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Improving the Efficiency of Wireless Multi-Hopping of MPEG-4 AVC Video Stream in WAN

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Abstract**—** Video streaming has become the application that drives the Internet to a new height. In this paper, we analyze and evaluate the performance of H.264-based video streaming over multi-hop wireless local area networks (WLANs). Contrary to common believes that adding relays in the same wireless channel may increase coverage but has to reduce throughput, our analysis and simulation results show a wide spectrum of coverage-capacity tradeoff in generic scenarios and confirm previous measurement observation in specific cases.

Keywords**—** H.264-based video streaming; wide spectrum

I. INTRODUCTION

Recently, video streaming and IPTV (Internet Protocol Television) have attracted a lot of attention. One of the challenges in video streaming and particularly for IPTV is how to distribute the video streams already delivered to the doorstep of residential customers among almost all rooms in a household environment. Ethernet is a preferred technology, but rewiring is expensive and sometimes prohibitive. Therefore, wireless technologies, particularly IEEE 802.11-based ones, become the first choice by many consumers for home networks. So far, delivering High-Definition TV (HDTV) signals over wireless with high bandwidth and low delay/jitter requirement is still a challenge. Due to wall attenuation, obstacle shadowing, and multi-path fading, the throughput and coverage achieved by a single wireless Access Point (AP) are limited and vary a lot. Multi-hop wireless networks have emerged, such as those enabled by Wireless Distribution System (WDS), but their performance is yet to be understood in real environment, especially due to the concern that adding more relays in the same wireless channel may increase coverage but has to reduce achievable throughput. In this paper, we further our investigation on video streaming over multi-hop wireless LANs with more emphasis on performance analysis and evaluation, in order to understand the coverage-capacity tradeoff in more generic scenarios. We have extended Bianchi's two-dimensional Markov chain model [1] to consider transmission error, retry limit and post backoff in both saturated and unsaturated cases. Simulation results also confirm the efficacy of the extended model. Using a multirate extension to the Network Simulator version 2 (ns-2) we have evaluated the application-oriented performance metrics such as Peak Signal-to-Noise Ratio (PSNR) and frame delay/jitter for video streaming over multiple hops and with multiple streams.. In this paper first, we build the analysis and simulation models to capture the characteristics of video streaming over multi-hop wireless networks, especially for H.264-based HDTV in-home distribution over IEEE 802.11 WDS. Second, our analysis and simulation results reveal a wide spectrum of the coverage-capacity tradeoff and help identify how to achieve the best possible balance. We believe this work is of particular importance for service providers that are deploying IPTV services.

II. RELATED WORK

To capture the characteristics of video streaming over household wireless networks, we consider the non-ideal channel condition, retry limit and post backoff in our analysis model in this paper. Video streaming over wireless networks has also received a lot of attention in recent years, and here we only list the most relevant related work. On the performance evaluation side, there is work focusing on video streaming over existing IEEE 802.11 WLANs with different encoding schemes, background traffic, packet size and so on, and proposing the optimal encoding and MAC layer parameters for certain scenarios [4]. On the performance improvement side, there is work following application level approaches, such as retransmission, channel resource allocation and Forward Error Control [3], [12], to deal with high packet loss and delay variation in wireless networks. However, most existing work focuses on single-hop scenarios using legacy IEEE 802.11b. For IPTV in-home distribution, the coverage and throughput of a single AP are very limited. To deliver multiple highquality video streams across the house, it is advantageous to use multi-hop IEEE 802.11g networks with higher and more flexible TxRate, which is the focus of this paper.

III. THROUGHPUT ANALYSIS

In order to evaluate the throughput of multi-hop wireless networks, we propose a bi-dimensional discrete time Markov chain model in this section. Our model focuses on unsaturated traffic in non-ideal channel condition, and takes retry limit and post backoff into account. We assume the collision probability pc at each transmission attempt is a constant regardless of previous attempts. We also assume that the transmission error caused by channel impairments such as attenuation, shadowing and fading is independent of transmission collision, and the error probability pe is a constant as well. We define an equivalent transmission failure probability p as follows:

$$p = 1 - (1 - pe)(1 - pc) = pc + pe - pcpe \qquad (1)$$

We model the backoff counter in wireless nodes by state (i, k) as shown in Fig. 1, where $0 \le i \le r$ is the backoff stage, $0 \le k \le Wi - 1$ is the current backoff counter value, r is the retry limit and Wi is the Contention Window (CW) size. Wi = 2iW0 when $0 \le i \le m$, where m = log2Wm/W0, and W0 and Wm are minimal and maximal CW size, respectively; when $m < i \le r$, Wi = Wm. If the transmission fails with probability p due to collision or error, it enters stage i+1 with a backoff counter uniformly chosen from [0,Wi+1 −1]. If the transmission succeeds, the node enters stage 0 with probability q when there is another packet to transmit; otherwise it enters the so-called post backoff stage −1; in either case, a backoff counter is uniformly chosen from [0,W0−1]. During the post

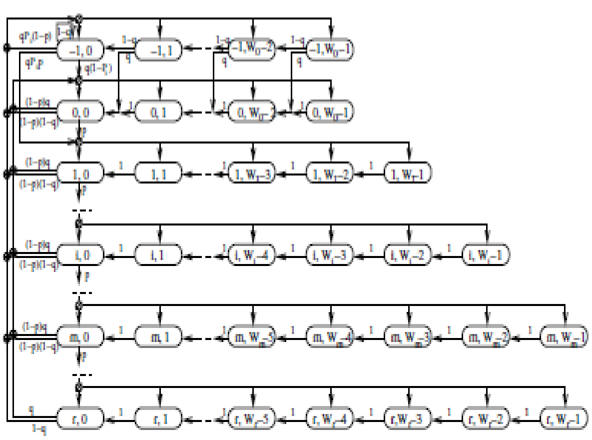

Fig. 1. Bi-dimensional Markov chain with unsaturated traffic, retry limit and post backoff stage in non-ideal channel condition

backoff stage, if a packet arrives, the node enters stage 0 and inherits its stage −1 counter; if the counter is already 0 in stage −1 and the medium is free with probability Pi, the packet can be transmitted immediately. The state transition probabilities in the model are given by the following:

$$\begin{cases}
P[(i,k-1)|(i,k)] = 1 & 0 < i \le r, 0 < k \le W_i - 1 \\
P[(-1,k-1)|(-1,k)] = 1-q & 0 < k \le W_0 - 1 \\
P[(0,k-1)|(-1,k)] = q & 0 < k \le W_0 - 1 \\
P[(-1,k)|(i,0)] = \frac{(1-p)(1-q)}{W_0} & 0 \le i < r, 0 \le k \le W_0 - 1 \\
P[(0,k)|(i,0)] = \frac{(1-p)q}{W_0} & 0 \le i < r, 0 \le k \le W_0 - 1 \\
P[(-1,k)|(r,0)] = \frac{1-q}{W_0} & 0 \le k \le W_0 - 1 \\
P[(0,k)|(r,0)] = \frac{q}{W_0} & 0 \le k \le W_0 - 1 \\
P[(-1,0)|(-1,0)] = 1 - q + \frac{qP_i(1-p)}{W_0} & \\
P[(-1,k)|(-1,0)] = \frac{qP_i(1-p)}{W_0} & 0 < k \le W_0 - 1 \\
P[(1,k)|(-1,0)] = \frac{qpP_i}{W_1} & 0 \le k \le W_1 - 1 \\
P[(0,k)|(-1,0)] = \frac{q(1-P_i)}{W_0} & 0 \le k \le W_0 - 1 \\
P[(i,k)|(i-1,0)] = \frac{p}{W_i} & 0 < i \le r, 0 \le k \le W_i - 1
\end{cases}$$

First, the transition probability from (i, 0) to all stage i + 1 states has been replaced by p, taking into account both transmission collision and error, especially due to the channel impairments in household environment. Second, after r +1 transmission attempts, the node will enter either a stage 0 or −1 state regardless of the outcome of the last transmission attempt, i.e., the packet is dropped if the last attempt fails, which is defined in IEEE 802.11 standard and preferred by video streaming to reduce packet delay and jitter. Third, unsaturated traffic and post backoff are considered in our model, which can capture the burstiness of H.264-encoded video streams and the increasing load of multiple streams. After some mathematical manipulation, we get the relation among the steady-state stationary probability b(−1, 0), b(0, 0) and b(1, 0) for state (−1, 0), (0, 0) and (1, 0), respectively.

$$b(0,0) = \left(\frac{q^2 W_0}{1-(1-q)^{W_0}} - qP_i(1-qp)\right)\frac{b(-1,0)}{(1-q)} \qquad (2)$$

$$b(1,0) = pb(0,0) + qpP_i b(-1,0) \qquad (3)$$

Applying the normalization condition, we can obtain

$$\begin{aligned}
1 &= \sum_{i=1}^{r}\sum_{k=0}^{W_i-1} b(i,k) + \sum_{k=0}^{W_0-1} b(0,k) + \sum_{k=0}^{W_0-1} b(-1,k) \\
&= \frac{2W_0(1-(2p)^r)(1-p) + (1-2p)(1-p^r)}{2(1-2p)(1-p)} b(1,0) \\
&+ \frac{q(W_0+1)}{2}(qpP_i + 1 - P_i)b(-1,0) \qquad (4) \\
&+ \frac{q^2(W_0^2+W_0) - 2q + 2q(1-q)^{W_0}}{2(1-(1-q)^{W_0})} b(-1,0) \\
&+ \frac{q(W_0+1)}{2} b(0,0) + b(-1,0)
\end{aligned}$$

The transmission probability τ of a wireless node in a given time slot is given by

$$\tau = \frac{1-p^r}{1-p} b(1,0) + b(0,0) + qP_i b(-1,0) \qquad (5)$$

Suppose all nodes in same network have homogeneous traffic, then Pi is given by

$$P_i = (1-\tau)^{n-1} = \frac{1-p}{1-p_e} \quad (6)$$

Since we have six unknown variables in six independent equations (1), (2), (3), (4), (5) and (6), we can solve them by numerical methods and obtain τ and p. With the per node transmission probability τ , we can define Ptr, the probability that at least one node in an n-node network attempts to transmit in a given time slot, by

$$P_{tr} = 1-(1-\tau)^n \quad (7)$$

We define the conditional successful transmission probability, Ps, as only one node transmits and all other n − 1 nodes defer on the condition that at least one node should transmit in a given time slot, so Ps is given by

$$P_s = \frac{n\cdot\tau\cdot(1-\tau)^{n-1}}{P_{tr}} \quad (8)$$

The system throughput is defined by the fraction of time that the channel is used to successfully transmit payload bits.
Let E[PL] denote the expected payload length. Let Tc and Te be the average channel time that the medium is sensed busy when there is transmission collision and error, respectively. Let Ts be the average channel time for a successful transmission. The system throughput S is given by

$$S = \frac{P_{tr}P_s(1-p_e)E[PL]}{(1-P_{tr})\sigma + P_{tr}(1-P_s)T_c + P_{tr}P_s(1-p_e)T_s + P_{tr}P_sp_eT_e} \quad (9)$$

where σ is the slot time defined in IEEE 802.11 standard.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of video streaming through analytical calculation and network simulation. We first outline our evaluation methodology, including simulation model and configuration. We then validate our analysis and simulation models with throughput evaluation in both saturated and unsaturated cases. After that, we focus on the video performance evaluation by simulation in different multihop scenarios and with multiple background video streams.

A. Evaluation Methodology

For calculation, we used numerical methods to solve the equation set (1)–(6). After obtaining τ , we calculate Ptr, Ps and system throughput S by following (7)–(9) with Tc, Te, and Ts defined in IEEE 802.11 standard. For a given SNR and packet size, we used the Trivellato's IEEE 802.11g PER table in dei80211mr [2] to obtain the correspondent pe. For simulation, we used ns-2 with the dei80211mr extension. In order to better capture the realistic wireless channel and advanced IEEE 802.11g features such as multi-rate PHY, we applied the dei80211mr extension to ns-2 for an SINR based packet-level error model. That is, each packet is evaluated individually by the received signal power, noise level and interference power, as well as packet capture effect. We have found that the ns-2 with dei80211mr extension can give close approximation to the performance observed on our testbed. To emulate a real environment, we set the wireless transmission power to 18 dBm and retry limit to 7, the same as those of Linksys WRT54GL routers used in our wireless testbed. All wireless nodes work in IEEE 802.11g OFDM-only mode, and the TxRate set is 6, 12, 18, 24, 36, 48 and 54 Mbps (9 Mbps is excluded since it is always worse than 12 Mbps with the same SNR due to modulation reasons). Multiple relay routers are distributed evenly in between the video source (e.g., residential gateway) and destinations (e.g., set-top boxes).

B. Throughput Evaluation

We first calculate the saturated throughput following our analysis model. We used a Log-Normal shadowing model with path loss exponent of 5 to emulate an in-door, non-line-of-sight environment. The source-destination distance is set to 18 m, which we consider as the maximum distance in a typical North American single-family house and is of our most interest since it shows the bound of achievable performance. We obtained the Packet Error Ratio (PER) at 6, 9 and 18 m from the transmitter with packet size of 1500 bytes and SNR 31, 22 and 7 dB. At a given distance, PER increases with TxRate, since a higher data rate modulation and coding scheme requires a higher SNR. Also, PER increase is not linear to the increase of TxRate. The tradeoff between increased TxRate and PER becomes obvious for the calculated saturated end-to-end throughput listed in Table I. When the PER increase is moderate, increased TxRate reduces the transmission time for a packet and increases saturated throughput, e.g., when TxRate is increased from 6 to 12 Mbps for the 1-hop scenario. However, an excessive PER increase with a higher TxRate can reduce saturated throughput considerably due to many more failed transmission attempts and dropped packets, e.g., when TxRate is increased from 12 to 18 Mbps for the 1-hop scenario and from 48 to 54 Mbps for the 2-hop scenario. Thus, it is only meaningful to use a higher TxRate when PER increase is not significant, so in the following, we only focus on the best TxRate for data and video traffic evaluation, i.e., 12, 48 and 54 Mbps, for the 1-hop, 2- hop and 3-hop scenario, respectively.

TABLE I
SATURATED END-TO-END THROUGHPUT AT 18 M BY CALCULATION

TxRate (Mbps)	6	12	18	24	36	48	54
1-hop Thruput	5.26	**9.71**	5.03	0	0	0	0
2-hop Thruput	2.53	4.72	6.67	8.35	11.22	**13.45**	10.92
3-hop Thruput	1.62	3.04	4.30	5.40	7.32	8.85	**9.61**

In Fig. 2, we plot the achieved throughput from calculation by lines, and that from simulation with an average of 20 runs by connected points. We present two groups of simulation results with 0 and 7 dB SNR deviation in the shadowing model, respectively. The achieved throughput increases almost linearly with the increased offered load until the network is saturated.

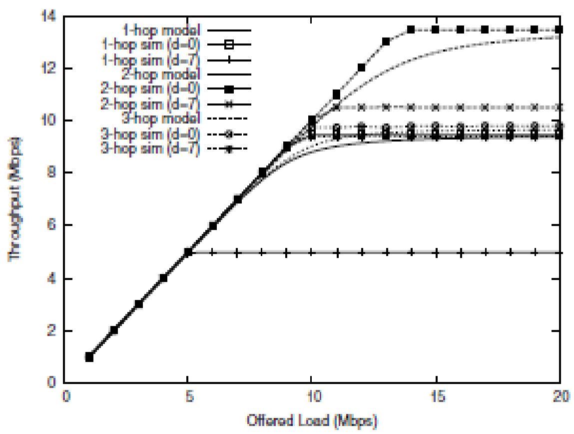

Fig. 2. Throughput vs. offered load by calculation and simulation.

As shown in Fig. 2, the achieved throughput from simulation for all scenarios with 0 dB SNR deviation matches closely to that predicted by calculation, which also shows the validity of our analysis model. However, the achieved throughput is affected by a 7 dB SNR variation, especially for the 1-hop scenario where the average SNR is only 7 dB. For 2-hop and 3-hop scenarios with a higher average SNR, their performance is much less affected, which also shows the efficacy of our analysis model. In a typical household environment, signal quality varies quite often due to various obstacles. Therefore, in the following, we only present the simulation results with the highest SNR variation for all scenarios. To give a big picture on how source-destination separation affects achievable performance, we show in Fig. 3 the maximum achieved throughput with the best possible TxRate and highest SNR variation. Normally, when the source-destination distance increases, the saturated throughput decreases, no matter for 1-hop, 2-hop or 3-hop scenarios, but the throughput drop has very different behaviors. The saturated throughput in 1-hop scenario drops much faster with the increased distance than 2-hop and 3-hop ones. To achieve the highest possible

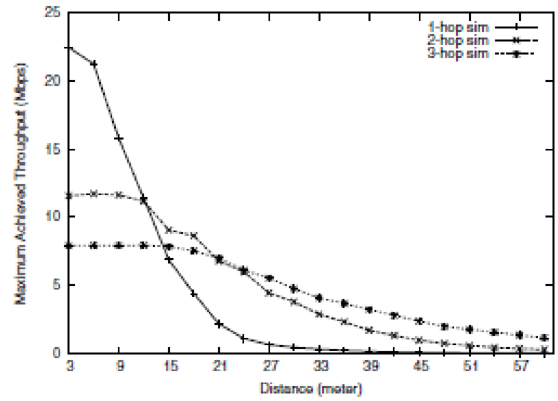

Fig. 3. Saturated throughput with increased source-destination distance.

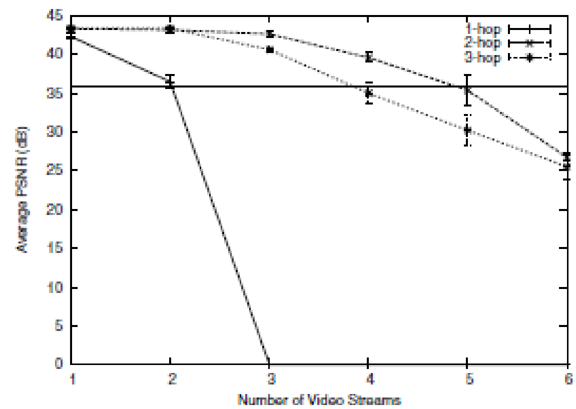

Fig. 4. Average PSNR of the first video stream with background streams.

throughput, the choice for a multi-hop scenario is different at different distance. When the source-destination separation is small (e.g., lower than 12 m), there is no need to introduce any wireless relay nodes, since the SNR for 1-hop is high enough to support a higher TxRate at low PER, while multi-hop scenarios are dominantly constrained by link contention. Between 12 and 15 m, 2-hop achieves higher saturated throughput than 1-hop, but 1-hop still achieves higher saturated throughput than 3-hop, due to the heavy link contention in 3-hop scenario. Only after 24 m, 3-hop achieves higher saturated throughput than 2-hop, and 2-hop achieves higher than 1-hop. This figure shows the intrinsic tradeoff between transmission error and link contention in multi-hop wireless networks.

C. Video Performance

In addition to throughput, we also focus on PSNR and frame delay/jitter for video performance evaluation. Our video streaming simulation used a trace-driven traffic generator.

The sample video is a 2-minute Sony HDTV camera demo with resolution 1280x720 at 24 frames per second. The video stream is compressed by the H.264 reference encoder [8], and the average and peak data rate are around 2 Mbps and 32 Mbps, respectively. To emulate a typical wireless home router, we set the wireless transmission interface queue size at 1024 KB. The simulation trace was processed by Evalvid [6] for video performance evaluation. The details of the simulation setting and video evaluation method can be found in [7].

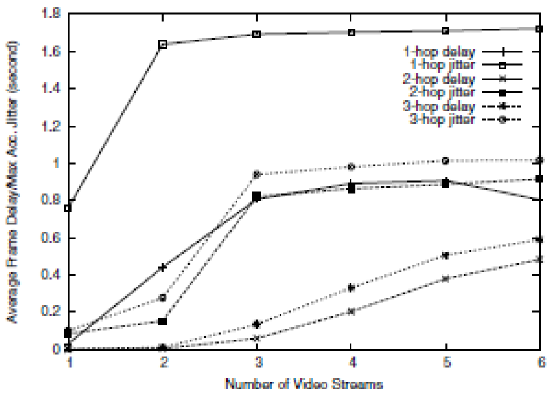

Fig. 5. Average frame delay and maximum accumulated frame jitter.

Fig. 4 shows the average PSNR of the first video stream with a different number of background video streams for different scenarios. Since the achieved throughput of the 2-hop scenario is about 10 Mbps and the average video stream data rate is 2 Mbps, it is supposed to serve five streams. To avoid frame synchronization, streams have their inter-arrival time uniformly chosen from 4.5 to 5.5 s. Here, PSNR reflects the fidelity of the reconstructed video when compared to the original one. Higher PSNR means that the received video has higher quality. From the figure, we can see that the average PSNR decreases as the number of concurrent video streams increases, since the increased contention for wireless channel and interface queue can cause more video frames to be dropped. However, the 2-hop scenario has much lower PSNR loss than the 1-hop or 3-hop scenario due to a reasonable link contention and higher SNR to support a higher TxRate. Due to the high burstiness in H.264 encoded video, the 2-hop scenario can actually support four concurrent streams with acceptable video quality, while the 1-hop and 3-hop scenarios can only support two and three, which is greatly less than their CBR capacity. It is also interesting to see that although 3-hop achieves its CBR capacity close that of 2-hop, its video performance is much lower and close to that of 1-hop. Video streaming is sensitive to delay/jitter introduced by the network. In Fig. 5, we show the average frame delay and maximum accumulated jitter for different multi-hop scenarios with multiple concurrent video streams. With more video streams competing for wireless channel and interface queue, it is intuitive that frame delay/jitter will increase. However, the delay/jitter increase in the 2-hop scenario is much slower than in other scenarios. This is due to the fact that in the 3-hop scenario, video traffic has to go over the air three times before arriving at the destination, and in 1-hop scenario, although video traffic goes over the air just once, it is more likely to suffer transmission error due to a lower SNR and take more time for retransmission. Therefore, both 1-hop and 3- hop suffer higher frame delay/jitter.

V. CONCLUSIONS

In this paper, we investigated H.264-based video streaming over multi-hop IEEE 802.11g wireless networks. An extended two-dimension Markov chain model is proposed to analyze the unsaturated throughput of IEEE 802.11 DCF. With the consideration of retry limit and post backoff stage, the model can capture the IEEE 802.11 features better. Through modeling and analysis, we established a baseline for our video streaming simulation. We adopted an SINR-based extension to ns-2, which provides us a better way to capture the IEEE 802.11g features in a real environment. Extensive simulations have been done on the video performance over multi-hop wireless network. The simulation results reveal the limitation of the traditional single-AP infrastructure mode wireless networks for video streaming, and show the tradeoff between coverage and capacity of multi-hop wireless networks.

REFERENCES

[1] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," Selected Areas in Communications, IEEE Journal on, vol. 18, no. 3, pp. 535–547, 2000.

[2] NS-2 network simulator, //www.isi.edu/nsnam/ns/

[3] D. Malone, K. Duffy, and D. Leith, "Modeling the 802.11 distributed coordination function in nonsaturated heterogeneous conditions," Networking, IEEE/ACM Transactions on, vol. 15, pp. 159–172, 2007.

[4] F. Daneshgaran, M. Laddomada, F. Mesiti, and M. Mondin, "Unsaturated Throughput Analysis of IEEE 802.11 in Presence of Non Ideal Transmission Channel and Capture Effects," Wireless Communications,IEEE Transactions on, vol. 7, no. 4, pp. 1276–1286, 2008.

[5] Majumda, A. and Sachs, DG and Kozintsev, IV and Ramchandran, K. and Yeung, MM, "Multicast and unicast real-time video streaming over wireless LANs", Circuits and Systems for Video Technology, IEEE Transactions on, vol. 12, pp. 524–534, 2002

[6] Stockhammer, T. and Jenkac, H. and Kuhn, G., "Streaming video over variable bit-rate wireless channels", Multimedia, IEEE Transactions on, vol. 6, pp. 268–277, 2004
[7] Ksentini, A. and Naimi, M. and Gueroui, A., "Toward an improvement of H. 264 video transmission over IEEE 802.11 e through a cross-layer architecture", IEEE Communications, vol. 44, pp. 107–114, 2006
[8] E. Setton, T. Yoo, X. Zhu, A. Goldsmith, and B. Girod, "Cross-layer design of ad hoc networks for real-time video streaming," IEEE Wireless Communications, vol. 12, no. 4, pp. 59–65, 2005.
[9] EvalVid, http://www.tkn.tu-berlin.de/research/evalvid/
[10] H.264/AVC reference software, http://iphome.hhi.de/suehring/tml/

