Evaluation of Wireless High Definition Video Transmission using H.264 over WLANs

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***Abstract*—Many challenges and limitations stand in the way of streaming high resolution video content over a wireless network. A shift towards the 60-GHz band is taking place in order to accommodate for current High Definition streaming demands. However, today's Wi-Fi networks are able to provide the necessary bandwidth with the help of compression. In this paper we evaluate the effectiveness of streaming video over wireless LANs using the H.264 codec. Our study shows that streaming HD content wirelessly over 802.11n is a viable option. However, perceptual quality of video is affected by the amount of background traffic and the presence of interfering nodes, i.e., hidden nodes.**

I. Introduction

Wireless video transmission is an important technology for consumer electronics, such as digital television (DTV), mobile multimedia devices (e.g., smartphones, mobile video terminals, and pad/tablet devices), and video telephony. However, streaming video, especially high definition (HD) video, over bandwidth limited wireless media poses a significant challenge. Recently, technologies such as *Wireless Home Digital Interface* (WHDI) [1] and *Wireless High Definition* (WirelessHD) [2] have emerged to allow transmission of uncompressed HD video. WHDI operates at 5 GHz at a data rate of 3 Gbps with a Non-line-of-sight (NLOS) range of about 100 feet. On the other hand, WirelessHD operates in the 60 GHz spectrum at a maximum data rate of 28 Gbps, but requires Line-of-sight (LOS) that limits its range to about 30 feet. These technologies, referred to as *wireless HDMI*, are attractive replacements for HDMI cables.

Alternatively, existing 802.11 networks also make wireless transmission of video possible with the help of compression, and the ubiquity of such networks allows for a wide range of consumer applications. However, the question still remains as to how 802.11 fares with enormous demands of HD video transmission. Full HD video (1080p @60fps) encoded with H.264 using Main Profile and Level 4.2 can require a data rate of up to 50 Mbps, which may stress a typical 802.11g network. Moreover, the crowded WiFi spectrum needs to be shared with multiple devices within carrier sense range of each other and is prone to interference from other on-going transmissions due to the hidden node effect. However, the future of 802.11 networks is bright for wireless video transmission as new strides are being made to increase their bandwidth with efforts such as 802.11ac [3] and the Wireless Gigabit Alliance (WiGig) [4].

Numerous studies have been performed to analyze video transmission of H.264 over 802.11b [5]–[9], 802.11g [10] and 802.11n [11]. Error resilient features of H.264 have been observed by way of corrupting videos with synthetic packet loss [12]–[15]. Studies have also been performed on the proposed 802.11e standard for QoS [16]–[18]. However, with the exception of [9], which studied Scalable Video Coding (SVC), none of the prior efforts are based on experimentation of real testbeds. Typically, Network Simulator 2 (NS2) is the main platform used. In addition, most of these studies (with the exception of [10], [11], [18]) used videos no larger than CIF resolution (352×288), which are not consistent with current home entertainment demands. There are also 802.11n-based commercial solutions such Apple's AirPlay™ [19], Intel's WiDi [20], and Cavium's WiVu™ [21]. However, as with any commercial products, their measured quality is unknown.

Therefore, this paper presents our evaluation of wireless transmission of HD video over WLANs using H.264. The evaluation was performed using both a real testbed and simulation. The testbed consisted of three laptops that serve as receivers and a laptop, iPad2, and iPod Touch as a set of senders. The simulation was carried out using the *Open Evaluation Framework for Multimedia Over Networks* (OEFMON) [22], which was developed at Korea Advanced Institute of Science and Technology (KAIST) and integrates a multimedia module

TABLE I
DEVICE SPECIFICATION.

Device	Specification
Laptop1∼3	2.4 GHz Intel Core 2 Duo processor 4GB 1067 MHz DDR3 memory
Laptop4	2.5 GHz Intel Core 2 Duo processor 4 GB 667 MHz DDR2 memory
iPad2	1 GHz dual-core A5 Application processor 512 MB memory
iPod	1 GHz A4 Application processor 256 MB memory

and a network simulator. The OEFMON tool allows us to not only study networks that are difficult to create with testbeds, but also facilitates evaluation of perceptual video quality as well as network performance to provide additional insight into the issues that take place within the network.

Our study shows that streaming HD content wirelessly over 802.11n is a viable option. However, perceptual quality of video is affected by the amount of background traffic and the presence of interfering nodes, (i.e., hidden nodes). The rest of the paper is organized as follows: Sec. II presents the experimental study using a testbed. Sec. III discusses the simulation study using OEFMON. Finally, Sec. IV concludes the paper and discusses our future work.

II. EXPERIMENTAL STUDY

Our testbed consists of HD video streamed among six mobile devices (four laptops, an iPad2, and an iPod Touch) connected as an ad hoc network using both 802.11n and 802.11g radios on channel 9. The specifications for the devices are listed in Table I. The open source *VLC Media Player* is run on all devices for streaming and playback [23]. The RTP protocol is used for streaming and network statistics are gathered using *Wireshark* [24]. The test video is a 10-second clip from *Battlefield 3* encoded with H.264 (Main Profile, L4.2) at 1080p @60fps generating an average bitrate of 20 Mbps. This video is representative of current trends in high-end video entertainment. The trailer is in fact a new video game title that will soon hit the market.

Our experiments were based on the following three configurations: (1) laptop-to-laptop stream (L2L), which serves as the primary video stream for the performance study, (2) L2L with an iPod-to-laptop interference stream (L2L+iPod), and (3) L2L+iPod with a second iPad-to-laptop interference stream (L2L+iPod+iPad). Note that all video streams are the same Battlefield clips.

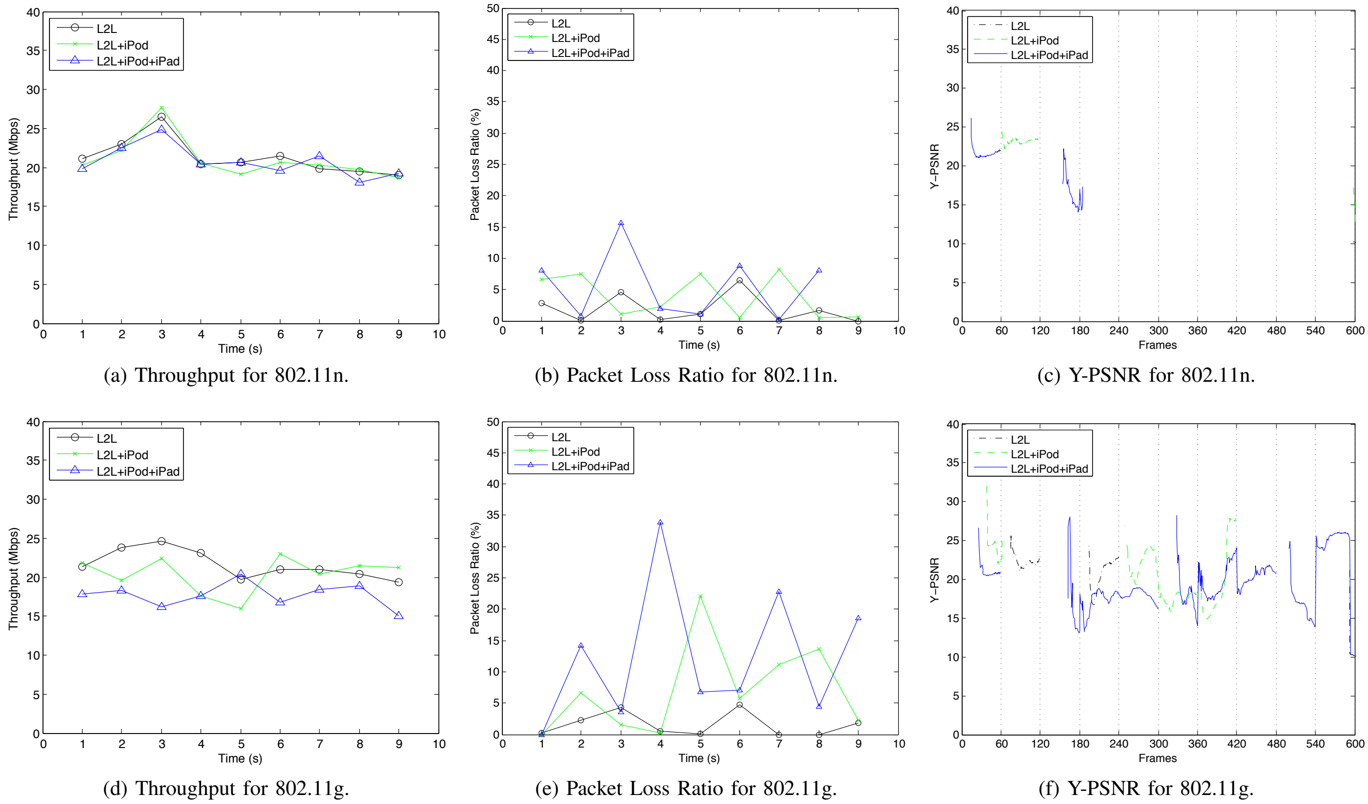
Fig. 1 shows the throughput, packet loss ratio (PLR), and luminance peak signal-to-noise-ratio (Y-PSNR) for both 802.11n and 802.1g from the perspective of the primary video stream (L2L) for all three configurations. Fig. 1a shows throughput for 802.11n, which closely matches the encoded bitrate of the corresponding video clip for all three configurations. Fig. 1d shows throughput for the same configurations in an 802.11g network. These results show that throughput for the primary video stream suffers with reduced bandwidth of 802.11g and becomes worse as additional interference streams are added. This can be explained by the higher maximum transmission rate available in 802.11n, which was consistently at 145 Mbps versus 54 Mbps for 802.11g. This in turn leads to higher packet loss as shown in Figs. 1b and 1e, particularly when throughput of the primary video stream reaches its peak (16% for 802.11n and 35% for 802.11g).

Figs. 1c and 1f show the quality of the received videos. Both the sent and received videos are decoded to raw YUV sequences. These graphs clearly indicate the advantage of using 802.11n for streaming full HD video. Perfect PSNR (the blank segments of the graph) is observed for large portions of the streamed video with background traffic. No distortion is observed throughout the entire video for the L2L configuration. In contrast, major degradation is experienced by the primary video stream for 802.11g, especially when both the iPod and iPad2 generate additional background traffic. The portions of degraded video come to an average Y-PSNR of 19.56 dB for the latter case. Note that I-frames occur at intervals of every 60^{th} frame, as depicted by the dotted lines in the figures, and do have a role in restoring quality to the primary stream. However, when packet losses are severe as in the case of 802.11g, this is short-lived and the quality of the video quickly degrades. For the L2L+iPod+iPad configuration, 69 frames are dropped as opposed to 15 for L2L+iPod and 9 for L2L alone. Lost frames are replaced by duplication of the previous frame, which is a typical decoder behavior.

For the most part, PLR shown in Figs. 1b and 1e coincide well with the reduction in video quality depicted in Figs. 1c and 1f, respectively. Increases in PLR cause noticeable degradation in video quality, particularly for the L2L+iPod+iPad case in 802.11g. However, for the L2L configuration in 802.11n, there is some packet loss but no degradation in Y-PSNR. This is most likely due to the nature of the video, types of packet losses, missing packets (i.e. not captured), the error concealment features used in VLC, and as with any testbed, limitations that prevent precise control over the various parameters. We are currently investigating these relationships and their affect on video quality.

III. SIMULATION STUDY

The simulation portion of our evaluation was performed using OEFMON [22]. OEFMON integrates the *DirectShow* multimedia framework and the *QualNet* [25] network simulator, resulting in a versatile, modular framework for evaluating video quality with respect to network performance. OEFMON requires three primary inputs. The first input is a *YUV 4:2:0 video source*. The primary video selected for this study was 300 frames (10 seconds of 1920×1080 @30fps) from the *African Cats* trailer. The second input is a *DirectShow filter graph*, which is used to specify the encoding/transmission/decoding process that the YUV input file will go through. For this evaluation, the raw input file was encoded using the MONOGRAM H.264 encoder [26] and then passed to QualNet via the OEFMON QualNet Connector filter to undergo simulated wireless network transmission. The received packets



(a) Throughput for 802.11n. (b) Packet Loss Ratio for 802.11n. (c) Y-PSNR for 802.11n.

(d) Throughput for 802.11g. (e) Packet Loss Ratio for 802.11g. (f) Y-PSNR for 802.11g.

Fig. 1. Experimental Results.

are then passed to a decoder (for this evaluation, the CoreAVC decoder [27] was used) and then saved as a decoded YUV file. The third input is a *QualNet network configuration file*, which details node placements, types of communications between nodes, and other various network settings such as network type and link speed.

Three network configurations were constructed for the purposes of this simulation study. Configuration 1 represents a typical single source, single destination scenario where one device streams the primary video to another device via an ad-hoc network. Configuration 2 represents a dual source, dual destination scenario where two videos are being streamed simultaneously. The primary video is streamed from Device 1 to Device 2, as before, but a secondary video is streamed from Device 3 to Device 4. The secondary video is a 10 Mbps of CBR data representing a video encoded at H.264 Level 3.1 (1280×720 @30fps). Configuration 3 repeats the network traffic of Configuration 2, but the nodes are now positioned in a classical hidden-node arrangement.

Fig. 2 shows the placement of devices for all three configurations implemented as ad-hoc 802.11g (QualNet does not currently support 802.11n) networks with a link speed of 18 Mbps.

Fig. 3 shows the performance from the perspective of the primary video stream in terms of end-to-end delay, throughput, PLR, and Y-PSNR for all three configurations. Fig. 3a shows that there is an increase in delay from Configuration 1 to

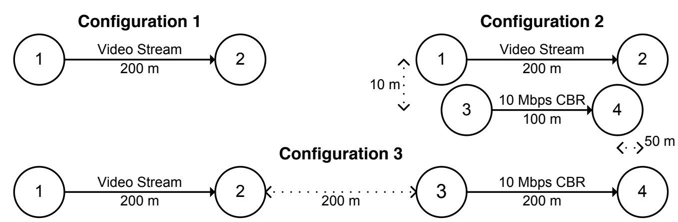
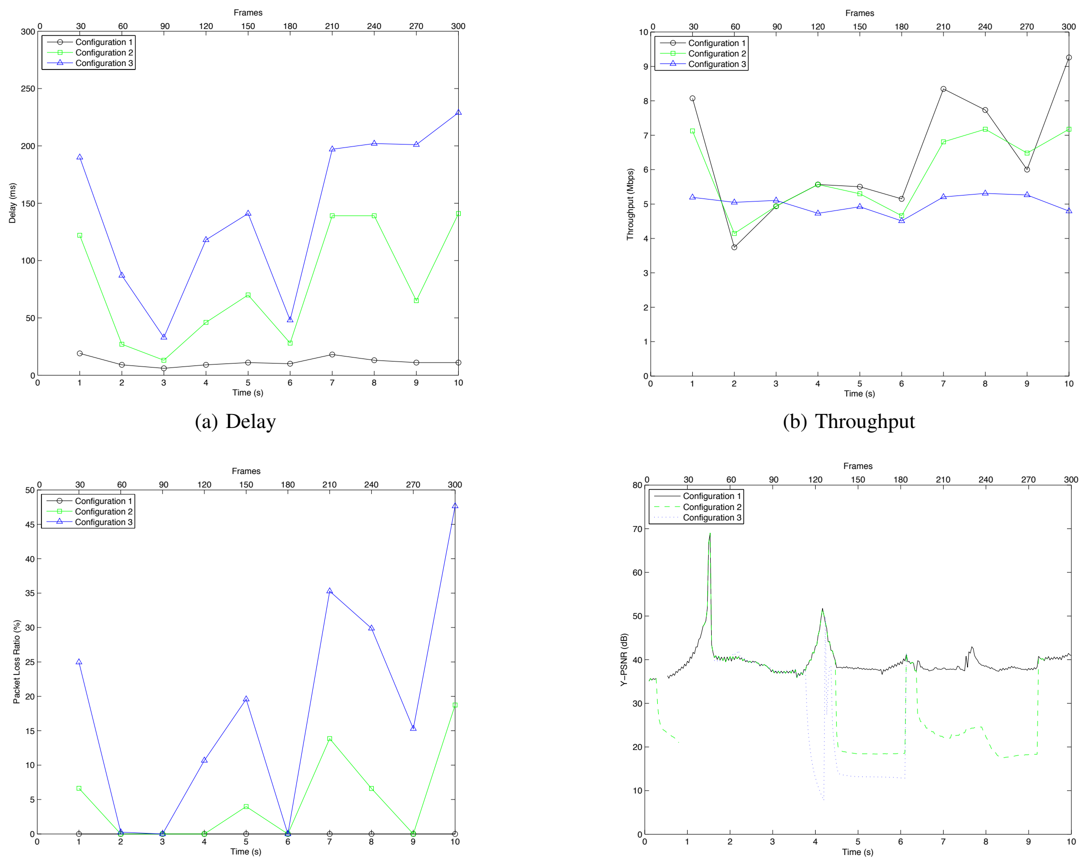


Fig. 2. Simulated Network Scenarios

Configuration 2, and a further increase in delay from Configuration 2 to Configuration 3. The former can be attributed to a significant increase in average time spent by packets in the outbound queue. This is a direct result of competition to seize the wireless medium between the primary video stream and the CBR stream. The latter is also due to increased average time spent by packets in the outbound queue. However, in this case the extra delay is due to increased packet retransmissions due to ACK timeouts at the MAC layer, caused by packet collisions resulting from the hidden-node effect.

Fig. 3b shows that the throughput for Configuration 1 is the highest among the three configurations and serves as an indication of the amount of data the video transmission generates when unconstrained. Fig. 3b also shows that in Configurations 2 and 3, the network is unable to meet the throughput demands of the video source due to severe network congestion and hidden-node-induced collisions, respectively. Although there



(a) Delay

(b) Throughput

(c) Packet Loss Ratio

(d) Y-PSNR

Fig. 3. Simulation results

are a couple data points where Configurations 2 and/or 3 appear to achieve a higher throughput than Configuration 1, this is simply a side effect of the whole-second averaging process used by OEFMON to generate performance results. When averaged over the entire 10 seconds, the throughput of Configuration 1 is clearly higher than Configuration 2, which in turn achieves a higher throughput than Configuration 3.

Fig. 3c shows that Configuration 1 exhibited no packet loss while Configuration 2 exhibited minor packet loss during parts of the transmission, sometimes even leading to lost frames. On the other hand, Configuration 3 resulted in major packet loss. These packet loss ratio results also relate directly to the throughput results. Figs. 3c and 3b together clearly show that the larger the difference between throughput demand and achieved throughput, the larger the percentage of packets lost. Additional packet losses in Configuration 3 occur due to hidden-node collisions.

Occasionally, there are no packet losses in the congestion scenario, or even in the hidden-node scenario. This is a result of the bursty characteristics of CBR traffic generation used in QualNet. In our simulations, CBR data is generated as a 2500 byte item being sent every 2 ms, which yields an effective bitrate of 10 Mbps. If a 2500 byte item is successfully sent relatively early within its 2 ms interval, then the primary video stream will have uncontested use of the wireless medium for the rest of the 2 ms. This is a limitation of using CBR to represent a second, background video stream.

Fig. 3d shows the Y-PSNR results for all three configurations. These results are best interpreted in terms of packet loss. When Figs. 3c and 3d are considered together, there is a direct correlation between packet loss and degradation in user-perceived quality. For packet loss of 0∼15%, there is a significant decrease in user-perceived quality. Fig. 4 shows the received frame 24 for Configurations 1 and 2 (frame 24 for Configuration 3 was lost entirely and thus not shown). For Configuration 1, this received frame has a Y-PSNR of 37.8 dB, with a corresponding high user-perceived quality. For Configuration 2, this received frame has a Y-PSNR of 21 dB, with a corresponding low user-perceived quality. The low quality of this Configuration 2 frame is due to the loss of AC component and motion vector data for many macro blocks from the previous several frames. The exact PLR values that lead to entire frames being lost is mostly a function of a specific decoder's implementation. For the CoreAVC decoder, our results show that when packet loss is more than 15%, entire frames are lost. As an example of this relationship, Fig. 3d shows that frames 188∼300 are lost for Configuration 3, while in Fig. 3c, frames 188∼300 correspond to PLRs that

(a) Configuration 1 (b) Configuration 2

Fig. 4. Received frame number 24.

are consistently above 15%.

IV. Conclusion and Future Work

The results of our experimental and simulation studies show that, while 802.11g has fundamental bandwidth limitations that prevent successful wireless transmission of multiple HD videos, 802.11n with H.264 continues to be a viable method for wireless streaming of HD video. This conclusion is supported by the recent increase in popularity of consumer devices that utilize 802.11n to facilitate wireless video transmission. However, there are still some situations which can have a diminishing effect on 802.11n's ability to provide wireless video content, specifically severe network congestion and hidden-node scenarios.

Our future plan is to continue developing and expanding our wireless video transmission evaluation toolset, with the goal of researching and evaluating new techniques in error resiliency, error concealment, and MAC-layer optimizations, all in order to make H.264 over 802.11n more robust and efficient.

References

[1] [Online]. Available: http://www.whdi.org/

[2] [Online]. Available: http://www.wirelesshd.org/

[3] [Online]. Available: http://www.ieee802.org/11/Reports/tgac_update.htm

[4] [Online]. Available: http://wirelessgigabitalliance.org/

[5] C. Calafate, M. Malumbres, and P. Manzoni, "Performance of h.264 compressed video streams over 802.11b based manets," in *Distributed Computing Systems Workshops, 2004. Proceedings. 24th International Conference on*, march 2004, pp. 776 – 781.

[6] P. Bucciol, E. Masala, N. Kawaguchi, K. Takeda, and J. De Martin, "Performance evaluation of h. 264 video streaming over inter-vehicular 802.11 ad hoc networks," in *Personal, Indoor and Mobile Radio Communications, 2005. PIMRC 2005. IEEE 16th International Symposium on*, vol. 3, sept. 2005, pp. 1936–1940.

[7] E. Masala, C. Chiasserini, M. Meo, and J. Martin, "Real-time transmission of h.264 video over 802.11b-based wireless ad hoc networks," in *DSP for In-Vehicle and Mobile Systems*, H. Abut, J. H. Hansen, and K. Takeda, Eds. Springer US, 2005, pp. 193–207.

[8] A. Moid and A. Fapojuwo, "Application layer optimization for efficient video streaming over ieee 802.11 based wireless networks," in *Electrical and Computer Engineering, 2009. CCECE '09. Canadian Conference on*, may 2009, pp. 789 –793.

[9] A. Detti, P. Loreti, N. Blefari-Melazzi, and F. Fedi, "Streaming h.264 scalable video over data distribution service in a wireless environment," in *World of Wireless Mobile and Multimedia Networks (WoWMoM), 2010 IEEE International Symposium on a*, june 2010, pp. 1 –3.

[10] D. Li and J. Pan, "Performance evaluation of video streaming over multi-hop wireless local area networks," *Wireless Communications, IEEE Transactions on*, vol. 9, no. 1, pp. 338 –347, january 2010.

[11] R. Stapenhurst, D. Agrafiotis, J. Chung-How, and J. Pledge, "Adaptive hrd parameter selection for fixed delay live wireless video streaming," in *Packet Video Workshop (PV), 2010 18th International*, dec. 2010, pp. 142 –149.

[12] S. Wenger, "H.264/avc over ip," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 13, no. 7, pp. 645 – 656, july 2003.

[13] S. Kumar, L. Xu, M. K. Mandal, and S. Panchanathan, "Error resiliency schemes in h.264/avc standard," *Journal of Visual Communication and Image Representation*, vol. 17, no. 2, pp. 425 – 450, 2006, introduction: Special Issue on emerging H.264/AVC video coding standard.

[14] X. Zhang and X. Peng, "An unequal packet loss protection scheme for h.264/avc video transmission," in *Information Networking, 2009. ICOIN 2009. International Conference on*, jan. 2009, pp. 1 –5.

[15] X. Wang, K. Tang, and H. Cui, "A novel unequal error protection scheme for roi based video coding in h.264/avc," in *Computer Modeling and Simulation, 2010. ICCMS '10. Second International Conference on*, vol. 3, jan. 2010, pp. 175 –178.

[16] A. Ksentini, M. Naimi, and A. Gueroui, "Toward an improvement of h.264 video transmission over ieee 802.11e through a cross-layer architecture," *Communications Magazine, IEEE*, vol. 44, no. 1, pp. 107 – 114, jan. 2006.

[17] B. J. Oh and C. W. Chen, "Performance evaluation of h.264 video over ad hoc networks based on dual mode ieee 802.11b/g and edca mac architecture," in *Circuits and Systems, 2008. ISCAS 2008. IEEE International Symposium on*, may 2008, pp. 3510 –3513.

[18] R. MacKenzie, D. Hands, and T. O'Farrell, "Effectiveness of h.264 error resilience techniques in 802.11e wlans," in *Wireless Communications and Networking Conference, 2009. WCNC 2009. IEEE*, april 2009, pp. 1–6.

[19] [Online]. Available: http://www.apple.com/appletv/

[20] [Online]. Available: www.intel.com/WirelessDisplay

[21] [Online]. Available: http://www.caviumnetworks.com/PureVu_WiVu-Solution.html

[22] C. Lee, M. Kim, S. J. Hyun, S. Lee, B. Lee, and K. Lee, "OEFMON: An open evaluation framework for multimedia over networks," *IEEE Communications Magazine*, pp. 153–161, September 2011.

[23] [Online]. Available: http://www.videolan.org/

[24] [Online]. Available: http://www.wireshark.org/

[25] *QualNet 5.0.2 User's Guide*, Scalable Network Technologies, Inc., 2010.

[26] [Online]. Available: http://blog.monogram.sk/janos/2009/05/20/monogram-x264-encoder-1050/

[27] [Online]. Available: http://corecodec.com/products/coreavc

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