PROACTIVE ENERGY-AWARE VIDEO STREAMING TO MOBILE HANDHELD DEVICES

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In this paper, we present a adaptive middleware solution for power-aware video streaming to mobile handheld devices. Using knowledge of dynamic device parameters(e.g residual energy), changing network noise levels and device mobility patterns, the middleware dynamically determines video streaming properties(e.g video burst sizes) to maximize the user QoS(reduce packet loss) while optimizing power consumption of the device. Specifically, we propose a **proactive** video transcoding and streaming technique that uses global system knowledge to effect power optimization, by transitioning the wireless NIC to sleep mode. Our performance results indicate that such a proactive scheme can reduce the energy consumption of network cards by as much as 70%, even in the presence of network noise and provide graceful video adaptations for better user experience.

1 Introduction

Improving the service lifetimes of low-power mobile devices through effective power management strategies can facilitate optimization of user experience for streaming video on to handheld devices. To achieve this, a system should be able to dynamically adapt to global system changes, such that the entire duration of a requested video is streamed to the user at the highest possible quality, while meeting the power constraints of the user's low-power device. We achieve such an optimal balance between power and performance, by introducing a notion of "*Utility Factor U_F*" for a system, and optimizing the U_F for the system. This approach precludes the system from aggressively optimizing for power at the expense of performance and vice-versa; thereby providing an optimized operating point for the system at all times.

We assume the system model depicted in Fig. 1. The system entities include a multimedia server, a proxy server that utilizes a directory service, a mobility manager service and a realtime video transcoder, the wireless access point and users with mobile low-power wireless devices. The dotted arrows represent the noise at the access point. The multimedia servers stream videos to clients and all communication between the handheld device and the servers are routed through the proxy server, which can transcode the video stream in realtime. An adaptive middleware executes on both the handheld device(lightweight) and the proxy, and performs two important functions. On the device, it obtains residual energy information and feeds it back to the proxy, updates its mobility information on the directory service and relates the video stream parameters and network related control information to underlying layers(OS). On the proxy, it performs a energy-aware video stream adaptation through realtime transcoding. It also regulates the video transmission over the network based on the noise level and the residual power at the device. The proxy utilizes the mobility manager to predictively determine future network noise levels. The proxy implements an adaptation control module that performs the proactive adaptations and admission control.

2 Energy-Aware Video Streaming

In this section, we first identify discrete video transcoding levels for handheld computers. This significantly reduces the realtime video transcoding costs as the transcoding parameters no longer have to be identified in real time. We then briefly describe a *reactive* proxy-based adaptation scheme and suggest a *proactive* scheme that significantly improves the U_F for the system. Finally we present our characterization of the network traffic regulation for energy-aware video streaming. The "*Utility Factor U_F*" is a measure of "user satisfaction" and we specify it as follows: given the residual energy E_{res} on a handheld device, a threshold video quality level (Q_A : $Q_{MAX} \geq Q_A \geq Q_{MIN}$) acceptable to the user, and the time of the video playback T, the U_F of the system is non-negative, if the system can stream the

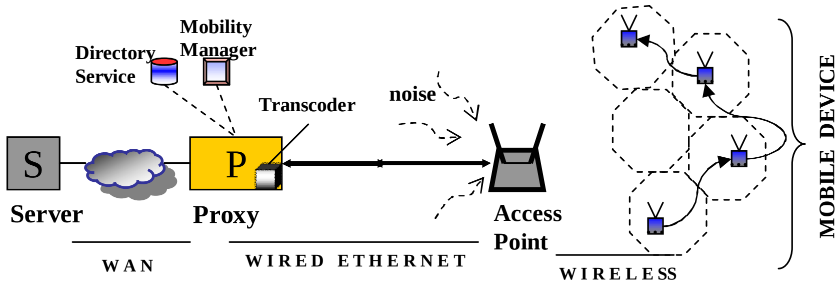

Figure 1. **System Architecture**

highest possible quality of video to the user such that the time, quality and the power constraints are satisfied; otherwise U_F is negative. Let P_{VID} denote the average power consumption rate of the video playback at the handheld and Q_{PLAY} be the quality of video streamed to the user by the system. Using the above notation, we define U_F as follows:

$$U_F = \begin{cases} Q_{PLAY} - Q_{MIN} & \textit{IFF } P_{VID} * T < E_{RES} \\ & \textit{and } Q_{PLAY} \geq Q_A \\ -1 & \textit{Otherwise} \end{cases}$$

2.1 Energy-Sensitive Video Transcoding

We conducted extensive experiments to determine video transcoding levels that have a significant bearing on energy. To validate our assessments, we also conducted an extensive survey to subjectively assess [3] the human perception of video quality on handhelds(iPAQ). We briefly present some of our findings: (i) *It is hard to programmatically identify video quality parameters(a combination of bit rate, frame rate and video resolution) that produced a user perceptible change in video quality and/or a noticeable shift in power consumption in handhelds.* (ii) *For all the video streams on handheld devices, it was enough to use just three standard intermediate formats(e.g SIF(320x240), Half SIF(340x160) and Quarter SIF(160x120)) for frame resolution values. Other resolutions did not produce a perceptible quality change or power uptake compared to the nearest SIF encoded video with similar bit and frame rates.* Based on these conclusions, we identified eight dynamic video stream transformation parameters (Table 1) for our proxy-based realtime transcoding and use the profiled average power consumption values to perform our adaptations.

2.2 Reactive vs. Proactive Adaptation

In traditional proxy-based *reactive* adaptation schemes [1], the proxy reacts to dynamically changing system conditions by adapting video streams (by either lowering or improving stream quality) for improved performance. In this approach, a change in system state is first detected (possibly due to dropped packets, increased noise/congestion levels or low-power at the device), at a potential loss of performance (video jitter). A subsequent adaptation is then performed to react to the global system change, by dynamically exploring an optimal search space for an optimized operating point. To improve performance in such dynamic environments, we propose a *proactive* adaptation scheme in which the proxy "proactively" predicts future system conditions and determines an optimized operating point in advance. Specifically, the middleware at the proxy exploits its cognizance of the optimized network transmission search space, the profiled energy consumption levels of transcoded video streams, the residual power at the client device and the predicted dynamic network noise levels within each cell, to "proactively" adapt the video stream to maximize the end user experience. For example, the proxy middleware can predict the noise/congestion level of a cell just before a user moves into the cell, and determine how to adapt the stream as the user enters the cell. The "mobility manager" can be used to track users in the target cell. Two factors significantly influence the performance of the schemes: dynamic noise levels within each cell and the velocity of the device. We therefore compare the schemes using these criteria. To represent the dynamic noise levels we characterize the noise induced by each mobile device as the following distributions: *constant, random, poisson, uniform.*

Quality	Transformation Parameters	Avg. Power (Windows CE)	Avg. Power (Linux)
(Q8) Like Original	SIF, 30fps, 650Kbps	4.42 W	6.07 W
(Q7) Excellent	SIF, 25fps, 450Kbps	4.37 W	5.99 W
(Q6) Very Good	SIF, 25fps, 350Kbps	4.31 W	5.86 W
(Q5) Good	HSIF, 24fps, 350Kbps	4.24 W	5.81 W
(Q4) Fair	HSIF, 24fps, 200Kbps	4.15 W	5.73 W
(Q3) Poor	HSIF, 24fps, 150Kbps	4.06 W	5.63 W
(Q2) Bad	QSIF, 20fps, 150Kbps	3.95 W	5.5 W
(Q1) Terrible	QSIF, 20fps,100kbps	3.88 W	5.38 W

Table 1. **Energy-Aware Transformations for Compaq Ipaq 3650 with bright backlight, Cisco 350 Series Aironet WNIC card.**

2.3 Energy-Aware Video Stream Regulation

In this section, we characterize a proxy-based traffic regulation mechanism to reduce energy consumption of the wireless network interface. We exploit the fact that wireless network interface(WNIC) cards consume significantly less energy in the *sleep mode* (0.184W) than in the *idle/recv mode*(1.34W/1.435W). In our scheme, the middleware at the proxy, buffers the transcoded video and transmits I seconds of video in a single burst along with the time τ=I for the next transmission as control information. The device then uses this control information to switch the interface to the active/idle mode at time $\tau + \gamma \times D_{EtoE}$, where γ is an estimate between zero and one and D_{EtoE} is the end-to-end network delay with no noise.

Let B be the average video transmission bit-rate, F the video frame rate, S_N the packet size used by the underlying network protocol. Let there be N users in the system. We model each "*other*" user as a Poisson process that injects packets into the network with the packet inter-arrival times following an exponential distribution with rate λ, with a density function of $f(t) = \lambda.e^{-\lambda t}$. Therefore, the number of packets introduced into the network by each user in an interval 't' has an expected value $E(t) = \lambda.t$. Assume that the AP employs a simple round robin service for transmitting packets and let L_{AP} be the buffer length(in number of packets) available at the AP for downstream traffic. Let BW_s, BW_d be the bandwidth available to the wireless device for transmitting and receiving data; T_{AP}, P_d be the queueing transmission delay per packet of the AP and propagation delay of the wireless network respectively. Using the above characterization, the number of packets per frame $\alpha = \frac{B}{8 \times S_N \times F}$ and the total number of packets transmitted in one burst $P_b = \alpha \times F \times I$.

To simplify the analysis, we further assume that there are no loss of packets at the AP due to weak signal strengths or collisions. However, packets do get dropped if the AP buffer capacity (L_{AP}) is less than the number of arriving packets. A queueing theory analysis is used to predict packet loss rates at the AP. If T_b is the time taken to transmit the burst by the proxy, then the total expected number of packets received at the AP in that interval is $\sigma = P_b + \sum_{k=1}^{k=N-1} E_k(T_b)$, where E_k is the expected value of noise from by user k. The worst case expected transmission delay experienced by the last packet in the burst is $D = \sigma \times T_{AP}$. Using the above approach of bursty transmissions, the total "*sleep*" time(δ) of the network interface can be calculated as $\delta = \tau - (D + \gamma \times D_{EtoE})$, neglecting the propagation delay of the final packet. As significant power gains are only achieved when the network interface is in the sleep mode, the total power savings are P_{saved} = δ * (P_{IDLE} - P_{SLEEP}). Observe that large values of I can result in packet losses at the access point and/or buffer overflows at the device. The above analysis can be used by an adaptive middleware to calculate an optimal I(burst length) for any given video stream and noise level. Other approaches for power management of NIC cards have been studied in [2,1].

3 Experimental Results

We simulated the overall system(Fig. 1) with the adaptation mechanisms and energy-aware streaming for measuring the *Utility factor(U_F)* for the system.

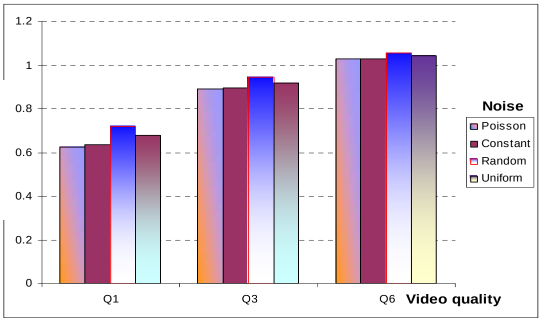

Figure 2. Impact of Noise Patterns

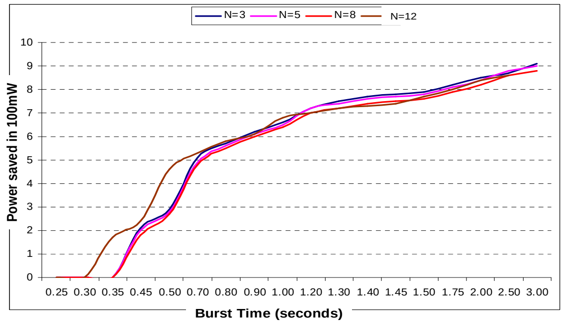

Figure 3. Power Saved vs Burst Time

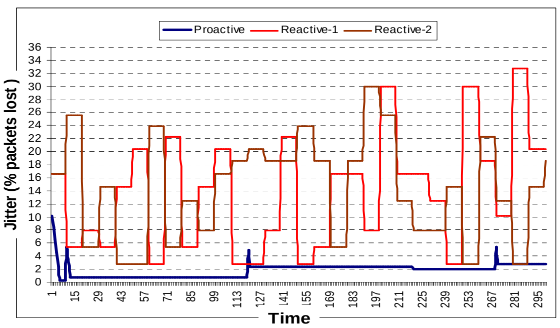

Figure 4. Proactive vs. Reactive

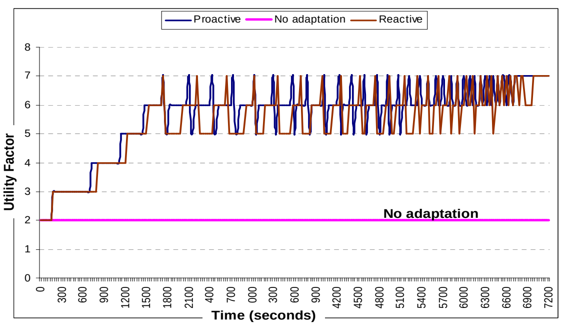

Figure 5. U_F vs. Adaptation scheme

Our simulations were based on measurements made for a Compaq iPAQ 3650 and a 206Mhz Intel StrongArm processor. The iPAQ used a Cisco 350 Series Aironet 11Mbps wireless PCMCIA NIC for communication. In our simulator, a constant end-to-end network delay of 400ms was used; the wired and wireless ethernet bandwidths were set to 10Mbps and 8Mbps(effective B/W, 802.11b is capable of higher throughput) and γ was set to a 0.85. The transmission delay of the wireless access point was also fixed at 400μs per packet. First, for each video quality(Q1-Q8), we varied the video burst time(100ms to 20sec) and the network noise levels(users), the network packet size (200bytes to 700 bytes) and measured the power savings. An incremental mobility model [5] was implemented. Fig. 2 shows the impact of *noise patterns* on the maximum energy saved for different video quality levels. Lower quality streams consume less power, but for a given video quality the distribution used to model the noise has little impact. Fig. 3 shows the variation of power savings with video burst sizes at different noise levels. Using these values a search space is generated for ascertaining optimized video burst times for a particular video quality and noise level. Fig. 4 shows that the proactive adaptation results in a much smoother video when compared to reactive adaptation. Finally, we see in Fig. 5, that using a proactive adaptation scheme a significant improvement in the U_F of the overall system can be achieved.

References

1. Prashant Shenoy and Peter Radkov, “Proxy-Assisted Power-Friendly Streaming to Mobile Devices”, in MMCN 2003.
2. Surendar Chandra, “Wireless Network Interface Energy Consumption Implications of Popular Streaming Formats”, in MMCN 2002.
3. ITU-R Recommendation BT-500.7, “Methodology for the subjective assessment of the quality of television pictures”, ITU Geneva Switzerland.
4. S.Mohapatra, R.Cornea et.al., “Integrated Power Management for Video Streaming to Mobile Handheld Devices”, in ACM MM 2003.
5. Z. Haas, “A new routing protocol for the reconfigurable wireless networks”, in IEEE Personnal Comm. 1997.