Submitted to IGI Global for publication on BOOK: "** Multimedia Services and Streaming for Mobile Devices: Challenges and Innovations* **" © Elsa Mª Macías and Alvaro Suarez. August, 20, 2010

Recent Advances and Challenges in Wireless QoE-aware Multimedia Streaming Systems

Rosinei Oliveira[1], Elisangela Aguiar[2], Paulo Bezerra[2], Allan Costa[2], Eduardo Cerqueira[2], Ádamo L. Santana[1], João C. W. A. Costa[1], Carlos. R. L. Frances[1] and Antônio J. G. Abelém[2]

[1]Laboratory of High Performance Networks Planning (LPRAD)
Faculty of Electronic Engineering, Federal University of Pará - PPGEE
Augusto Corrêa Avenue, 01, Belém, Brazil
Building of the Laboratory of Electrical Engineering, Room 26
Phone: +55 913201 8112 Fax: +55 91 3201-7740

[3]Research Group on Computer Networks and Multimedia Communications (GERCOM)
Faculty of Computing, Federal University of Pará – PPGEE / PPGCC
Augusto Corrêa Avenue, 01, Belém, Brazil
Building of the Institute of Natural and Exact Sciences.
Phone: +55 91 3201-8000 Extension: 2101

E-mail: {nei, eaguiar, paulohgb, allan, cerqueira, adamo, jweyl, rfrances, abelem}@ufpa.br

ABSTRACT

It is expected that multimedia applications will be the most abundant application in the Internet and thousands of new wireless and mobile users will produce and share multimedia streaming content ubiquitously. In this multimedia-aware system, it is important to assure the end-to-end quality level support for video and voice applications in wireless systems. Traditional Quality of Service (QoS) techniques assure the delivery of those services with packet differentiation assurance and indicate the impact of multimedia traffic only on the network performance, however, they do not reflect the user's perception. Recent advances in multimedia are exploring new Quality of Experience (QoE) approaches and including metrics and control schemes in wireless networking systems in order to increase the user´s satisfaction and optimize network resources. QoE-based operations can be used as an indicator of how a networking environment meets the end-user's needs and new assessment and packet control approaches are still important challenges. This chapter presents an overview of the most recent advances and challenges in assessment and traffic conditioner procedures for wireless multimedia streaming systems. In addition, an intelligent packet dropper mechanism for IEEE 802.11e systems is proposed and evaluated by using the Network Simulator 2 (NS2) and Evalvid Tool.

KEYWORDS

Quality of Service, Quality of Experience, Multimedia Streaming, Wireless System

1 INTRODUCTION

Recently, advances in multimedia and mobile communications have emerged to offer a novel and comfortable living style for users. In this context, the delivery of multimedia content, such as video streaming, anytime, anywhere and with an end-to-end quality level support is a key requirement. This fact explains the increase of wireless networking standards, such as the Institute of Electrical and Electronics Engineers 802.11 and 802.16 ([IEEE] 802.11, & [IEEE] 802.16, 2010), as well as the emerging new multimedia streaming applications.

With respect wireless systems, the IEEE 802.11 standard provides communication coverage limited to an area of 100m and can also operate in mesh mode, 802.11s (Akyildiz, & Wang, 2005), to increase the coverage area. The IEEE 802.16 was designed to work in outdoor scenarios, with a range of up to 50km and rates of up to 75Mbps for architectures fixed (802.16d), and coverage of up to 4km and bandwidth up to 15Mbps for mobile devices (802.16e). The wireless facility can allow the ubiquitous access of multimedia content with low operational cost. It is expected that video-based services will account for 50 percent of all consumer network traffic in 2012 and 80 percent in 2020.

In order to keep and attract customers, wireless operators must also provide quality level assurance for multimedia applications in order to maximize the user's satisfaction and the usage of network resources, while increasing the profits of network providers. However, wireless and multimedia-aware Quality of Service (QoS) assessment and management schemes must be implemented to fulfill such important requirement.

To cope with QoS issues in Wireless Local Area Network (WLANs), the IEEE 802.11e working group was created, where the draft version brought new Media Access Control (MAC) improvements incorporated in the IEEE 802.11 standard (IEEE 802.11e, 2010). To provide QoS assurance, eight User Priorities (UPs) were defined. Each packet is assigned to an UP and mapped to an Access Category (AC). Each AC is directly mapped to a queue, where several queues have different priorities, and applications are assigned to them according to requirements, policies, content, among other parameters.

In the case of broadband access in Wireless Metropolitan Area Network (WMAN), the Worldwide Interoperability for Microwave Access (WiMAX) system, aIEEE802.16 standardized architecture for all-IP networks, is the most attractive solution to last mile connectivity to Internet with quality level assurance. The WiMAX system provides differentiated levels of QoS for multimedia applications, based on the combination of a set of communication service classes, supported in both wired IP-based and wireless IEEE 802.16-based links. In the former, network elements with standard IP QoS models, such as Differentiated Services (DiffServ), can be configured to guarantee QoS support for sessions crossing wired links. In the latter, several IEEE 802.16 QoS services are defined to provide packet differentiation in the wireless interface (Andrews, Ghosh, &Muhamed, 2007).

As presented above, the current wired and wireless techniques that aim to maximize the quality level of multimedia services in a networking system are focused only on Quality of Service (QoS) aspects. QoS-based schemes define a set of network level (and packet level) measurement and control operations to guarantee the distribution of multimedia content over heterogeneous networks with an acceptable quality level (Zapter, &Bressan, 2007).

Existing QoS metrics, such as packet loss rate, packet delay rate and throughput, are typically used to indicate the impact on multimedia streaming quality level from the network's point of view, but do not reflect the user's experience. Consequently, these QoS parameters fail in capturing subjective aspects associated with human perception (Perkis, Munkeby, &Hillestad, 2006).

In order to overcome the limitations of current QoS-aware multimedia networking schemes respect to human perception and subjective-related aspects, recent advances in multimedia-aware system, named Quality of Experience (QoE) approaches, have been introduced (Takahashi, Hands, &Barriac, 2008). Hence, new challenges in emerging networks involve the study, the creation and the validation of QoE measurements and optimization mechanisms to improve the overall quality level of multimedia streaming content and the usage of scarce wireless network resources (Mu, Cerqueira, Boavida, &Mauthe, 2009).

The QoE applicability scenarios, requirements, evaluations and assessment methodologies in multimedia systems have been investigated by several researches and working groups, such as International Telecommunication Union – Telecommunication Standardization Sector ([ITU-T],2010), (Video Quality Experts Group [VQEG],2010) and (European Technical Committee for Speech, Transmission, Planning and Quality of Service [ETSI STQ], 2010).

In the emerging future multimedia networks, QoE assessment solutions and metrics are needed to measure the performance of multimedia streaming applications with human-based precision. Currently, there are subjective and objective measurement approaches to evaluate the quality level of multimedia content from the user´s point of view. Additionally, new network and application-sensitive mechanisms are required to optimize network resources and increase the end-to-end quality level of multimedia streaming. The results of QoE investigations can be used as an extension to the traditional QoS schemes, in the sense that QoE provides information regarding the delivered multimedia service from the user's point of view. Examples of control mechanisms that will be included in QoE support in wired and wireless systems are new routing approaches, base station selection process and traffic conditioners.

In this chapter, an overview of the most recent advances and challenges in wireless multimedia streaming systems, with focus on QoE measurements and packet control proposals will be addressed. In order to demonstrate the benefits and efficiency of QoE solutions on controlling the quality level of multimedia streaming, simulation experiments were carried out, by using the Network Simulator 2 ([NS2], 2010) and the Video Quality Evaluation Tool-set Evalvid (Klaue, J., Rathke, B., &Wolisz, 2003), verifying Peak Signal-to-Noise Ratio (PSNR), Video Quality Metric (VQM), Structural Similarity Index (SSIM) and Mean Option Score (MOS) of real video sequences analyzed the proposed mechanisms, in a wireless system.

The remainder of this chapter is organized as follows. Section 2 discusses a survey of main metrics of QoE. Section 3 presents the state of the art approaches used to evaluate the QoE in video streaming. The optimization approach for streaming video over wireless networks, and its main features are described in section 4. In section 5, the scenario presented is detailed, as well as the tools used. The results are presented in section 6. Section 7 addresses the key challenges that exist in Wireless QoE-aware Multimedia Streaming Systems. Finally, section 8 presents the conclusions and future work.

2. QUALITY OF EXPERIENCE METRICS

Traditional techniques that aim to maximize the quality level of multimedia streaming are based only on QoS metrics. They define a set of management operations and measurement at the network level and packages, to control the delivery of multimedia content with an acceptable level of quality over heterogeneous networks (Zapater & Bressan, 2007). However, recent advances in multimedia system have presented the benefits of QoE metrics in assessing the quality level of applications based on the user's perspective/human perception.

There are several subjective and objective methods to measure the quality level and detect impairments (blocking, blurring and color errors) of multimedia streaming. Subjective methods are performed to acquire information about the quality level of processed video based on human opinion score schemes, while objective methods are used to estimate the performance of multimedia systems, by using models that approximate results of subjective quality assessment.

2.1 Subjective Metrics

Subjective metrics assess how audio and/or video streams are perceived by users, i.e., what is their opinion on the quality of particular audio/video sequences, as described in ITU-T recommendation BT 500 (1990). The most popular subjective metric is called Mean Option Score (MOS). The quality level of a video (or audio) sequence based on MOS model is rated on a scale from 1 to 5, with 5 being the best possible score, as presented in Table 1.

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Table 1. Mean Option Score

The MOS values are achieved based on subjective tests and methodologies performed with a set of viewers. For instance, the Single Stimulus Continuous Quality Evaluation (SSCQE) test allows viewers to dynamically rate the quality of an arbitrarily long video sequence using a slider mechanism with an associated quality scale. The drawback of subjective metrics is the fact that they are neither practical nor scalable for real-time multimedia environments.

2.2 Objective Metrics

Several objective QoE metrics have been studied and developed to estimate the quality level of multimedia streaming applications according to the user's perception. Among them, the Peak Signal to Noise Ratio (PSNR) is a traditional objective metric used to measure, in decibels, the video quality level based on original and processed video sequences. Typical values for the PSNR in lossy videos are between 30 dB and 50 dB, where higher is better. The PSNR of a video is defined through the Mean Square Error (MSE) metric; considering the luminance (Y) of the processed and original frames and assuming frames with MxN pixels, the MSE is obtained using Equation 1, illustrated in Table 2.

$$MSE = \frac{1}{MxN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left\| Ys\,(i,\, j) - Yd\,(i,\, j) \right\|^2 \qquad (1)$$

$$PSNR = 20 \log_{10} \left(\frac{255}{\sqrt{\frac{1}{MxN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left\| Ys\,(i,\, j) - Yd\,(i,\, j) \right\|^2}} \right) \qquad (2)$$

Table 2. MSE and PSN Equation

In Equation 1, while Ys (i, j) designates the pixel in the position (i, j) of the original frame, the Yd (i, j) represents the pixel located in the position (i, j) of the processed frame. Based on the MSE definition and on 8bits/sample, the PSNR, in a logarithmic scale, is obtained using Equation 2

The MSE and PSNR metrics only provide an indication of the difference between the received frame and a reference signal, and do not consider any other important aspects which can strongly influence the video quality level, such as Human Visual System (HVS) characteristics. A detailed analysis of HVS can be found in Wang, Lu, & Bovic (2004). The PSNR can also be used to map MOS values as described in Table 2.

PSNR (db)	**MOS**
> 37	5 (Excellent)
31 – 37	4 (Good)
25 – 31	3 (Fair)
20 – 25	2 (Poor)
< 20	1 (Bad)

Table 3. PSNR to MOS conversion

The Structural Similarity Index Metric (SSIM) improves the traditional PSNR and MSE, which are inconsistent with HVS characteristics, such as human eye perception (Wang, Bovik, Sheikh, & Simoncelli, 2004). The SSIM metric is based on frame-to-frame measuring of three components (luminance similarity, contrast similarity and structural similarity) and combining them into a single value, called index. The SSIM index is a decimal value between 0 and 1, where 0 means no correlation with the original image, and 1 means the exact same image.

The Video Quality Metric (VQM) method defines a set of computational models that also have been shown to be superior to traditional PSNR and MSE metrics (Revés, Nafisi, Ferrús, & Gelonch, 2006). The VQM method takes as input the original video and the processed video and verifies the multimedia quality level based on human eye perception and subjectivity aspects, including blurring, global noise, block distortion and color distortion. The VQM evaluation results vary from 0 to 5 values, where 0 is the best possible score.

The Moving Picture Quality Metric (MPQM) evaluates the video quality using HVS modeling characteristics (Lambrecht, & Verscheure, 1996). The input to the MPQM metric is an original video sequence and a distorted version of it. The distortion is first computed as the difference between the original and the distorted sequences. The original and the error sequences are then decomposed into perceptual channels segmented using uniform areas, textures and contours classification.

After that, HVS-based contrast sensitivity and masking parameters are considered for each perceptual channel in detection threshold calculation. Finally, data from channels are gathered to yield a single figure and to account for higher levels of perception, which is called pooling. Due to the MPQM's purely frequency-domain implementation of the spatio-temporal filtering process, this complex metric requires huge memory consumption. The final quality measure can be expressed either using a Masked PSNR (MPSNR) equation or can be mapped to MOS scale as detailed in (Lambrecht, &Verscheure, 1996).

The Perceptual Evaluation of Video Quality (PEVQ, 2010) provides MOS values of the video quality degradation as a consequence of end-to-end communication. The PEVQ approach is based on the combination of spatial and temporal artifacts measurement with human visual system behavior. PEVQ provides MOS scores of the video quality; in addition, PEVQ also provides information about the perceptual level of distortion in luminance, chrominance and temporal aspects of the evaluated video.

The previous QoE methods are based on a set of user/service information about the original and processed video. In order to reduce the system complexity and the amount of available reference information, a packet-based method, called Media Delivery Index (MDI), was proposed in IETF RFC 4445 by Welch, & Clark (2006).

The MDI metric is not the most accurate video quality level method and does not provide a good characterization of QoE, but can provide an indication of the video quality in a cost effective manner. The MDI scheme provides an indication of traffic jitter, a measure of deviation from nominal flow rates and a data loss at-a-glance measure for a particular multimedia service. According to MDI values, the overall video quality level through an end-to-end communication path can be estimated.

Regarding voice measurement, the E-Model is a non-intrusive Voice over IP (VoIP) metric based on the concept that impairments, which affect the voice call, are independent. Five factors are considered: the basic signal-to-noise ratio (Ro), which includes sources of noise as the circuit or environment, the impairments which occur more or less simultaneously with the voice signal (Is), the impairments caused by delay (Id), the impairments introduced by the equipment (Ie-eff) as losses, and the advantage factor (A) (Bandung, Machbub, Langi, & Supangkat, 2008; ITU-T G.107, 2005)). The A factor allows the compensation of impairment when there are other advantages of access to the user. A conventional wired access will have a smaller compensation compared to a wireless access in a remote area. Each parameter is calculated separately and combined to obtain the final result.

The Perceptual Evaluation of Speech Quality (PESQ) evaluates the voice QoE by comparing the signal sent and received in analog or digital networks. PESQ evaluation includes factors of distortion due to channel/encoder, losses and jitters and is recommended for speech quality assessment of narrow-band handset telephony and speech CODECs. Effects of loudness loss, delay, side tone, echo, and other impairments related to two-way interaction are not reflected in the scores (ITU-T P.862, 2001).

The PESQ presents values from -0.5 (lower value) to 4.5 (best value), although for most cases the output range will be a listening quality score, such as the Mean Opinion Score (MOS) scale, between 1.0 and 4.5. Although these results cannot directly be mapped to MOS, they can be approximated to it (Liang, Ke, Shieh, Hwang, &Chilamkurti, 2006).

In order to improve wireless control schemes, QoE quality metrics which have been designed and approved for video and voice quality assessment can be integrated into network/content management infrastructure, so that management operations can be proposed and selected according to user perceived quality.

3. QUALITY OF EXPERIENCE ASSESSMENT APPROACHES

Recent researches have focused on different ways of assessing the quality of video streaming considering the additional information used in the assessment process (by using subjective and objective metrics).These solutions are needed in wireless systems to measure the quality level of current and new applications, as well as, to provide input for optimization procedures in congestion situations or during failures in networking devices. The three main application-level approaches used to classify video quality assessment methods, based on reference-related video procedures are: Full Reference (FR), Reduced Reference (RR) and No Reference (NR).

The FR approach assumes unlimited access to the original video/multimedia sequence. This approach uses the video reference to predict the quality level (degradation) of the processed video, by comparing the difference of every pixel in each image of the distorted video with its corresponding pixel in the original video. As consequence, it provides, in general, superior quality assessment performance. The FR method is difficult to implement in real-time networking systems (QoE-aware equipment/monitoring agent) because it always requires the original sequence during the evaluation process (common for offline experiments). Examples of metrics based on an FR approach are PSNR, SSIM and MPQM.

For in service video quality measurements, RR and NR approaches are generally more suitable. The RR approach differs from the FR approach, whereas only selected multimedia parameters (or characteristics) are required during quality evaluation process, such as motion information. The set of reference parameters can be transmitted piggy-backed with the multimedia flow or by using a secondary channel. The objective of RR is to be as accurate as the full reference model, although using less network and processing resources. An example of an RR scheme is Video Quality Model (VQM), developed by the National Telecommunications and Information Administrative (NTIA) and reported in Pinson, & Wolf (2004).

The NR approach tries to assess the quality of a distorted multimedia service without any reference to the original content. This approach is usually, employed when the encoding method is known. NR-based metrics can be used in in-service network monitoring/diagnostic operations, when the original multimedia sequence is not available. The drawbacks of NR metrics are the following: (i) low correlation with MOS; (ii) high CPU and memory consumption; (iii) time limitation. An example of NR schemes is the V-Factor model (V-Factor, 2010) that outputs MOS. On important challenge in wireless multimedia systems is the specification and implementation of well-defined and high-performance NR schemes.

In addition to the previously application-level measurements approaches (reference-based classification), and, due to the time and processing demands, as well as feasibility issues of content based assessments, multimedia quality prediction mechanisms can be used as a manner to evaluate the quality level of video sequences in wireless networks. These schemes predict the quality level that a specific content will have after the encoding process, based on the encoding parameters, packet inspections, and network conditions. Further processing of the original data is not required, minimizing the associated complexity and resource consumption.

Implementations of prediction mechanism are the utility function models that offer a user-layer extension to existing user-aware measurement schemes to better assess the requirements of multimedia applications as detailed in Mu, Mauthe, & Garcia (2008). Impairment utility functions model the impact from each network QoS dimension (e.g., delay and packet loss) on the perceived quality. Utility values which are generated from all impairment functions are then aggregated as the application utility which quantifies the user's experience on target multimedia streaming application. The utility value represents the impact of application requirements and network resources on the user's perception.

Network-based approaches are suitable alternatives to assessment controllers in emerging wireless systems, where they evaluate the quality of multimedia content, basically, by verifying all transmitted packets related with the application and network conditions, and no decoding processing is required. The main issue is that such approaches need to perform deep-packet inspection. They need to gather information about the current network conditions, such as packet loss rate and packet one-way delay, to be used in the evaluation process. The final quality level assessment decision can be taken based on previous information, together with information about the multimedia characteristics, such as frame-rate, Group of Picture (GoP), frame type and dependence, only available at application level. This approach is preferable for in-service (real time) multimedia applications since the computational complexity is reduced. The performance is low to medium, but the feasibility is high. For example, in a simplest scenario, quality indicators are only some QoS parameters such as packet loss ratio or bit error rate.

Finally, Hybrid Content Inspection and Network Measurement approaches have also been proposed (Romaniak, Mu, Mauthe, D'Antonio, & Leszczuk, 2008). The main reason for the development of this kind of scheme is to allow network operators to combine the benefits of the previous approaches and adjust performance, complexity and feasibility, as well as to adjust operational cost issues according to different needs, multimedia content type, networks and equipments.

4. QUALITY OF EXPERIENCE OPTIMIZATION IN WIRELESS NETWORKS

There are different QoE optimization approaches for emerging wireless networking, ranging from MAC layer improvements and channel adaptation to routing (Gomes, Junior, Cerqueira, & Abelem, 2010) and packet control mechanisms (Rodrigues, Silva, Cerqueira, & Monteiro, 2008). The last approach is very useful, optimizes the usage of network resources, maximizes the user's satisfaction and will be detailed in this section. A state-of-art analysis will be presented and a novel and efficient user-aware solution to control the quality level of multimedia applications on IEEE 802.11 wireless systems will be described. Since multimedia flows are different in terms of encoder parameters, intra-frame dependence, as well as other QoS and QoE requirements, one key challenge to keep applications with good quality levels during congestions periods is to implement an IEEE 802.11 packet controller mechanism to discard packet according to the impact of each frame on the user perception.

Recent advances in wireless networks (IEEE 802.11e) aim to provide multimedia quality level assurance and are proposed and tested in (Ngoc, Tan, Lee, & Oh, 2007). This proposal adds a second queue to Distributed Coordination Function (DCF) in order to give priority to multimedia streams, and therefore reduces their delay. However, this approach is obsolete and does not focus on the new Hybrid Coordination Function (HCF) operation mode introduced by the IEEE 802.11e draft, which already includes several classes and queues that allow different priorities. Furthermore, few details are provided about performance evaluation issues and applicability scenarios. Thus, it is impossible to know how the multimedia flows were assessed and which scenarios were used. Finally, the conclusions are only based on network performance measurements, such as delay and losses, and no user level assessments were accomplished.

Another approach uses cross-layer architecture to map packets with different priorities to different Enhanced Distributed Channel Access (EDCA) queues of IEEE 802.11 (Haratcherev, Taal, Langendoen, Lagendijk, & Sips, 2006). In order to setup the importance of each packet, flows are divided into Parameter Set Concept (PSC), Instantaneous Decoding Refresh (IDR) pictures and partitions. PSC packets contain information about each flow, such as the resolution or the encoding process. IDR packets transport intra-pictures, i.e., pictures that require no other pictures to be decoded. The remaining pictures are divided into slides and each slide is divided into partitions using H.264 Data Partitioning (DP). The DP uses 3 partitions types: A partitions include header information; B partitions have intra-predictions and C partitions inter-predictions.

Because PSC packets contain the most important information, they are mapped to the Access Category (AC) with highest priority, which is, AC3. Given the mean priority of partitions A, they are mapped to AC2. B and C partitions are placed in AC1. Finally, best-effort traffic is mapped to the category with lowest priority, i.e., AC0. However, this proposal is not in accordance with the recommendations of the IEEE 802.11 standard, as well as, additional traffic placed in AC3 may damages voice flows and no scenario related to this problem was analyzed. Moreover, the use of AC1 for video flows makes it impossible to be used for other traffic, and thus no distinction between various types of non-multimedia flows can be done. Furthermore, the mapping of packets from the same flow in different queues increases the jitter that can lead to losses in the buffer on the receiver side. Finally, simulations only take into accounting QoS metrics and no user-based measurements are performed.

Moid, & Fapojuwo (2009) present a framework for streaming of H.264 video over an IEEE 802.11-based wireless network. A proposal was based on a cross-layer mechanism that jointly adapts the video transcoding parameters at the application layer and the video transmission parameters at the data-link layer to the network conditions defined by buffer length and wireless propagation channel. The validation of the proposal made by using the NS2 and Evalvid show that the model is adaptive to change according to network conditions and also in relation to the frame size of videos, with a gain of about 3 dB compared with the simulation model implemented. But the big gap left in this work is that it only deals with the PSNR metric, which despite being widely used, has several limitations related to the Human Behavior System, as presented in section 2

As discussed above, new QoE packet controllers for multimedia wireless systems are still challenges for both academy and industry. Novel approaches are required to assure the quality level support for video streaming applications based on user perception and also in mobility situations. Furthermore, the dependency of each frame of a sequence during the adaptation must be taken into accounting evaluated. The remainder of this section will present the benefits and discuss an intelligent packet controller mechanism for IEEE 802.11.

The proposed optimization wireless mechanism is configured with different selective dropping levels (extends the MAC QoS classifier, meter and dropper with multimedia and QoE-awareness), where a percentage of discarding associated with video and non-video traffics can be assigned to be used during adaptation process. For example, in congestion situations, video traffic can be protected to be discarded last (concurrent traffic is dropped first) or the system can be configured to drop only 10% of all video packets.

This scheme has two operational modes as follows: (i) in its basic configuration, it adapts video sessions to the current network conditions, by dropping frames only according to their importance in order to keep the system as simple as possible (low processing and state stored); (ii) in its enhanced configuration, it can adapt the video quality level also taking into account the dependency of intra-frame sequences and other relevant control information, such as audience size or cost.

Since video streaming are data flow containing application-level objects with special proprieties and dependence, the QoE optimization mechanism improves the packets dropping based on the dependency of a set of frames. The packet controller discards packets based on the importance of each frame. A typical MPEG-1/2/4 structure is presented in Figure 1, where *I* is the frame with highest priority and *B* the lowest ones.

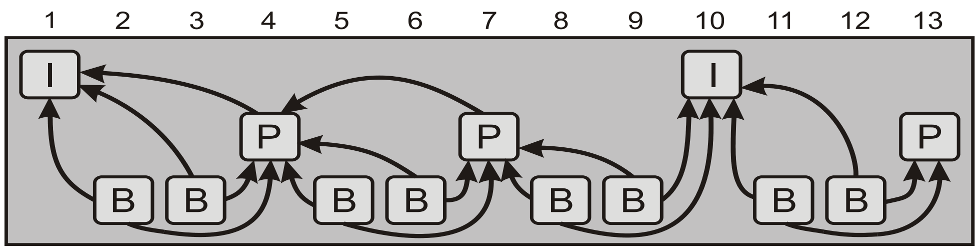


Figure1: A typical MPEG-1/2/4 structure

The QoE wireless controller includes an advanced packet drop scheme that performs its multimedia quality level management based on the importance of each frame of the CODEC. Therefore, if a packet containing an I frame is marked to be dropped (in congestion periods during failures), it will be beneficial to check whether a packet corresponding to a P or B frame is currently in the buffer. Since the number of frames that depends on a P or B frame is reduced, the loss of these frame types will have a reduced impact on the final quality and, therefore, on the user perception. The same process happens when a P frame is selected to be dropped and a B frame is in the queue. It will be beneficial to drop the B frame that is already in the buffer and enqueue the incoming P frame.

5. PERFORMANCE EVALUATION OF A QOE PACKET CONTROLLER

This section describes the benefits and impacts of the proposed QoE packet controller in IEEE 802.11e wireless networks on the user perception based on well-known assessment metrics. The evaluation was carried out by using the Network Simulator 2 (NS2). The Evalvid platform was also implemented to assess the video streaming quality delivery and configured to support MPEG I, P and B frames.

The main objectives of the simulation experiments are the following: (i) analyze the percentage of packet losses associated with frames of video streaming and non-video applications; and (ii) analyze the perceived quality of a video sequence by verifying PSNR, SSIM, VQM and MOS. Four IEEE 802.11e different configurations are implemented for the experiments, they are: Best-Effort (no traffic differentiation), Pure QoS (with traffic differentiation, but without QoE and multimedia support), QoE control (the most important frames are protected in congestion periods) and QoE control with 3% of Advanced Drop (the most important frames are protected and the percentage of non-video packets to be discarded are increased in 3%, in order to save more video packets). For each approach, 10 experiments were performed with different congestion rates (from 0 up to 200% of congestion in a system).

The Boston Representative Internet Topologies Generator ([BRITE], 2010) was used to generate a random topology with wired core nodes, wireless access points and users for the evaluation. Figure 2 illustrates the evaluated scenario, which is composed of 4 wireless nodes (2 sources and 2 receivers), 4 access points and 21 core routers. The wireless and core links have a bandwidth of 11Mb/s and 100Mb/s, respectively. The propagation delay of each link was assigned according to the distance between the edges of each link. Each source sends a real video sequence with average rate of 350Kb/s and a CBR traffic, in order to congest the links. The video sequence, denominated "News" (Evalvid,2010), consists of 300 frames (30 frame/s) with YUV format, sampling 4:2:0 and dimension 352x288. The video sequence was compressed with a MPEG-4 CODEC. The GOP of the sequence is composed of 30 frames, using two B frames for each P frame. Frames are then fragmented in blocs with 1024B.

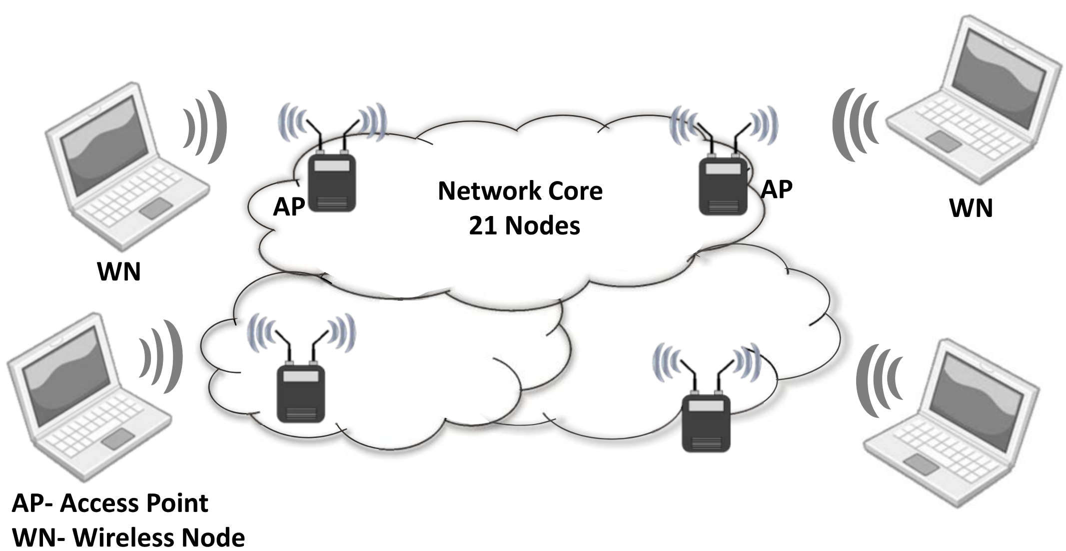


Figure 2: Evaluated Wireless QoE-aware Scenario

6. RESULTS

6.1 Frame Losses

This Section measures the percentage of frame losses (I, P, B and other frames/CBR) for different congestion rates when a system is configured with Best-Effort, Pure QoS, QoE Control and QoEAdv mechanisms.

As presented in Figure 3 (a), when the system is implemented only with the Best-Effort approach, packets are discarded randomly. Hence, as the network's congestion increases, the percentage of packet losses is proportionally increased for all frame types (including packets associated with the CBR traffic).

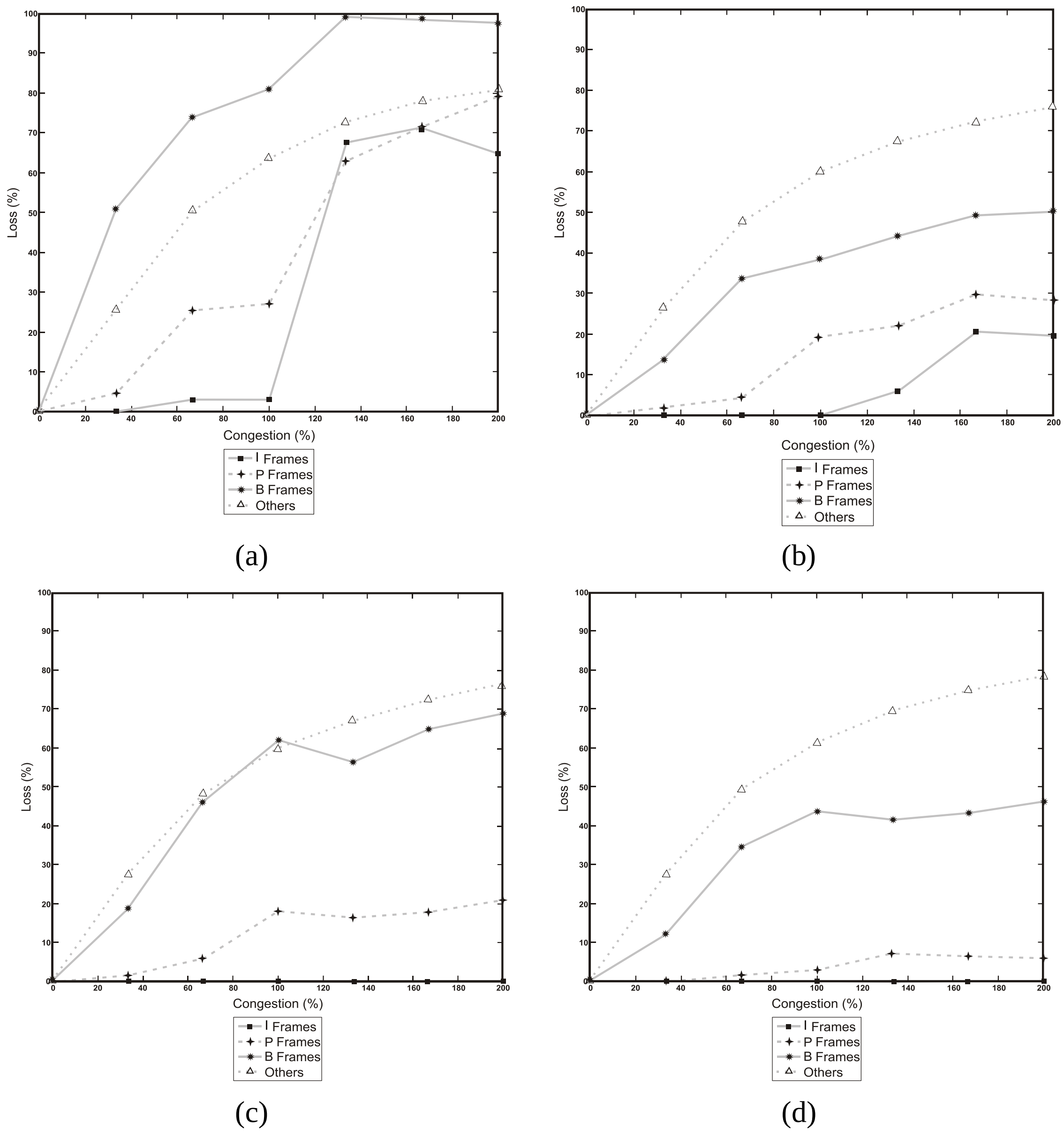


Figure 3 : Frame lost for each mechanisms

Figure 3 (b) describes the system behavior when the pure QoS approach is being used. The results reveal that it provides packet differentiation and protect the discard of video packets (compared to the Best-Effort class), because they are accommodated in a most important class. However, all video packets are dropped in a random "black-box" way (without frame type differentiation).

The benefits of the QoE control proposal on the video quality level are depicted in Figure 4 (c). By adapting the video content according to the importance of each frame, the QoE controller aims to protect most important video frames in congestion periods. Hence, B frames are dropped first and I frames arediscarded last, increasing the user's experience. Compared to Best-Effort and pure QoS approaches, the QoE solution reduces the percentage of P frame loss in 60% and 23% respectively, when the system overload is 100%.

Due to its frame protection schemes, I frames are not discarded during simulations when the QoE and QoEAdv approaches are configured. However, compared to a system with only QoE support, the percentage of P and B frame loss is decreased in 66% and 30% respectively, while the percentage of CBR packet loss is increased to a mere 3%, as presented in Figure 4 (d). Notice that there are more CBR packets than video packets in the system and, consequently, more non-video packets are discarded during congestion periods.

6.2 Peak Signal to Noise

Since packet loss rate does not indicate the real impact on the video quality level, PSNR values of the video sequences in different congestion periods were analyzed. Figure 4 shows the average PSNR for the videos with different approaches.

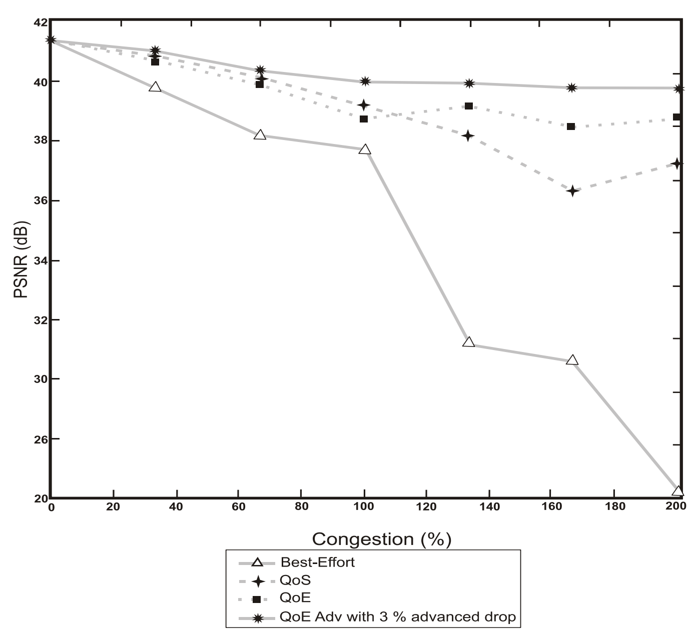


Figure 4: PSNR for each approach and congestion rates

The results reveal that when the Best-Effort approach is being used, the PSNR of the videos decreases as fast as the traffic increases, attaining a minimum value of 27dB. When the system is configured with only QoS, the PSNR of the videos is maximized in comparison with the Best-Effort (e.g., the PSNR is increased in 3% when the network is overloaded by 80%). Compared to the pure QoS approach, the QoE control increases the quality level of video sequences in 3% and 6% when the system is overloaded in 130% and 150%, respectively.

6.3 Structural Similarity Index

The SSIM results give more detail about the video quality level taking human perception into account. Figure 5 illustrates the average SSIM of the video sequences when the system is configured with Best-Effort, QoS, QoE and QoEAdv drop approaches.

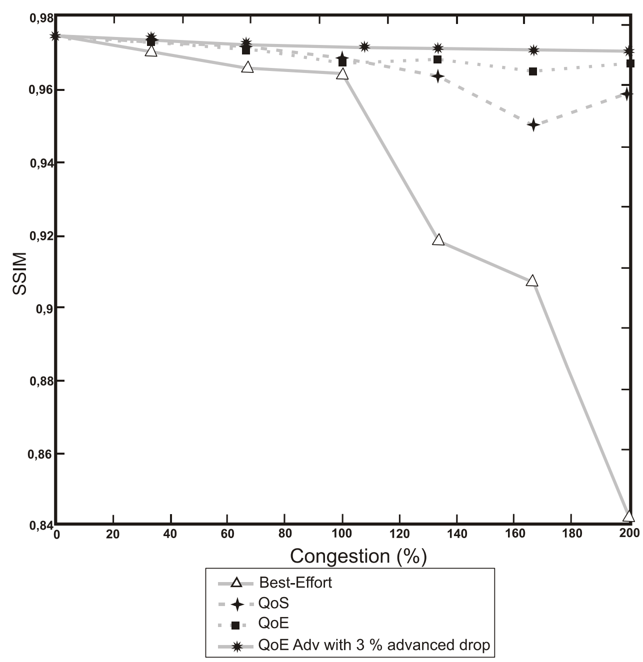


Figure 5. SSIM for each approach and congestion rates

The results reveal that, when the Best-Effort approach is configured, the correlation between the original and the received video is poor after a congestion of 100%. Compared to the pure QoS, the QoE controller increases the SSIM of video sequences in 3% when the system is overloaded in 200%. On average, the QoEAdv approach increases in 0.5% the video SSIM for all experiments, when compared with simulations based only on the QoE configuration.

6.4 Video Quality Metric

VQM is an important metric to verify the video quality level based on human eye perception and subjectivity. Figure 6 presents the average VQM results for each approach when the system has different congestion levels.

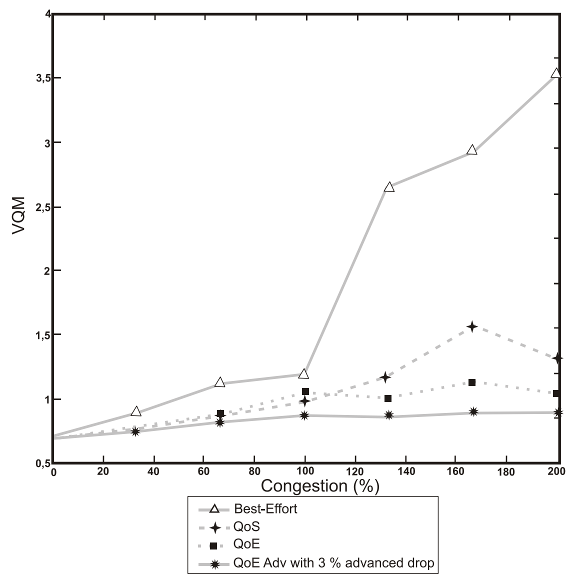


Figure 6.VQM for each approach and congestion rates

Due to its packet differentiation scheme, the pure QoS approach increases the video VQM in 18% (compared to the Best-Effort) when the system load is 80%. Additionally, during a congestion period of 100%, QoE control increases the video VQM in 43% and 70%, when the system is configured with the QoS and Best-Effort approaches, respectively. Compared to a system with the QoE, the QoEAdv approach maximized the video VQM, on average,by 15%, when the system is overloaded in 120%.

6.5 Mean Opinion Score

In order to present the user experience for each approach during congestion periods, the MOS was evaluated using Table 1 and illustrated in Figure 7.

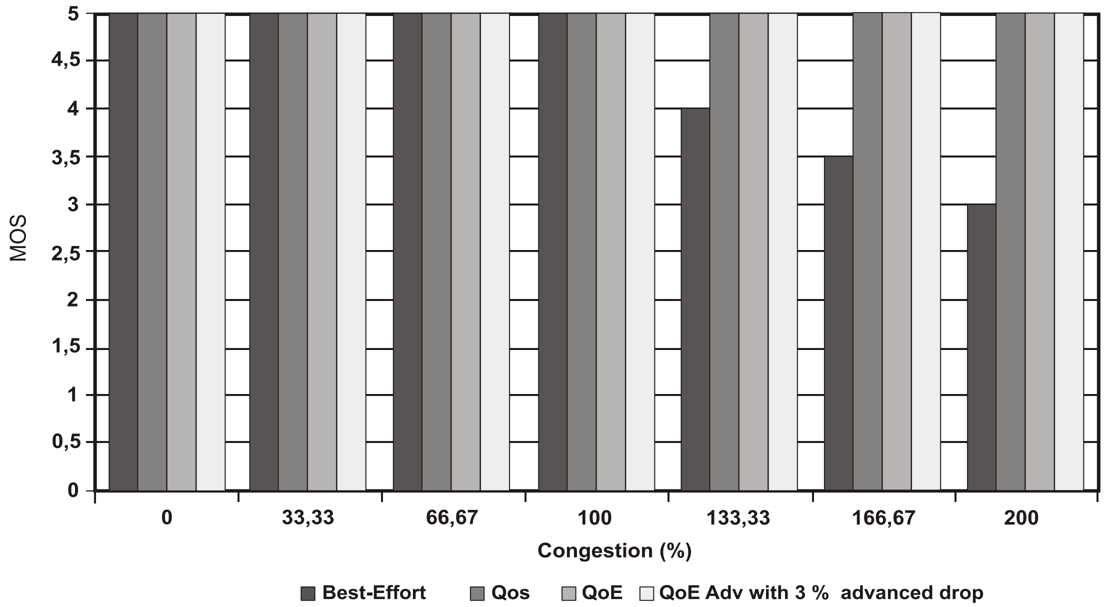


Figure 7.MOS variation when network load increase

The results revealed that, according to the MOS metric, the QoE and QoEAdv approaches kept videos with an excellent quality level during all congestion periods. In order to show the impact of the QoE control (compared to the pure IEEE 802.11e QoS controller mechanism) from the user point of view when the wireless system is experiencing 15% of congestion, some frames of the real video sequence, named News, were captured (Table 4). The benefits of the QoE adaptation process are visible in the frames of the video, particularly in the ballet dancer.

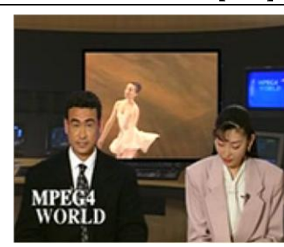
Mechanism	Frame Number [293]	Frame Number [294]	Frame Number [295]
QoEAdv			
Pure QoS			

Table 4. Some frames of "News" with different packet control mechanisms

7 CHALLENGES IN QOE-AWARE WIRELESS MULTIMEDIA SYSTEMS

Recently, solutions have been presented regarding multimedia measurement and optimization over heterogeneous wireless networks. However, there are still many important challenges that need to be addressed in future multimedia networks in several areas. It is not the goal of this chapter to propose an integrated solution for QoE management, but rather to identify the main issues from application to network layers.

Packet/network inspection-based (or even hybrid approaches) can be used to predict and measure video quality based on information gathered from packet and network conditions without accessing the decoded video streaming. The results of theseapproaches are useful for pricing/billing, management and optimization operations in future wireless multimedia systems.

In addition, new QoE-based application, transport and network level optimization mechanisms (whether a cross-layer approach is used or not) are still required in a near future, such as routing, inter/intra-session adaptation, resource reservation, traffic controller, seamless multimedia mobility and base station selection/user experience schemes. Moreover, the multi-homing capability of current devices can also provide an improved performance for multimedia streaming applications by taking advantage of the multiple connectivity levels from each wireless device.

8. CONCLUSIONS

Research in wireless multimedia area is envisioned to continue with various challenges emerging as a result of new applications, approaches, technologies, operational costs, changing user and terminal requirements, and highly heterogeneous networking infrastructures and devices. This chapter is intended to highlight some of the important topics in wireless and multimedia areas that need attention to address some of the most pressing challenges associated with them. The chapter is focused on two key areas, where the first one was on the assessment schemes and the second was on packet controller optimization schemes, including performance evaluation results.

QoE, although not always quantifiable, numerically, is the most important factor in assessing the user experience through metrics and techniques that can be categorized mainly into two categories, based on the subjectivity or objectivity. In the first category, in general, a group of viewers rate the quality of media, such as through the MOS, in its three axes, V (Viewing), A (Audio), C (Interaction). The second category in turn, makes use of indexes that have qualities associated with mathematical calculations and / or measurement by specific equipment, such as PSNR, MPQM and MDI.

The benefits generated by QoE wireless optimization schemes contribute to the creation of a ubiquitous multimedia era, where the user experience is a key parameter during the development of new solutions tomaximize the usage of network resources and the costumer´s satisfaction. QoE-aware packet controllers are examples of simples (and efficient) mechanisms to be implement in wireless multimedia systems.

We hope that this work will help improve our understanding of the issues and challenges that lie ahead in wireless multimedia networks and will serve as a catalyst for designers, engineers, and researchers to seek innovative solutions to address and solve those challenges.

Acknowledgements

Authors would like to thank the Pará State Government (Brazil), FAPESPA, REDE TIC, Federal University of Pará and CNPq 476202/2009-4, 559994/2010-9 and 475312/2010-4.

REFERENCES

Akyildiz, I. F., Wang, X., (2005).A survey on wireless mesh networks. *IEEE Communications Magazine*, vol. 43, no. 8, pp. 23–30.

Andrews, J. G., Ghosh, A., &Muhamed, R., (2007). *Fundamentals of WiMAX: Understanding broadband wireless networking*. Prentice Hall.

Bandung, Y., Machbub, C., Langi, A.Z.R.,&Supangkat, S.H., (2008, September). Optimizing voice over internet protocol (VoIP) networks based-on ex- tended e-model. *In Cybernetics and Intelligent Systems*, 2008 IEEE Conference on, pp. 801–805, Chengdu, China.

BRITE (2010).BostonUniversityRrepresentative Internet Topology Generator. Accessed in May 2010, ofhttp://www.cs.bu.edu/brite/

ETSI STQ (2010). European Technical Committee for Speech, Transmission, Planning, and Quality of Service, accessed in July 2010, of http://portal.etsi.org

Evalvid (2010). Acessed in May 2010, of http://ww.tkn.tu-berlin.de/research/evalvid/cif

Gomes, R.L., Junior, W.M., Cerqueira, E., Abelem, A.J., (2010, April). Using fuzzy link cost and dynamic choice of link quality metrics to achieve QoS and QoE in wireless mesh networks, *Journal of Network and Computer Applications*, ISSN 1084-8045.

Haratcherev, L., Taal, J., Langendoen, K., Lagendijk, R., & Sips, H., (2006).Optimized video streaming over 802.11 by cross-layer signaling.*Communications Magazine*, IEEE, 44(1), pp. 115–121.

IEEE Standard 802.11 (2010). Wireless LAN Medium Access Control (MAC) and physical layer (PHY) Specifications, accessed in June 2010, of http://grouper.ieee.org/groups/802/11/

IEEE Standard 802.11e (2010). Medium Access Controal (MAC) Enhancements for Quality of Service Specifications, accessed in June 2010, of http://grouper.ieee.org/groups/802/11/Reports/tge_update.htm

IEEE Standard 802.16 (2010). Working Group on Broadband Wireless Access, accessed in June 2010, of http://grouper.ieee.org/groups/802/16/

ITU-T (2010). International Telecommunication Union – Telecommunication Standardization Sector, accessed in July 2010 of http://www.itu.int/ITU-T/

ITU-T BT-500 (1990). Methodology for the Subjective Assessment of the Quality of Television Pictures, Technical Report, accessed in July 2010 of http://www.itu.int/ITU-T/

ITU-T G.107 (2005, March). The e-model: a computational model for use in transmission planning, accessed in June 2010 of http://www.itu.int/ITU-T/

ITU-T P.862 (2001, February). Perceptual evaluation of speech quality (PESQ): an objective method for end-to-end speech quality assessment of narrow-band telephone net- works and speech codecs, accessed in June 2010 of http://www.itu.int/rec/T-REC-P.862/

Klaue, J., Rathke, B., &Wolisz, A., (2003, September).EvalVid- A Framework for Video Transmission and Quality Evaluation.*13th International Conference on Modelling techniques and Tools for Computer Performance Evaluation*, Urbana, Illinois, USA.

Lambrecht, C., &Verscheure, O., (2006, January).Perceptual Quality Measure Using a Spatio-

Temporal Model of the Human Visual System.*In Proc. of SPIE*, Vol. 2668, San Jose, USA.

Liang, H.M., Ke, C.H.,Shieh, C.K., Hwang, W.S., &Chilamkurti, N.K., (2006,April). Performance evaluation of 802.11e EDCF in the ad-hoc mode with real audio/video traffic.*In Wireless and Optical Communications Networks*, 2006 IFIP International Conference.

Moid. A., &Fapojuwo. A.O., (2009). A Cross-Layer Framework for Efficient Straming of H.264 Video over IEEE 802.11 Networks. Jornaul of Computer Systems, Networks, and Communications.Accesed in May ,2010, of http://www.hindawi.com/journals/jcsnc/2009/682813.abs.html

Mu, M., Cerqueira, E., Boavida, F., &Mauthe, A., (2009, April). Quality of experience management framework for real-time multimedia applications. *International Journal Internet Protocol Technology*, 4(1): 54–64

Mu, M., Mauthe, A., & Garcia, F., (2008, September).A Utility-based QoS Model for Emerging Multimedia Applications, *IEEE International Workshop on Future Multimedia Networking*, Cardiff, UK.

Ngoc, D.M., Tan, P.A., Lee, J.S., & Oh, H., (2007, April).Improvement of IEEE 802.11 for multimedia traffic in wireless LAN.*In Wireless Telecommunications Symposium*, WTS 2007, pp. 1–4, Pomona, CA.

NS2 (2010). The network simulator – ns-2, accessed in July 2010, ofhttp://www.isi.edu/nsnam/ns/

Perkis, A., Munkeby, S., Hillestad, O.I., (2006, June).A Model for Measuring Quality of Experience.*In Signal Processing Symposium*, NORSIG. Proceedings of the 7th Nordic, pp. 198-201.

PEVQ (2010). PEVQ Perceptual Evaluation of Video Quality, accessed in July 2010, of http://www.pevq.org/

Pinson, H., & Wolf, S., (2004, September). A New Standardized Method for Objectively Measuring Video Quality, *IEEE Transaction of Broadcast*, Vol.50, issue 3.

Revés, X., Nafisi, N., Ferrús, R., &Gelonch, A., (2006, June). User perceived Quality Evaluation in a B3G Network Testbed. *IST MobileSummit*, Mykonos, Greece.

Rodrigues, D., Silva, D., Cerqueira, E., & Monteiro, E., (2008). Quality of Service and Quality of Experience in Video Streaming.*International Workshop on Traffic Management and Traffic Engineering for the Future Internet* (FITraMEn 08), Porto, Portugal.

Romaniak, P., Mu, M., Mauthe, A., D'Antonio, & S., Leszczuk, M., (2008, May).Framework for the Integrated Video Quality Assessment.*18th ITC Specialist Seminar on Quality of Experience*, Blekinge Institute of Technology, Karlskrona, Sweden.

Takahashi, A., Hands, D., &Barriac, V., (2008, February).Standardization Activities in the IUT for a QoE Assessment of IPTV.*IEEE Communication Magazine*, Vol. 46, N2.

V-Factor (2010). V-Factor Quality of Experience Platform, accessed in July 2010, of http://www.pevq.org/

VQEG (2010). Video Quality Experts Group, accessed in July, 2010, of http://www.its.bldrdoc.gov/vqeg/

Wang, Z., Bovik, A.C., Sheikh, H.R., &Simoncelli, E.P., (2004, April). Image Quality

Assessment: From Error Visibility to Structural Similarity. *IEEE Transactions on Image Processing*, Vol.13, N. 4.

Wang, Z., Lu, L., &Bovic, A.C, (2004, January). Video Quality Assessment based on Structural Distortion Measurement. *Signal Processing: Image Communication, Special Issue on Objective Video Quality Metrics*, Vol. 19.

Welch, J., & Clark, J., (2006, April). A Proposed Media Delivery Index (MDI).IEFT RFC 4445.

Zapter, M., &Bressan, G., (2007, January).A Proposed Approach for Quality of Experience Assurance for IPTV, *In Proc. of IEEE International Conference on the Digital Society*, Guadeloupe, French Caribbean.

ADDITIONAL READINGS

Cerqueira, E. C., Veloso, L., Curado, M., Mendes, P., & Monteiro, E., (2008) . QualityLevelControl for Multi-userSessions in Future Generation Networks. *In Proceedingsof IEEE Global TelecommunicationsConference (Globecom 2008)*, USA, New Orlean, November

Cerqueira, E.C., Zeadally, S., Leszczuk, M., Curado, M., &Mauthe, A.,(2010). Recentadvances in multimedia networking. *Multimedia Tools andApplications*, v. 52, p. 1-13, 2010;

Engelke, U., &Zepernick, H, J., (2007). Perceptual-based Quality Metrics for Imageand Video Services: A Survey. *Next Generation Internet Networks*, 3rd EuroNGIConference on, pp.190-197, May 2007

Garcia, M., Canovas, A., Edo, M., &Lloret, J., (2009).AQoE Management System for Ubiquitous IPTV Devices.*Mobile Ubiquitous Computing, Systems, Services and Technologies*, Third InternationalConference on, pp.147-152, 2009, UBICOMM '09

Greengrass, J., Evans, J. &Begen, A.C., (2009). Not All Packets Are Equal, Part I: *Streaming Video Coding and SLA Requirements*. IEEE Internet Computing, Vol.13 , No. 1, pp. (70 – 75)

Grega, M., Janowski, L., Leszczuk, M., Romaniak, P., &Papir, Z., (2008). Quality of Experience Evaluation for Multimedia Services, PrzeglądTelekomunikacyjnyiWiadomościTelekomunikacyjne, nr, pp. 142-153

Jailton, J. J., Dias, K. L., Cerqueira, E. C., Cavalcanti, & Dave, C., (2009). SeamlesshandoverandQoSprovisioning for mobile videoapplications in anintegrated WiMAX/MIP/MPLS architecture. *InternationalJournalofAdvanced Media and Communication*, v. 3, p. 404, 2009

Jain, R., (2004).*Quality of experience.IEEE Multimedia*, Vol. 11, No.1, 2004, pp. (95- 96)

Ke, C., &Chilamkurti, N., (2008). A new framework for MPEG video delivery over heterogeneous networks, *Elseiver Computer Communications*, Volume 31, Issue 11

Kishigami, Jay (2007). The Role of QoE on IPTV Services style, *Ninth IEEEInternational Symposium*, pp. 11-13, Taichung

Monteiro, J, M., Nunes, M. S., (2007).A Subjective Quality Estimation Tool for the Evaluation of Video Communication Systems.*Computers and Communications*, ISCC 2007, 12th IEEE Symposium on, p. MW - 75 - MW – 80

MSU MSU Video Quality Measurement Tool.accessed in August 2010, of http://compression.ru/video/quality measure/index en.html

Parker, A., (2006). Addressing the cost and performance challenges of digital media content delivery.,*P2P Media Summit*, Santa Monica, CA, October.

Pinson, H., &Wolf, S., (2004).A New Standardized Method for Objectively Measuring Video Quality", *IEEE Transaction of Broadcast*, Vol. 50, Issue 3, September

Schwarz, H., &Marpe, H., (2008). Overview of the Scalable Video Coding Extension of the H.264/AVC Standard,*IEEE Transaction on Circuits and Systems for Video Technology*, September, pp. 135-141

Siller, M.,& Woods, J., (2003) Improving Quality of Experience for Multimedia Services by QoS arbitration on QoEFramework.*Proceedings of the 13th Packed Video Workshop 2003*, Nantes, France

Video Traces Research Group, "YUV 4:2:0 Video Sequences," (http://trace.eas.asu.edu/yuv/qcif.html), Arizona State University, October 2008

Yamada, H., Fukumoto, N., Isomura, M., Uemura, S., &Hayashi, M., (2007). A QoE based service control scheme for RACF in IP-based FMC networks. *E-Commerce Technology and the 4th IEEE International Conference on Enterprise Computing*, E-Commerce, and E-Services, CEC/EEE, pp. 611-618

Zhao, H., Ansari, N., &Shi, Y., (2005). Layered MPEG video transmission over IP DiffServ, *Proceedings of the International Conference on Information Technology*: Coding and Computing (ITCC'05)