Multicast Video Streaming over WiFi Networks: Impact of Multipath Fading and Interference

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***Abstract*—Delivery of multimedia digital content through wireless networks poses non-trivial performance issues because of scarcity and volatility of the wireless medium. The goal of this study is to analyze the impact of multipath fading and interference on multicast video streaming in an indoor LOS(Line of Sight) wireless environment using off-the-shelf fixed WiFi equipment. Multipath fading experienced by the receivers is represented by empirically estimating ricean K factor from packet traces captured at the receivers. Degradation in the video quality incurred during transmission is quantified by measuring video quality metric(VQM). To quantify the impact of channel interference, controlled traffic is generated on a channel adjacent to the selected channel. We use human movements to alter the depth of signal fading at the receivers. Our experiments show that packet loss increased two times in the face of multipath fading and almost three times in the face of channel interference. The measurements presented in this paper can help users to monitor and maintain the quality of their wireless networks and optimize the use of limited network resources.**

I. Introduction

Wireless Internet is becoming commonplace, at the edge of the wired network, for distributing multimedia content because of increased flexibility and cost-effectiveness. Powerful wireless-enabled portable devices such as smart phones, tablets and laptops make it easier to access multimedia content while on the go. Multicast streaming is very useful for broadcasting live events, conference meetings, IPTV, distance education, etc. Unlike the wired packet switched networks where packet loss and delays are caused by congestion, wireless networks have to cope with unpredictable (random) channel conditions such as multipath fading, interference, path loss, etc. Wireless channel conditions could vary over very short time scale (order of microseconds). In case of 2.4 GHz band, small changes in path lengths can alter the signal highly since the wavelength is only 12.5 cm. Mobility of physical objects and people also impact the signal highly and cause signal envelop to fluctuate at the receiver. Measurement studies of fading report signal variations as high as 15-20 dB [1] [2]. Furthermore, because of license free access to the 2.4 GHz ISM band, it is difficult to avoid (inter/intra)-radio interference from other wireless networks, and other radio devices.

Therefore, multicast video streaming over wireless networks is more challenging as compared to their wired counterparts. As the UDP/IP communication stack does not provide any error detection and error correction scheme for multicast delivery over wireless channels, video quality can suffer from loss of information aggravated by multipath fading and radio interference. Furthermore, because the wireless network is broadcast in nature, a packet is transmitted only once and will reach all the recipients. If the sender transmits regardless of whether receivers are ready or not, serious loss of data may result.

The objective of the paper is to quantify the impact of interference, fading and signal attenuation on goodput, packet loss and ultimately on the video quality experienced by end user in a wireless (802.11 b/g) local area network(WLAN) environment. We use *ricean K factor* as a measure of multipath fading, spectrum analyzer to estimate channel interference and *received signal strength indicator (RSSI)*) as indication of signal power and attenuation. Furthermore, we use *VQM*(Video Quality Metric) [12] score to compare the quality of received video with that of original video. In order to realistically measure forementioned metrics, we conducted extensive wireless experiments against six test cases representing common real-world situations using off-the-shelf wireless equipment. Also, we study the relative impact of channel interference and multipath fading.

The remainder of this paper is organized as follows. In section II, we provide details about network performance and video quality metrics, evaluation methodology, and wireless scenario. Section III provides details about the results and analysis. Section IV concludes the paper.

II. Indoor LOS experiments for multicast video streaming

In this section, we present key metrics, measurement methodology and our multicast video streaming scenario. Key metrics were carefully chosen to represent channel characteristics as well as user level performance indicators. An indoor wireless testbed was set up using normal laptop machines. Two wireless networks were configured one for video streaming and one for generating adjacent channel interference. Video streaming network consists of multicast streaming server, client stations and probes. One spectrum analyzer was employed to log the entire 2.4 GHz band during the course of each experiment run. The scenario was subdivided into 6 test cases to reflect various channel conditions in different situations. The performance was evaluated using a well-defined set of performance and quality metrics as explained in section II-A.

A. Metrics

The metrics are categorized into primary and secondary metrics. *Secondary metrics* are concerned with the channel characteristics and include ricean K factor, RSSI and channel interference. These metrics can undergo high variations depending on the channel conditions. *Primary metrics* indicate network performance and depend on secondary metrics. Also they make more sense to the end user. We selected goodput, packet loss and VQM (Quality Video Metric) score [12] as primary metrics. For metrics such as K factor, RSSI, goodput and packet loss, results are averaged over 5 measurements to ensure accuracy and confidence intervals are computed to signify the level of fluctuations around the mean result. In this subsection, we explain the selected metrics and the mechanism to calculate each of them.

1) Channel interference and RF activity in 2.4 *GHz ISM band:* Because the radio spectrum used by wireless LAN (WLAN) is freely available for public and research use, it is usually highly congested. Interference occurs when communication from one node impedes communication from another node. Interference can be caused by not only wireless networks but also by devices such as wireless game controllers, Bluetooth, microwave, WiMAX, etc. The purpose is to capture frequency fluctuations in the entire wireless spectrum of either 2.4 GHz band (or at least adjacent channels) and study the impact of the level of interference on performance metrics such as packet loss, goodput, etc. The level of interference is quantified by computing average signal power over all the collected RF samples. Average signal power is relatively higher in the presence of channel interference.

Spectools [7] is configured to log frequency fluctuations for 2.4 GHz band. It collects information consisting of frequency range 2.400 to 2.483 at 419 points with a step size of 119 kHz.

2) Ricean K Factor: Ricean distribution is similar to rayleigh distribution except that a deterministic strong component is present. It is completely defined by ricean K factor. K factor is defined as the ratio of the signal power in dominant component to the (local-mean) signal power in multipath components. When the dominant component between the transmitter and the receiver disappears, K approaches 0 and ricean distribution degenerates to Rayleigh distribution. Therefore, the higher K is, the less multipath fading is. We estimate K factor from empirical power samples using a moment based method as explained in [9]. Received power measurements are extracted from the received packets and K is obtained using the following equation

$$K = \frac{\sqrt{1-\gamma}}{1-\sqrt{1-\gamma}} \tag{1}$$

where $\gamma = {}^{V[R^2]}/(E[R^2])^2$, with $V[.]$ denoting the variance, E[.] denoting the expectation and R denoting the received signal envelope. According to the literature, equation 1 gives fairly accurate estimation of K for a sample size of at least 500. In our estimation, each K value is calculated using 20,000 samples on average.

3) Received Signal Strength Indicator(RSSI): RSSI is a measure of power present in the RF signal. RSSI implementation varies from vendor to vendor. In madwifi, RSSI is equivalent to signal-to-noise ratio and essentially is a measure of signal power above the noise floor. It is calculated for each packet by subtracting noise power from the received signal power.

4) Packet Loss ratio: Packet loss ratio is ratio of the number of packets lost to the total number of packets transmitted. It is estimated by examining RTP sequence numbers of the received packets.

5) Goodput: Goodput is computed using a time window of 100 ms. In our wireless scenario, as the traffic is generated at low rate (at most 1 Mbps), we are able to signify goodput fluctuations better using the said time window.

6) Video Quality Metric(VQM): VQM [12] is an objective measure of video degradation (compared to the original video) which reflects the human visual system (HVS). Quality estimates are reported on a scale from zero to one. On this scale, zero means that no impairment is visible and one means that the video clip has reached the maximum impairment level.

B. Methodology

We use VideoLAN VLC [4] to stream an MPEG-4 video clip to multicast clients from the streaming server. On each client, the video stream is captured into a file. At the same time, probes are used to capture packet trace of the video stream. We didn't use the same node to capture both packet trace and video stream for performance reasons. Instead, each probe and each multicast client were placed on top of each other to ensure similar reception conditions. Captured video files are analyzed using BVQM (Batch Video Quality Metric) tool. Packet traces are loaded into a MySQL database and desired performance metrics are computed using SQL based analysis scripts.

C. Video Streaming Scenario

We employ one multicast streaming server, four multicast clients, one interference generator and four probes. Packet trace with radiotap wireless headers is captured using TCP-Dump. RF activity in the 2.4 GHz band is recorded using Wi-Spy spectrum analyzer [6]. More information is provided in Table I.

1) Configuration: We setup a wired local area network (LAN) using MyPLC [3] in order to manage wireless testbed resources. For scenario configurations, experiment workflow and data collection, we employ WEX(Wireless EXperimentation) toolbox [10]. The specifications of the network equipment and tools are shown in Tables II and III.

2) Placement of nodes: Around 20 nodes are installed in 8×5 m room in a regular fashion as shown in Figure 1. The nodes used in wireless video streaming scenario are *multicast streaming server (MS)* (labeled in red), experiment *control server*, *probes*, *multicast clients*, *interference generator* and

TABLE I
MULTICAST VIDEO STREAMING SCENARIO

Node	Qty.	Role
Multicast Server (MS)	1	Serves as both AP and Video Streaming Server. Channel=11, multicast PHY rate=24 Mbps
Multicast Clients (MCs)	4	Receive and capture the video stream. Channel=11
Probes	4	Capture radiotap packet trace. Channel=11
Interference Generator	1	Serves as both AP and traffic generator. Channel=10, PHY rate = 24Mbps, data rate = 11Mbps
Spectrum analyzer	1	Employes Wi-Spy 2.4x spectrum analyzer and kismet spectrum tools

TABLE II
WIRELESS SCENARIO (HARDWARE SPECIFICATIONS)

Hardware	Specifications
Computers	Dell Latitude E6500 laptops
Wireless Card (built-in)	Intel WiFi Link 5300 AGN
Wireless Card (External)	Atheros 5212 PCI card (For experimental wireless network)
Spectrum Analyzer	Wi-Spy 2.4x
Processor	Two x86-based Intel core duo processors (@ 2.4 GHz)
Physical Memory	4 GB

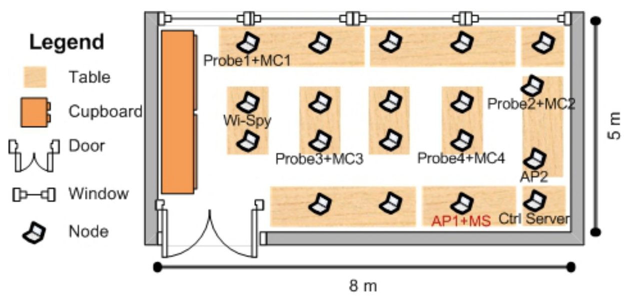

Fig. 1. Wireless testbed setup and placement of nodes

Wi-Spy. The nodes are placed on top of wooden tables with metal structures underneath. All of the stations are at 0.75 m height from the floor. The room is located at the top floor of a 3-floor building and is not RF isolated from the outside world. Actually, many APs are present at the different floors of the building, which makes possible to run experiments in a real working environment.

3) Software Parameters: Wireless tools for Linux [8] version 29 is used for interface configurations. VLC is used generate multicast video stream. In order to harness MetaGeek's Wi-Spy 2.4x portable USB spectrum analyzer [6], we use open-source tools from kismet known as Kismet spectrum tools [7] with custom modifications.

4) Hardware Parameters: Wi-Spy 2.4x is configured to scan radio activity in the entire 2.4 GHz band. We use Atheros wireless card (GWL $G650$) with Madwifi (Multimode Atheros driver for Wi-Fi on Linux) version $0.9.4$ revision 4128 from the trunk. Antenna diversity is disabled on all the machines in order to get consistent K factor values.

5) Wireless Parameters: MAC and PHY revisions used by the driver are 2414 and 2413 respectively. Channel type

TABLE III
WIRELESS SCENARIO (SOFTWARE SPECIFICATION)

Software	Specifications
OS	Fedora 10 (Kernel 2.6.27.14)
Wireless driver	MadWifi 0.94 revision 4928
Sniffer	TCPDump
Packet analyzer	Tshark
Spectrum Analysis Tools	Kismet Spectrum Tools [7]
Wireless Tools	Wireless Tools for Linux version 29 [8]
Streaming Server and Clients	VLC 1.1.7
Video	Format = MPEG, bit rate = 800 kbps, fps = 25, resolution = 640 x 360

is *IEEE 802.11g* (operates in 2.4 GHz frequency range). Fragmentation, RTS and retries are turned off. Transmission (TX) power is fixed at 6 dBm. The maximum transmission power for our Atheros wireless cards is 6 dBm.

6) Time duration: The total time duration, for which traffic is generated and results are calculated, is 200 seconds.

7) Workload generation: We use an MPEG-4 video clip to stream over the wireless network using VLC as streaming server. Video clip is transcoded using MPEG-4 codec and transmitted using RTP protocol. The video is played for a duration of 200 seconds.

8) Scenario Test Cases: The entire video streaming experimentation campaign consists of six test cases as shown in Table IV. The first 4 test cases were carried out in the afternoon during office hours. Two more cases were tested in non-office hours, when the spectrum is usually quieter, to focus on the impact of only multipath fading on packet loss.

TABLE IV
TEST CASES

Test case	Office hours	Description	Runs
1	Yes	Video streaming + controlled interference − human movements	5
2	Yes	Video streaming − controlled interference − human movements	5
3	Yes	Video streaming + controlled interference + human movements	5
4	Yes	Video streaming − controlled interference + human movements	5
5	No	Video streaming − controlled interference + human movements	5
6	No	Video streaming − controlled interference − human movements	5

III. ANALYSIS: MULTICAST VIDEO STREAMING PERFORMANCE

In this section, we demonstrate plots for the metrics described in section II-A and explain the results in the light of various factors such as channel interference, multipath fading, signal attenuation, etc. The results in section III-A correspond to the measurement campaign conducted during office hours when interference from production networks is

Fig. 2. Snapshot of received video on multicast client(MC) 2 in test case 2

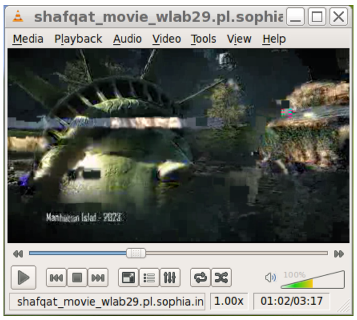

Fig. 3. Snapshot of received video on multicast client(MC) 2 in test case 3

high. However, the level of interference from external networks was comparatively lower during test cases 3 and 4. So despite higher multipath fading during test cases 3 and 4, network performance slightly improved. This is because performance improvement brought by reduced interference overshadowed the packet loss induced by increased multipath fading. In order to demonstrate this, we added test cases 5 and 6 [Table:IV] to understand the impact of multipath fading in greater isolation from interference. The results for experiments conducted during the two cases are reported in section III-B.

A. Measurements during office hours

1) Snapshot of captured videos : Figures 3 and 2 are temporal snapshots from videos captured on multicast client(MC) 2 during two different test cases. Figure 3 shows a snapshot which underwent slight degradation because of loss of data due to interference and mobility in the environment (Table IV:case 3). Figure 2 shows a frame which has better image quality. The snapshot belongs to the case when there was no interference and no mobility in the environment (Table IV:case 2). In the subsequent subsections, results are obtained based on packet analysis.

2) Channel interference and radio activity in 2.4 *GHz band:* The RF landscape in 2.4 GHz wireless band during the course of one wireless experiment is shown in the Figure 4. Spectrum information captured by Wi-Spy spectrum analyzer is in the form of frequency vs. amplitude. For graphical demonstration, we map entire band 2400 - 2483 MHz each frequency to the corresponding 14 WiFi channels.

Figure 5 shows the evolution of channel interference during 6 test cases. Overall interference (per channel) for channels

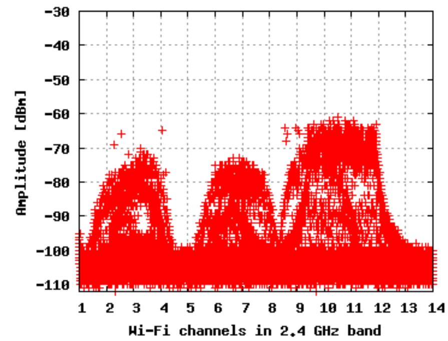

Fig. 4. Spectrum analysis in test case 6

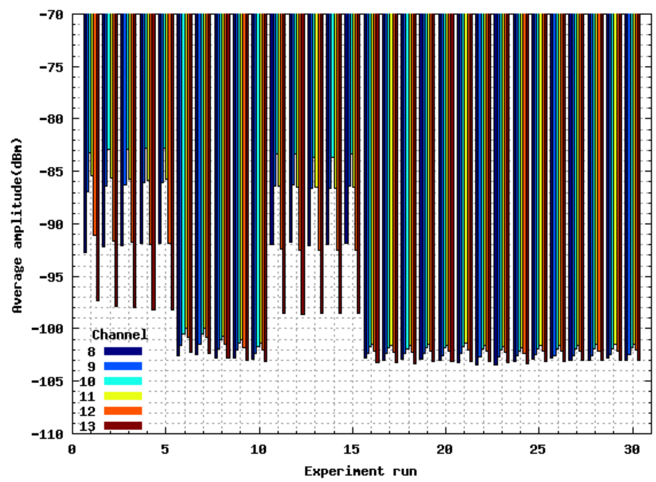

Fig. 5. Average signal power per channel per run in test cases [1,6]

[8, 13] is estimated by averaging all the frequency amplitudes falling in the frequency range of each channel. Channel interference results in an increase in average signal amplitude in that channel. It is evident that during first 3 test cases (especially in test cases 1 and 2) interference is higher than rest of the cases. The impact of interference on goodput and packet loss is demonstrated in subsections III-A5 and III-A6.

3) Ricean K Factor: Figure 6 shows the impact of each test case on multipath fading. Large value of K signifies lower multipath fading which is the case in test cases 1 and 2 [IV] when there are no movements in the environment. Small value of K means greater depth of fading which is the case for test cases 3 and 4 when there are human movements. This fact is further explained by sub figures in the Figure 7 which demonstrate received power at Probe 2 in 4 test cases [IV]. The band representing received power in case 1 and 2 is thinner than cases 3 and 4, therefore K factor is greater in cases 1 and 2 than in cases 3 and 4. Both location of receivers and movement of objects in the environment have a clear impact on the fading. In the first 4 test cases, the impact of fading on packet loss is not obvious as shown in Figure 10 and goodput as shown in Figure 9 because of substantial interference from external networks. The behavior is investigated more in section

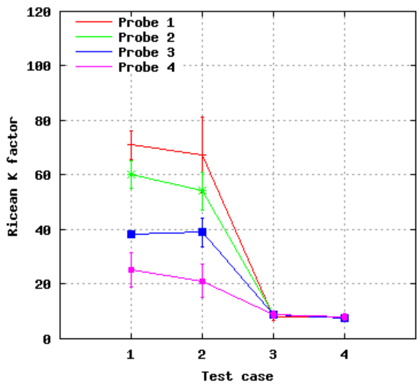

Fig. 6. *K factor* averaged over 5 runs

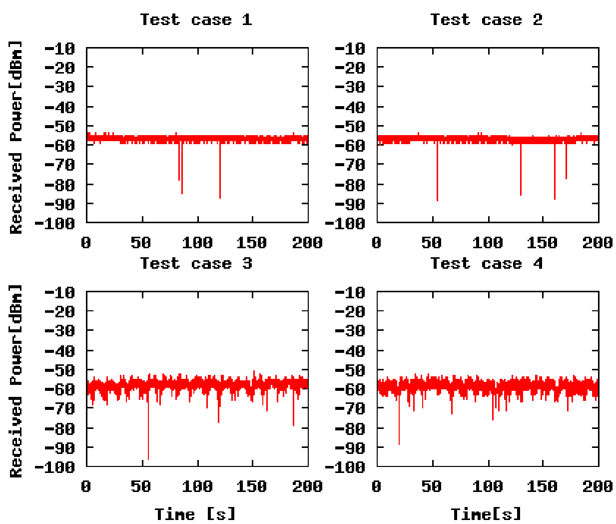

Fig. 7. Received power recorded at Probe 2 in test cases [1,4]

III-B.

4) RSSI: As it is obvious from the Figure 8, average RSSI remains pretty much same despite fluctuations caused by the movements in the wireless environment. Because all the receivers are placed within the same room, the signal is strong enough and the transmission power at AP, does not have any noticeable impact on packet loss and K factor. Furthermore K factor depends more on signal fluctuations rather than the strength of the signal as shown in Figure 6.

5) Goodput: Figure 9 shows average goodput as well as goodput variations(confidence intervals) as measured on each probe. There is a drop in goodput at all the probes in cases 1 and 3 when there is more interference comparative to the cases 2 and 4 [Table IV].

6) Packet loss ratio: Packet loss incurred at each probe during the course of experiments, corresponding to the first 4 test cases [Table IV], is demonstrated in Figure 10. There is higher packet loss when there is more interference in the wireless environment.

7) VQM (Video Quality Metric): We use BVQM tool [11] in order to assess the quality of captured videos on multicast

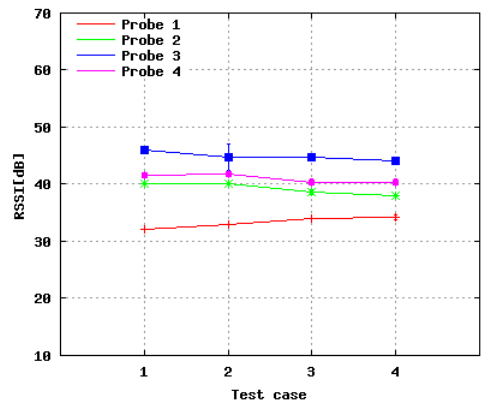

Fig. 8. *RSSI* averaged over 5 runs

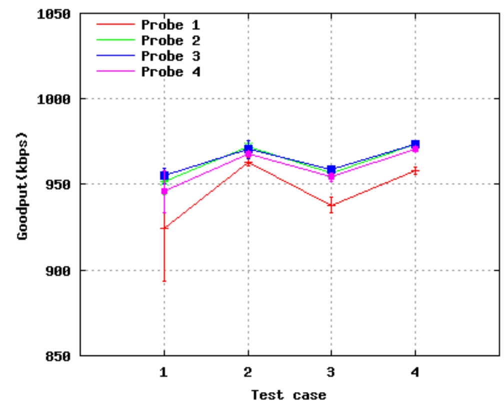

Fig. 9. *Goodput* averaged over 5 runs

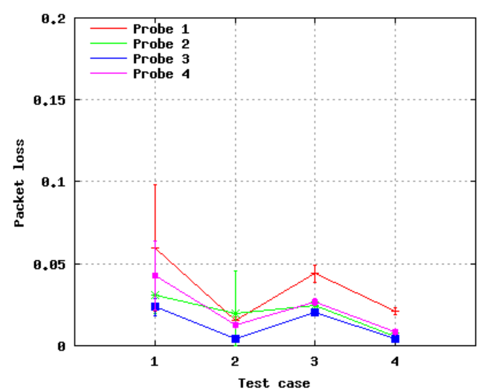

Fig. 10. *Packet loss ratio* averaged over 5

clients. Video is calibrated using *full reference calibration* model and VQM is computed using *video conferencing* model. Video *scanning standard* is set to *progressive*. One video (out of 5) on each multicast client is selected against each test case. Figure 11 shows the results for 24 such videos that belong to test cases 1 to 6 [Table:IV]. Videos clips 1 to 4 (corresponding to clients 1 to 4) belong to case 1, next 4 clips belong to test case 2 and so on. Because of size limitations imposed by

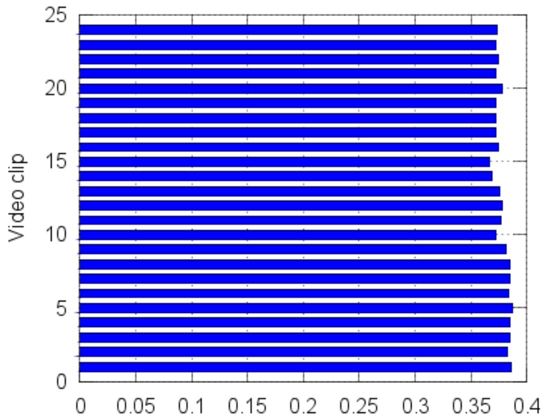

Fig. 11. Quality of video received at each client in cases [1 6]

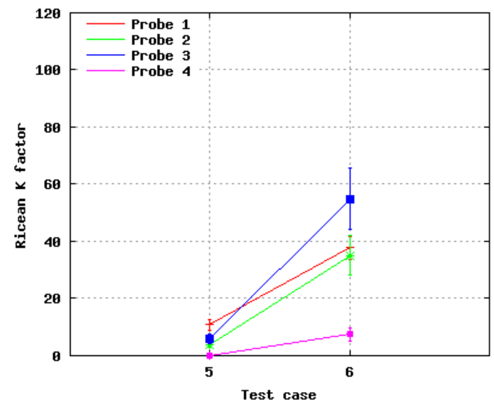

Fig. 12. *K factor* averaged over 5 runs

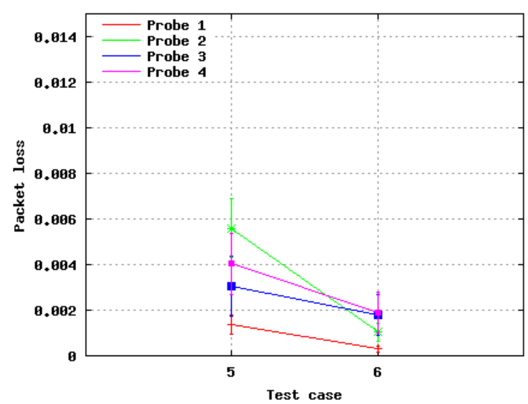

Fig. 13. *Packet loss ratio* averaged over 5 runs

BVQM, VQM analysis was performed on first 15 seconds of each video clip. Therefore, the VQM score reported in Figure 11 represents video quality degradation during first 15 out of 200 seconds for each video clip. The lower the VQM score is, the lower the distortion is. For clips corresponding to test cases [1,4], overall VQM score is higher than overall VQM score of clips received during test cases [5,6]. We believe that these differences would become more prominent if VQM could be calculated over full length of each video clip. Video Clips [1,16] were captured during office hours when ISM radio spectrum is very busy. Therefore, interference played a dominant role in video quality degradation.

B. Measurements during non-office hours

Figure 13 demonstrates the impact of ricean fading on packet loss. Each packet loss value has been averaged over 5 runs. In the face of movements in the wireless environment [test case 5], ricean K factor on average fell below 10 as shown in Figure 12. This caused almost 50% increase in packet loss. However, the packet loss reported in Figure 13 against cases 5 and 6 is much lower than the packet loss reported in Figure 10 against cases 1, 2, 3 and 4. This is because there was significant interference from production networks during office hours which caused more packet loss compared to multipath fading. The impact of fading became prominent when the 2.4 GHz spectrum was less congested during non-office hours.

IV. Conclusion

We conducted six sets of multicast video streaming experiments over 802.11b/g WLAN against six test cases corresponding to different realworld situations with varying levels of exogenous interference and signal fading. It is shown that interference has more impact on performance than multipath fading. Multipath fading can result in considerable performance degradation in environments where moving objects cause perturbance. On the contrary, channel interference is more frequent and more prominent cause of performance degradation in wireless networks because ISM 2.4 GHz band is increasingly being utilized in homes and work places. Being able to quantify the impact of multipath fading and interference is crucial in planning, troubleshooting, managing as well as benchmarking and optimizing wireless networks.

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