# MPEG-2 Streaming over IEEE 802.11g WLAN: Performance Characterization using Video Perceptual Quality Metrics

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## ABSTRACT

The robust streaming of video over IEEE 802.11g Wireless Local Area Networks (WLANs) poses many challenges, such as coping with bandwidth variations and the unreliability of the wireless channel. This paper presents simulation results characterizing the performance of streaming MPEG-2 over 802.11g in a frequency selective channel. In the study perceptual video quality metrics are used to assess system performance both as a function of signal to noise ratio (SNR) and range between the WLAN Access Point (AP) and the station (STA). Perceptual quality metrics provide a more realistic indication of the WLAN's performance as they take into account the end-users' perceived quality while being sensitive to encoded data rate.

## INTRODUCTION

The IEEE 802.11 standardization body for WLANs has defined specifications for the Medium Access Control (MAC) sub-layer and three different low bit rate physical layers supporting 1 and 2 Mbps [1]. Due to their limited bit rate capabilities, the low rate systems have been used for data traffic only. Two higher speed physical layers have also been defined [2]: the 802.11b PHY in the 2.4 GHz ISM band and the 802.11a PHY in the 5 GHz U-NII band. 802.11b offers bit rates up to 11 Mbps while 802.11a offers bit rates up to 54 Mbps. In 2002, the IEEE Task Group G (802.11g) developed a high-speed extension to the 802.11b (PHY) in the 2.4 GHz ISM band. Coded Orthogonal Frequency Division Multiplexing (OFDM) has been adopted as the mandatory modulation in the IEEE 802.11g draft specifications [3]. This new standard provides data rates from 6 Mbps to 54 Mbps. With this substantial increase in the data rates offered by 802.11g, both real-time and on-demand audio/video applications over WLANs have become realities.

The transmission of video over WLAN presents a number of problems due to the strict delay constraints of video traffic and the unpredictability of the wireless link characteristics. Unlike data traffic, video transmission is delay-sensitive. For non-real time video transmission, packet loss can be countered by repeated retransmissions until the packet is received error free. However, for real-time traffic due to the delay constraints the number of retransmissions is limited and is usually small [4]. In this study, a perceptual video quality metric derived from the Rohde&Schwarz (R&S) Digital Video Quality (DVQ) tool [5] is used to evaluate the performance of streaming MPEG-2 over 802.11g in order to characterize the maximum coverage that guarantees a given perceptual Quality-of- service.

## MPEG-2 VIDEO CODING OVERVIEW AND QUALITY METRIC

Video coding methods exploit both spatial and temporal redundancy in the source data. Spatial redundancy is eliminated by using the block-wise Discrete Cosine Transform (DCT) and quantization followed by entropy coding of the remaining coefficients. This is known as intra-frame coding. Temporal redundancy is reduced by coding the differences between any two successive frames. Several methods exist to perform temporal coding, such as differencing, motion estimation and motion-compensation predictions. These methods are known as inter-frame coding [6].

MPEG-2 is a video coding and compression technique that takes advantage of intra- and inter-frame coding methods. It uses three types of frames, namely I-, P-, and B-frames. I-frames are solely intra-coded frames, P-frames are predicted frames depending on the previous I-frame, and B-frames are bidirectional frames depending on the previous and following I- or P-frame. Frames are arranged in a Group of Pictures (GOP) which consists of one I-frame and several P-frames and B-frames. In MPEG-2, I-frames contain most of the information, so loosing an I-frame produces severe distortion of the following frames in a GOP. The loss of a P- frame only influences the B-frames and the loss of a B-frame would not influence any other frame.

MPEG-2 defines two types of streams called the programme and transport streams, respectively. The programme stream uses long and variable packets which are well suited to software based processing and error free environments such as coding for storage of video on disc. The MPEG-2 transport stream offers robustness for noisy channels by using error resilience techniques. The transport stream consists of packets of fixed length containing 4 bytes of header followed by 184 bytes of data [7].

Video quality depends on many parameters such as coding and compression parameters (e.g. output bit rate, frame rate, and the temporal relation among frame kinds), network parameters (e.g. packet loss rate, delay) and other parameters like nature of the scene (e.g. amount of motion, color, contrast, image size) [8]. It is clear that conventional network metrics such as packet error rate (PER) and bit error rate (BER) do not give a consistent measure of perceptional video quality. In order to address this issue, a perceptional video quality metric based on an objective measure of the perceived quality has been used.

An effective Perceptual Quality Metric (PQM) was derived from the Rhode & Schwartz DVQ tool [5] as the weighted mean (Wm) of the perceived quality values (PQVs) returned by the tool [5]. Each PQV is an objective measure on the scale 0-to-100 of the perceptual video quality of an individual YUV video frame. The PQM is determined from equation (1).

$$PQM = Wm(PQV) = \frac{1}{N}\sum_{n} n \cdot F_n \qquad (1)$$

Where $N$ is the total number of the YUV frames in the video clip, $n$ = 0, 10, 20… 100 denotes the partition ranges of the PQV scale and $F_n$ is the number of YUV-frames whose PQV satisfies the condition $n \leq$ PQV < $n$+10.

Equation (1) defines an absolute perceptual quality metric for video sequences. It is also useful to define a relative perceptual quality metric referred to as the relative-PQM or rel-PQM over a transmission channel. Then the rel-PQM is defined in equation (2) as the ratio of received PQM ($PQM_{rx}$) to transmitted PQM ($PQM_{tx}$). That is, rel-PQM is a measure of the relative degradation in PQM due to transmission impairments *wrt* the unimpaired video sequence.

$$\text{Relative } PQM = \frac{PQM_{rx}}{PQM_{tx}} \qquad (2)$$

The rel-PQM is a useful metric for dimensioning the radio resource used on a wireless link by determining the minimum $E_b/N_0$ that ensures a given video sequence is received without impairment (i.e. the minimum $E_b/N_0$ to achieve unity rel-PQM).

## SYSTEM MODEL

In our study, a computer based simulator was implemented to model the 802.11g PHY layer of 8 transmission modes with different coded-modulation configurations and data rates ranging from 6Mb/s to 54Mb/s. In the simulation, coded OFDM symbols were generated according to the 802.11g specification, passed through a multipath channel and AWGN added. At the receiver, demodulation and decoding was performed and finally the impaired video clip was reconstructed.

MPEG2 encoded video clips of bit rates 2, 4, and 6 Mbit/s were passed through the 802.11g PHY layer using a packet size of 100 bytes. The MPEG packet was encapsulated into an IEEE 802.11g packet and transmitted over a multipath channel. The multipath channel model between the Access Point and the station (STA) was based on an exponentially decaying Rayleigh fading channel. The impulse response ($h_i$), as expressed in equation (3) [8], is composed of complex samples with uniformly distributed random phases 0 to $2\pi$ and Rayleigh distributed magnitudes with average powers decaying exponentially.

$$h_i = N\left(0, \sigma_k^{\,2}/2\right) + jN\left(0, \sigma_k^{\,2}/2\right)$$

$$\sigma_k^{\,2} = \sigma_0^{\,2} e^{-KT/\tau_{RMS}} \quad \text{and} \quad \sigma_0^{\,2} = 1 - e^{-T/\tau_{RMS}} \qquad (3)$$

Where $N\left(0, \sigma_k^{\,2}/2\right)$ is a zero mean Gaussian random variable with a variance of $\sigma_k^{\,2}/2$, and $\sum \sigma_k^{\,2} = 1$ in order to ensure unity average received power. We have set the delay spread, $\tau_{RMS}$ equal to 100 ns in order to model the multipath behaviour of an office environment. For this delay spread, the cyclic extension will protect the OFDM symbol from intersymbol interference (ISI) as introduced by the multipath channel.

## SIMULATIONS AND RESULTS

In our simulation experiments, as the STA moves away from the AP, the WLAN signal power drops considerably due to path loss. The decrease in signal-to-noise ratio causes a substantial degradation in the perceived video quality. The relative PQM was used to measure the relative change in perceived video quality for three MPEG-2 encoded bit rates of 2, 4, and 6 Mb/s for the same video content when transmitted at 802.11g data rates of 24 and 36 Mb/s. Figures 1 and 2 show curves of rel-PQM versus $E_b/N_0$ which indicate that the video quality is restored at 16 dB for a data rate of 24 Mb/s and 19.5 dB for a data rate of 36 Mb/s. According to these requirements, the maximum coverage radius that can be achieved is 70m at a data rate of 24 Mb/s and 55m at a data rate of 36 Mb/s as shown in Figures 3 and 4, which show curves of rel-PQM versus range D. Figures 3 and 4 also indicate that the rate of change of rel-PQM as a function of range is more or less the same for each encoded bit rate.

In addition to measuring relative PQM, the absolute PQM was measured as a function of range D between the STA and AP for the same three encoded bit rates when transmitted at 802.11g data rates of 24 Mb/s and 36 Mb/s. Figures 5 and 6 show curves for absolute PQM versus range D with encoding rate as a parameter. As expected, the results show that in general the perceived video quality improves with increasing encoded bit rate and decreases with increasing range. However, in contract to Figures 3 and 4, Figures 5 and 6 show that as the range increases, the curves for different encoded bit rates converge. This result indicates that at large ranges lower encoded bit rates can be used without causing a significant loss in perceptual video quality.

**CONCLUISION**

This paper has investigated the performance of streaming MPEG-2 encoded video clips over an IEEE 802.11g PHY for different signal-to-noise ratio (SNR) conditions on a frequency selective channel. A perceptual video quality metric has been used instead of conventional metrics (i.e. BER and PER) to characterize the 802.11g coverage when MPEG-2 encoded video clips are used. The results showed that the video quality depends on the encoded bit rate of the video clip as well as the coverage radius (D). A large coverage radius can be achieved at a data rate of 24 Mb/s when a robust coding rate is used and it is clear that the video quality degrades as the coverage radius increases. However, at large separations between the AP and STA, low encoded bit rate video was able to attain similar perceptual video quality levels to high encoded bit rate video.

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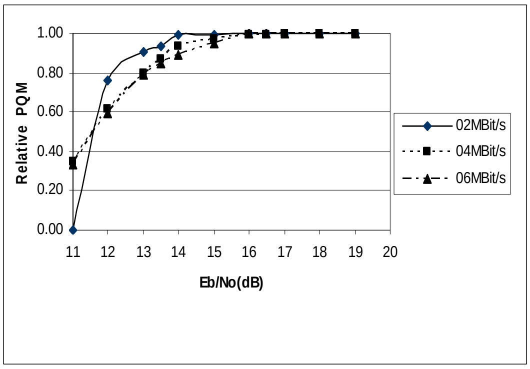


Figure 1. Relative PQM vs. $E_b/N_0$ (dB) at an 11g data rate of 24 Mb/s

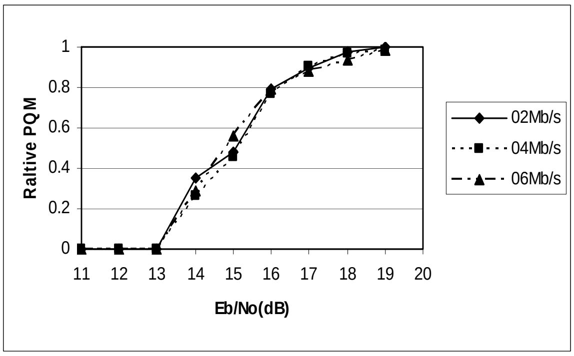


Figure 2. Relative PQM vs. $E_b/N_0$ (dB) at data an 11g data rate of 36 Mb/s

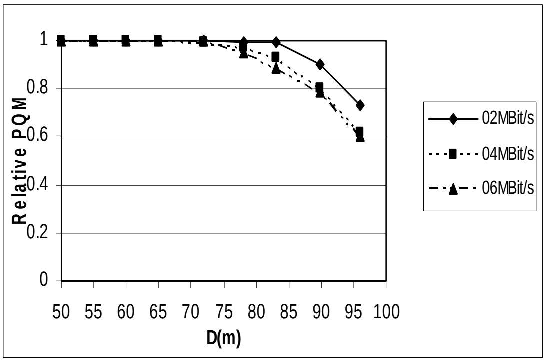


Figure 3. Relative PQM as a function of the distance between AP and STA at 24Mb/s

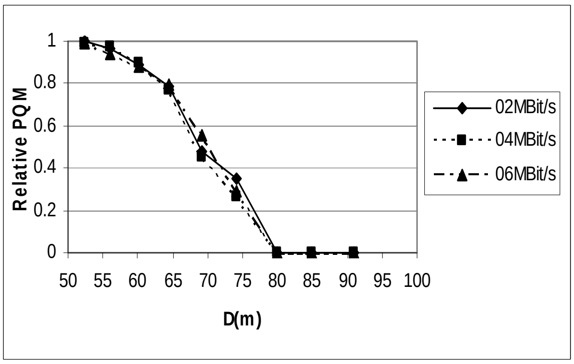


Figure 4. Relative PQM as a function the distance between AP and STA at 36 Mb/s

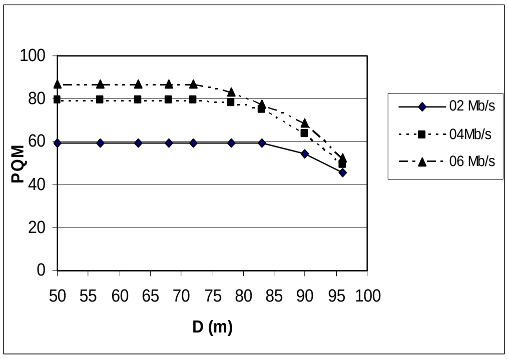


Figure 5. Absolute PQM as a function of the radius at data rate 24 Mb/s

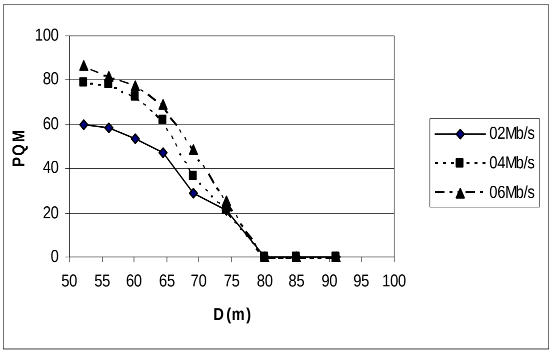


Figure 6. Absolute PQM as a function of the coverage coverage radius at data rate 36 Mb/s