computation involves extraction of the perceptual features, computing video quality parameters and combining these features to give the overall system. More details about the VQM system and calculation process can be found in [14]. VQM calibration mechanisms consist of a complete automated objective video quality measurement system as presented in Figure 1.

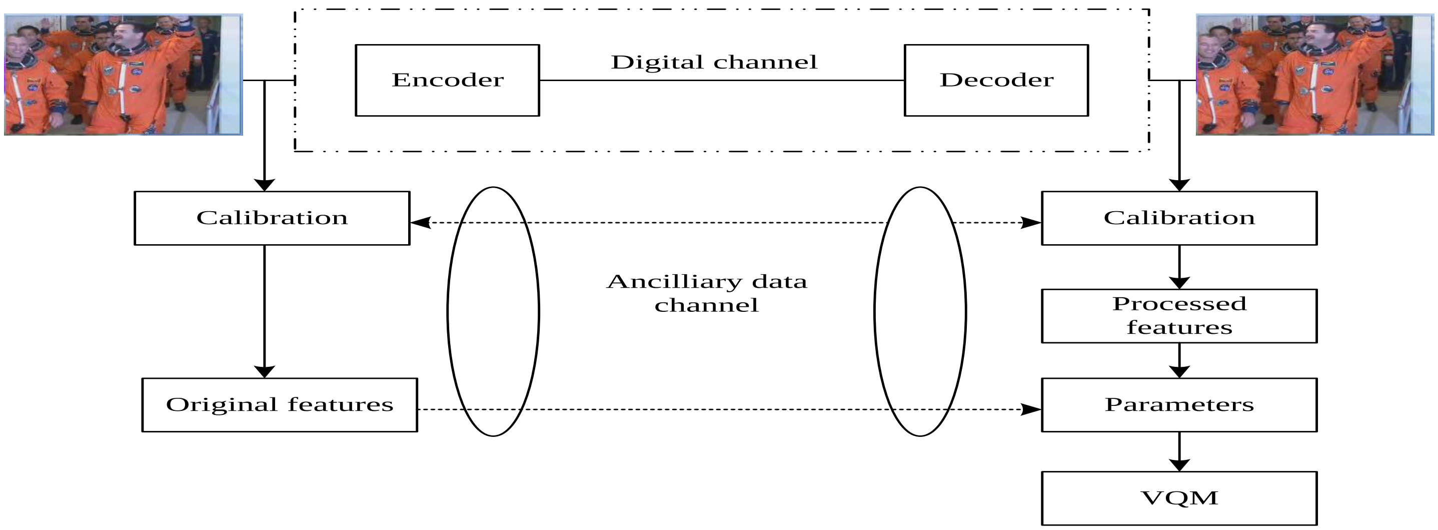

Figure 1: Block diagram of VQM

The ancillary data channel in VQM system is used in transmission of calibration information and the extracted quality features. Feature in this context include the quantity of information extracted from a spatial-temporal sub-region of media stream. The features are function of space and time that characterize perceptual changes in the spatial, temporal and chrominance properties of multimedia signal. In VQM, the level of distortions in multimedia signal due to gains and losses in the feature values are calculated by comparing features extraction from the calibrated processed multimedia sequence with features extracted from the reference multimedia sequence. The differential of the comparison depicts perceptual change in multimedia quality. The magnitude of impairment in VQM scale ranges from 0 to 10, where 0 represents the best and 10 represents the worse quality performance level. More details on VQM are available in the literature [15].

2.5 *Experimental Set-up*

The experimental set up to study the performance of PSNR, SSIM and VQM objective multimedia metric systems has been performed. The Crew and Akiyo standard test sequence samples are used in the experiment. The test sequence are in YUV format (4:2:0), Common Intermediate Format (CIF) of 352x288 resolution with 30fps, made of 300 frames. The choice of the test samples is done to observe the metrics performance across wide video samples with different temporal activity. The temporal analysis of the test sequence samples were evaluated using media motion characteristic algorithm, discussed in [16]. H.264AVC software was used in the encoding of the test sequence samples used in this research work. The channel simulations were performance using error traces which models wireless channel. The simulations were performed at various bitrates configuration, 1.92Mbs, 3.84Mbs, 5.76Mbs and 7.68Mbs respectively, representing different network conditions to facilitate better quality performance analysis. The modulation configuration include Quadrature Amplitude Modulation (16QAM) scheme with 1/2 code rate. The channel simulation were performed to examine the impact of transmission errors on quality performance of multimedia applications over wireless channel. At the receiving end, the decoder reconstructs the compressed test mediastream in appropriate order. The header information is decoded first in the decoded test mediastream, followed by reconstruction frame identical to the original predicted frame generated in the encoder. The predicted frame is then added to the relative difference to create approximate replica of the original frame. In case of losses, error concealment algorithm [17] is applied to conceal the lost data by predicting and reconstructing a lost data from the previously decoded information. The experimental setting is presented in Figure 2.

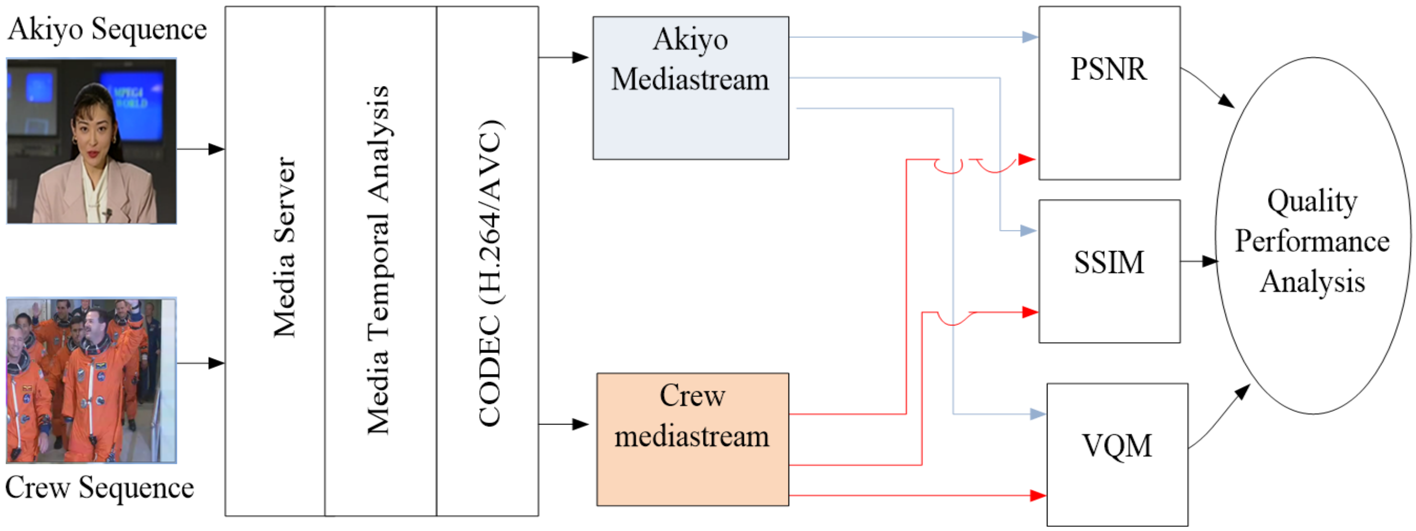

Figure 2: Experimental setting

The experimental set up is presented in Figure 2. The two test sequence samples, Akiyo and Crew are stored in the media server. The temporal analysis estimate the temporal activity of the test sequence samples. H.264/AVC reference software version 15.1 [18] is used for encoding and decoding of the test media samples. The quality performance of the mediastreams are analyzed using the PSNR, SSIM and VQM tools. Calibration process of the PSNR, SSIM and VQM comprise of an automated objective video quality measurement system. VQM calibration process of the original and encoded multimedia streams includes spatial alignment, temporal alignment, and valid region estimation. The spatial alignment processes horizontal and vertical spatial shift of the processed video relative to the original video. The ancillary data channel of the VQM system is used to transmit calibration information as well as the extracted quality features. Feature in this context is defined as quantity of information extracted from a spatial-temporal sub-region of media stream. The features are function of space and time that characterize perceptual changes in the spatial, temporal and chrominance properties of media streams. Quality parameters that measures distortions in video quality due to gains and losses in the feature values are calculated by comparing features extracted from the calibrated processed media stream with features extracted from the original media stream. The differential of the comparison depicts perceptual change in multimedia quality. The magnitude of impairment in VQM scale ranges from 0 to 100, where 0 represents the best and 100 represents the worse quality level. SSIM and PSNR scales also range between 0 and 100, but the higher the SSIM and PSNR values the better the quality performance.

3.0 RESULTS AND DISCUSSION

The results obtained from the quality assessment tools, PSNR, SSIM and VQM were analyzed for performance evaluation. The temporal analysis of the test sequence samples classified Akiyo as low temporal activity level and Crew as high temporal activity level test sequence. Based on the comparative analysis, PSNR is cost effective, time efficient, flexible, capable of carrying out repetitive assessments at ease, less complex in the calculation and widely employed for objective video quality assessment compared to SSIM and VQM. Two different encoding experimental scenarios, UBA and CABA were applied for the experiment. For UBA, encoder configuration include fixed bitrates allocation while in CABA setting, bitrates were distributed based on temporal activity level of the test sequences. The experiments were repeated at different channel conditions of 1.92Mb/s, 3.84Mb/s, 5.76Mb/s and 7.68Mb/s for effective evaluation and assessment of consistency of the quality performance systems. Figure 3, presents PSNR quality performance for Akiyo test sequence.

Figure 3, present a plot of PSNR values against bitrates BW(Mb/s) for Akiyo test sequence sample. Consistent quality evaluation performance by PSNR has been observed for the UBA and CABA test scenarios at different bitrates allocation. It has been observed that at the bitrates allocation of 1.92Mb/s, the corresponding PSNR values for UBA and CABA test scenarios are 46.62dB and 45.83dB respectively. It has been further observed that as the bitrates improve from 1.92Mb/s to 3.84Mb/s, the corresponding PSNR values for Akiyo sequence for UBA and CABA test scenarios also increase from 46.62dB and

45.83dB to 48.70dB and 46.63dB respectively as presented in Figure 3. Figure 4, presents SSIM quality performance for Akiyo test sequence.

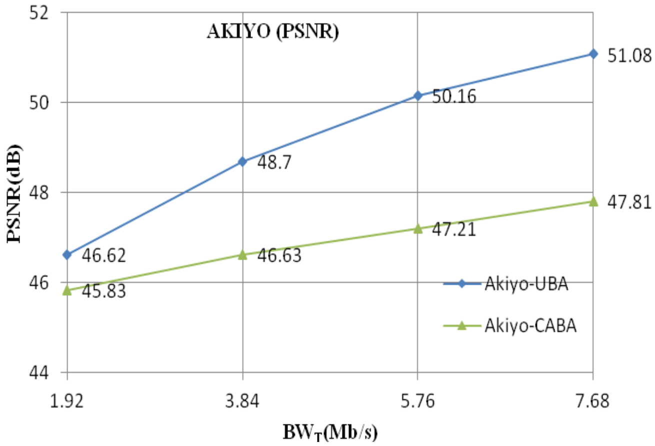

Figure 3: PSNR quality performance for Akiyo test sequence

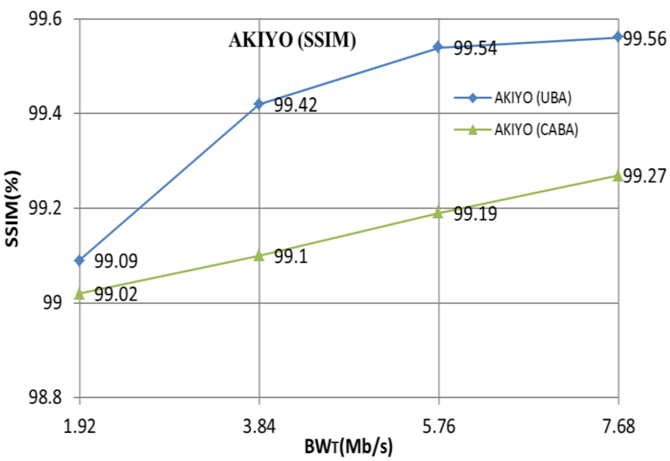

Figure 4: SSIM quality performance for Akiyo test sequence

Figure 4, presents the test results obtained from SSIM quality assessment metric for UBA and CABA test scenarios. It has been observed that at bitrates allocation of 1.92Mb/s, the corresponding SSIM values for UBA and CABA test scenarios are 99.09% and 99.02% respectively. It has been further observed that as the bitrates increase from 1.92Mb/s to 3.84Mb/s, the corresponding SSIM values for Akiyo test sequence for UBA and CABA test scenarios also increase from 99.09% and 99.02% to 99.42% and 99.10% respectively as presented in Figure 4. Consistence performance has also been observed from the results obtained from SSIM quality assessment tool. Figure 5, presents VQM quality performance for Akiyo test sequence.

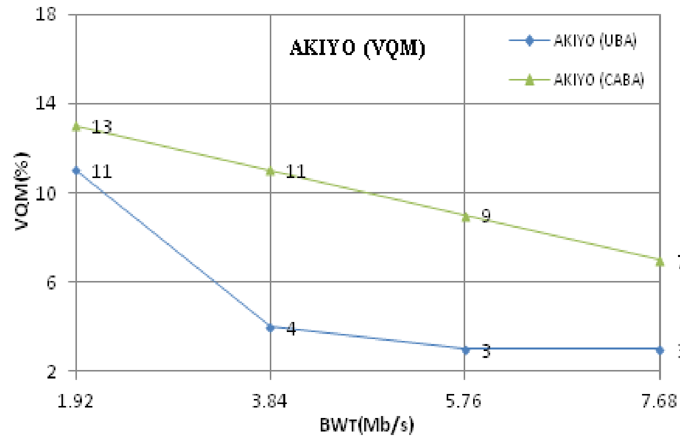

Figure 5: VQM quality performance for Akiyo test sequence

Test results obtained from VQM quality assessment system is presented in Figure 5. The magnitude of impairment in VQM scale ranges from 0 to 100 (%), where 0 represents the best and 100 represents the worse quality performance. For the test of consistency of VQM system, analysis were carried out by comparing the results obtained at different test scenarios. From Figure 5, at the bitrates of 3.84Mb/s, the VQM quality performance for Akiyo test sequence for UBA and CABA test scenarios are 11.00% and 4.00%. At the increment of the bitrates from 3.84Mb/s to 5.76Mb/s, the corresponding VQM results for UBA and CABA also improve from 11.00% and 4.00% to 9.00% and 3.00% respectively (lower value of VQM indicates better). The average quality performance analysis of PSNR, SSIM and VQM for Akiyo test video sequence is presented in Table 1.

Table 1: Average quality performance of PSNR, SSIM and VQM for Akiyo test sequence

Bitrates (Mb/s)	PSNR (dB)		SSIM (%)		VQM (%)	
	CABA	UBA	CABA	UBA	CABA	UBA
1.92	45.83	46.62	99.02	99.09	13.00	11.00
3.84	46.63	48.70	99.10	99.42	11.00	4.00
5.76	47.21	50.16	99.19	99.54	9.00	3.00
7.68	47.81	51.08	99.27	99.56	7.00	3.00

Table 1, shows the average quality performance of PSNR, SSIM and VQM results for Akiyo test sequence. The PSNR, SSIM and VQM have demonstrated consistence quality performance across the CABA and UBA test scenarios. It has also been depicted that as the bitrates increase the quality performance also improves correspondingly. For better analysis, the quality performance of the PSNR, SSIM and VQM systems were also verified using Crew test sequence. Figure 6, present the PSNR, quality performance for Crew test sequence.

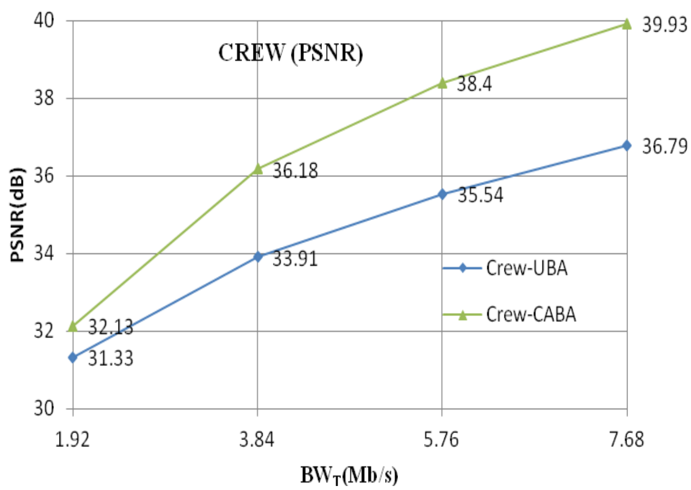

Figure 6: PSNR Quality performance for Crew test sequence

Figure 6, shows PSNR quality performance for Crew test sequence. Comparing the results, it is observed that CABA outperformed that UBA in terms of average PSNR value across different bitrates allocation. For example, with the bitrates of 1.92Mb/s, the PSNR results for CABA and UBA are 32.13dB and 31.33dB. When the bitrates was increased to 5.76Mb/s, the corresponding results increased to 38.40dB and 35.54dB for CABA and UBA test configurations. Figure 7 presents test results of SSIM test sequence.

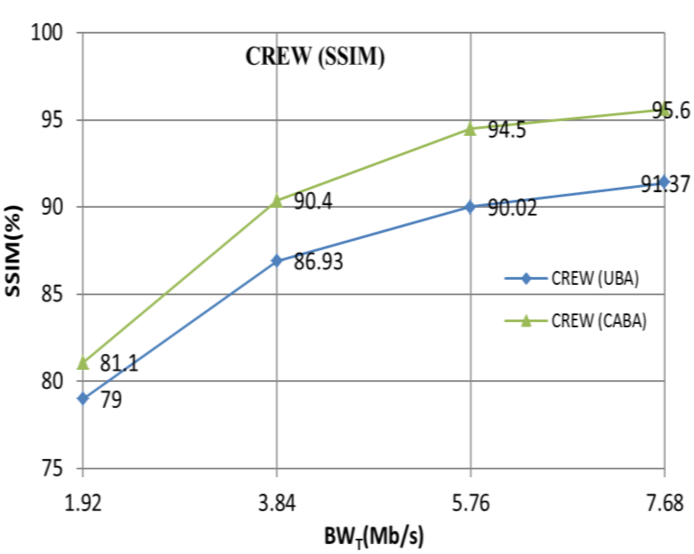

Figure 7: SSIM Quality performance for Crew test sequence

Figure 7, presents SSIM quality performance for Crew test sequence. Observation shows that at 3.84Mb/s bitrates configuration, the CABA and UBA test scenarios recorded SSIM values of 90.40% and 86.93% respectively. Also, as the bitrates increase from 3.84Mb/s to 5.76Mb/s, the corresponding SSIM values also improve from 90.40% and 86.93% to 94.50% and 90.02% for CABA and UBA test scenarios. Figure 8, shows VQM quality performance for Crew test sequence.

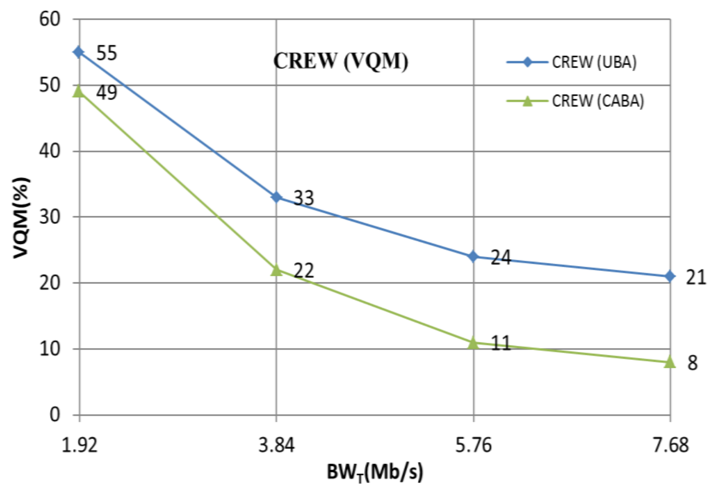

Figure 8: **VQM Quality performance for Crew test sequence**

The consistency of VQM has also been observed in the quality performance for Crew test sequence as presented in Figure 8. The quality of the Crew test sequence increase as the bitrates allocation improve. Comparing the results at 3.84Mb/s bitrates allocation, it is observed that VQM results for CABA and UBA test scenarios are 22.00% and 33.00%. At the increment of the bitrates from 3.84Mb/s to 5.76Mb/s the corresponding VQM results increase from 22.00% and 33.00% to 11.00% and 24.00% respectively for CABA and UBA test scenarios. Table 2, present further analysis to examine consistency of PSNR, SSIM and VQM quality assessment systems for Crew test sequence.

Table 2, shows summary of quality performance of PSNR, SSIM and VQM for Crew test sequence. The comparative analysis has shown as the bitrates increase the corresponding values for PSNR and SSIM quality performance also increase, indicating enhancement in quality performance. For the case of VQM lower value indicates better quality performance while higher VQM value indicates lower poor quality performance shown in Table 2. Generally, it is observed that as the bitrates increase the corresponding quality performance increase as well in similar pattern across PSNR, SSIM and VQM. It has been observed that under similar test condition of 5.76Mb/s fixed bitrates, Akiyo test sequence, experienced better quality performance of 47.21dB (PSNR), 99.19% (SSIM) and 9.00(VQM) compared to lower quality performance of 38.40dB (PSNR), 94.50% (SSIM) and 12.00% (VQM) experienced by Crew test sequence. The improvement in quality performance of Akiyo test sequence compared to Crew test sequence is as a result of low temporal activity level in Akiyo test sequence compared to high temporal activity level in Crew test sequence.

Table 2: Average quality performance of PSNR, SSIM and VQM for Crew test sequence

Bitrates (Mb/s)	PSNR (dB)		SSIM (%)		VQM(%)	
	CABA	UBA	CABA	UBA	CABA	UBA
1.92	32.13	31.33	81.10	79.00	49.00	55.00
3.84	36.18	33.91	90.40	86.93	22.00	33.00
5.76	38.40	35.54	94.50	90.02	12.00	24.00
7.68	39.93	36.79	95.60	91.37	8.00	21.00

4.0 CONCLUSION

In this research, performance of the popular media quality assessment metrics, PSNR, SSIM and VQM systems have been reviewed. Experiments have been performed to examine the consistency and performance of these metrics in assessing quality of media applications. The scope of quality performance analysis of the metrics falls within the freely available Akiyo and Crew standard test sequences, representing contents with low and high temporal activity levels. For the test of consistency and quality performance of the metrics, Table 1 and Table 2 were examined. Observation shows that for a given bitrates of 3.84Mb/s, under CABA test configuration, Akiyo test sequence, experienced better quality performance of 46.63dB (PSNR), 99.10% (SSIM) and 11.00 (VQM) compared to lower quality performance of 36.18dB (PSNR), 90.40% (SSIM) and 22.00% (VQM) experienced by Crew test sequence. The lower quality performance for Crew test sequence is as a result of high temporal activity level compared to Akiyo with low temporal activity level. Thus, high temporal activity media content requires significant higher bitrates to achieve similar quality level with low temporal activity media contents. The insights gained in this research can be harnessed towards providing solution to the challenges facing wireless media services providers in assessing and monitoring of quality of multimedia services for improved wireless multimedia communication experience.

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