Content-Aware Rate Control to Improve the Energy Efficiency in Mobile IPTV services

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Summary
To be able to deploy the mobile IPTV service, energy efficiency is an important design consideration due to the limited battery lifetime of mobile devices. Moreover, the Scalable Video Coding (SVC) scheme, which allows for data rate adaptation without re-encoding, should also be considered for supporting a variety of mobile devices. This paper proposes a new streaming system, called the Content-Aware Streaming System (CASS), which improves energy efficiency by reducing the unnecessary transmission of bitstreams and by reducing the operating time of wireless network interface cards. The proposed streaming system utilizes the Peak Signal to Noise Ratio (PSNR) based on a content-aware and client buffer occupancy on the basis of a network-aware streaming system using SVC. The simulation results demonstrate the effectiveness of the proposed streaming system.

Key words:
Mobile IPTV, Streaming, SVC, PSNR, Rate Control, Energy Efficiency

1. Introduction

Recently, due to the prevalence of various mobile devices and broadband wireless networks, there has been a significant increase in interest and demand for multimedia streaming services such as the mobile IPTV. Continuous playback service in wireless networks is difficult, however, because mobile devices have limited battery lifetime. Energy efficiency should be considered to enable mobile devices to provide continuous playback service [1]. Moreover, wireless networks have limited and arbitrary bandwidth characteristics. These characteristics will cause network congestion. Thus, delivery of multimedia streaming, which efficiently adapts a transmission rate to changing network conditions and characteristics, is one of the important and challenging tasks in setting up the mobile IPTV service. Moreover, to support a variety of mobile devices, which differ in terms of their display resolution and processing power capabilities, the Scalable Video Coding (SVC) scheme that allows for data rate adaptation without re-encoding, should be a candidate for an adaptation scheme to support QoS in the mobile IPTV service [2].

Network-aware rate control systems using SVC have been studied to adapt the transmission rate to the varying bandwidth caused by Internet congestion and to adapt the transmission rate to different available bandwidths of different clients. However, the latter systems do not consider the essential content characteristics, such as the Peak Signal to Noise Ratio (PSNR) , and mobile devices' characteristics such as limited battery lifetime. Therefore, mobile devices that use the existing rate control systems, which are the network-aware rate control system that uses SVC, have an energy inefficiency problem when they use the combined scalability of the SVC bitstream. As shown in Fig. 1, the bitrate of the SVC bitstream is not always proportional to the PSNR that presents video quality.

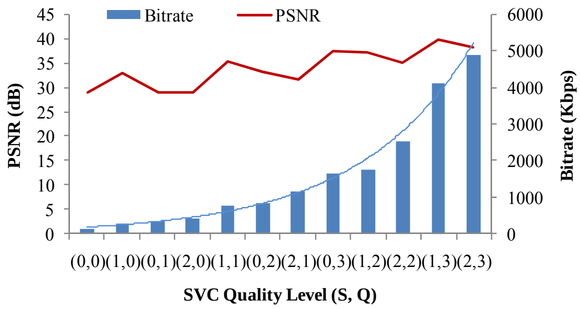

Fig. 1 PSNR and bitrate for spatial-SNR resolution (n-th spatial level, m-th SNR level) with the fixed temporal layer of a typical bitstream coded by JSVM (Joint Scalable Video Model)

However, the bitrate of the SVC bitstream is proportional to the energy consumption of mobile devices. Therefore, without considering the PSNR, transmitting a bitstream that has the maximal bitrate according to the available network bandwidth leads to the transmission of unnecessary bitstreams. This causes the energy inefficiency problem in wireless networks.

This paper proposes a new streaming system, called the Content-Aware Streaming System (CASS), for improving the the energy efficiency of mobile devices. CASS reduces energy needed to decode bitstreams via the adaptive rate control scheme based on content-aware and network-aware information. The remainder of this paper is organized as follows. In Section 2, related works are reviewed. Section 3 presents the overall architecture of the

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proposed CASS system and introduces the rate control scheme for achieving energy efficiency. Section 4 presents the performance evaluation, and we conclude this paper in Section 5.

2. Related Work

The JVT (Joint Video Team) of the ITU-T VCEG (International Telecommunication Union Telecommunic-ation Video Coding Experts Group) and the ISO/IEC (International Organization for Standardization/Inter-national Electrotechnical Commission) MPEG (Moving Picture Experts Group)have standardized a SVC extension of the H.264/AVC standard [3]. SVC enables the transmission and decoding of partial bit-streams to provide video services with lower temporal or spatial resolutions or reduced fidelity while still retaining a reconstruction quality that is high relative to the rate of the partial bitstreams. SVC enables the delivery of video data to the underlying network. However, this is insufficient because the Internet provides the best-effort service and has a time variant characteristic. Moreover, it is not explicitly optimized considering the specific characteristics of multimedia streaming services.

In order to support QoS for multimedia streaming services, variances of the rate control schemes using the SVC are studied. The network-aware rate control system using SVC, which is proposed in [4], transmits the maximal bitrate according to an estimated available network bandwidth. This system adjusts the quality level of the SVC bitstream to adapt the transmission rate to a varying bandwidth. This system, however, has an underflow problem, that does not support the continuity of media playback because this system does not consider the status of the client buffer.

The recent paper by Koo et al. [5] proposes another rate control scheme called the Network and Client-Aware Rate Control (NCAR) scheme, to prevent the overflow and underflow of the client buffer, which adjusts transmission rate based on an updated network-aware congestion control scheme and a client-aware flow control scheme. This scheme, however, does not consider the characteristics of mobile devices such as limited battery lifetime. To support the continuous playback service in the wireless network, energy conservation should be considered during multimedia streaming.

To provide energy-saving feature needed for streaming video playback, Agrawal et al. [6] proposes a power-saving technique by selectively dropping the I, P, and B frames of the bitstreams. This power-saving technique, which simply reduces the frames, degrades the quality of the streaming video playback. This problem is addressed in [7] by specifying the user's area of interest in the picture with the MPEG-21 DIA (Digital Item Adaptation) framework so that only that area of interest is trimmed off and transcoded. Moreover, in our previous work [8], we utilized the variance of PSNR and the distortion characteristics of content on the basis of a network-aware streaming system to improve energy efficiency by reducing the transmission of unnecessary bitstreams. These schemes, however, consider only energy conservation for the bitstream decoding. Yip et al. [9] proposes another power-saving technique by regulating the power for the radio wave output in IEEE 802.11b WLAN. Also the IEEE 802.11 standard [10] recommends the following technique for power conservation. A mobile that wishes to conserve power may switch to sleep mode and inform the access point of this decision. The base station buffers packets received from the network that are destined for the sleeping mobile. The base station periodically transmits a beacon that contains information about such buffered packets. When the mobile wakes up, it listens for this beacon, and responds to the base station which then forwards the packets [11]. These studies provide ways to achieve energy efficiency, but do not improve the QoS for the mobile IPTV service because they do not consider network congestion and the client buffer status.

3. Content-Aware Streaming System for Energy Efficiency

Fig. 2 shows the architecture of the proposed CASS. In CASS, the server uses information from the network to improve the energy efficiency by reducing the transmission of unnecessary bitstreams. Moreover, the client uses the client buffer status information to achieve power saving by reducing the operating time of the wireless network interface card (NIC). As shown in Fig. 2, CASS consists of the following four closely interacting modules:

- CIMM (Content Information Management Module): manages the content information table that consists of the PSNR and the bitrate for each quality level of the SVC bitstreams.

- QDM (Quality Decision Module): determines the quality level of the SVC bitstream to be sent according to the network status and the PSNR information.

- TCM (Transmission Control Module): adjusts the transmission rate of the bitstream according to the network status and the client status. TCM controls the operation of the streaming service whether or not the transmission of the bitstream

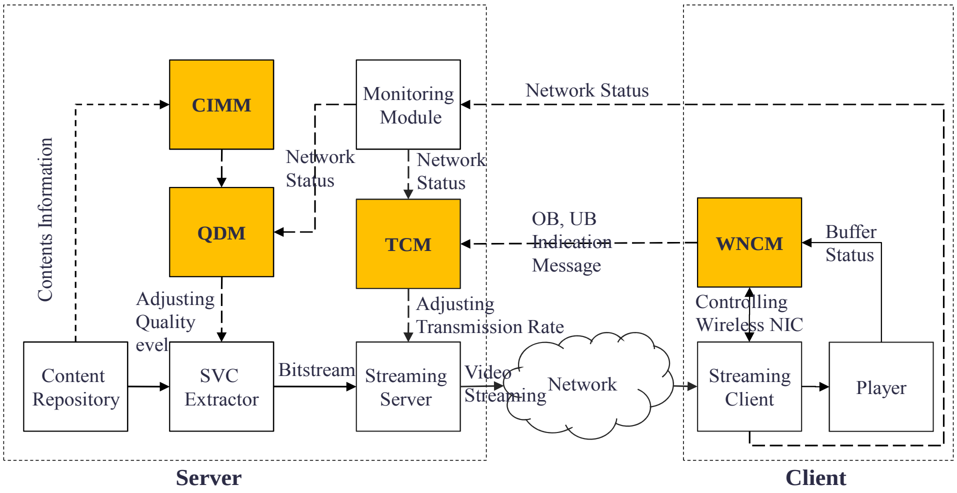

Fig. 2 Overall architecture of the CASS (Content-Aware Streaming System)

stops based on a requested message from WNCM.

- WNCM (Wireless NIC Control Module): controls the activation of the wireless NIC based on the client buffer status. The activation can be controlled by switching between the sleep and active modes of the power saving mechanism in the 802.11 standard [10] or by turning on and off the wireless NIC.

3.1 An Energy Efficiency Scheme in the CASS Server

The CASS server has a new adaptive rate control scheme to achieve energy savings and to improve the QoS in the wireless network. To be able to adapt the streaming rate to a new estimated available network bandwidth, the rate control scheme of CASS uses two methods: adjustment of the quality level of the bitstream, and adjustment of the transmission rate of the multimedia streaming of the SVC bitstream.

As the network status is getting better, TCM adjusts the transmission rate of the multimedia streaming according to the new estimated available network bandwidth (R_{ABW}), which is calculated using the TFRC (TCP-Friendly Rate Control) equation [12]. QDM calculates the new quality level (Q_{NEW}) of the SVC bitstream, which has the closest bitrate to the new estimated available network bandwidth, based on the network status information. As shown in Fig. 3, if the PSNR of the new quality level ($PSNR_{NEW}$) is larger than the PSNR of the current quality level ($PSNR_{Cur}$), the new quality level is used as the quality level of the SVC bitstream for the multimedia streaming. If $PSNR_{NEW}$ is smaller than $PSNR_{Cur}$, the current quality level is used as the quality level of the SVC bitstream for multimedia streaming service. CASS can transmit many bitstreams that are larger than the required bitstream to playback a video, for the client. This operation is called the over-buffering function. On the other hand, when the network status is getting worse, TCM also adjusts the transmission rate of the multimedia streaming according to R_{ABW}. QDM calculates Q_{NEW} based on R_{ABW}. As shown in Fig. 3, if $PSNR_{NEW}$ is larger than the PSNR of a lower Q_{NEW}, Q_{NEW} is used as the quality level of the SVC bitstream for the multimedia streaming. In another case, QDM uses a lower quality level than Q_{NEW}. It can provide a chance to use the over-buffering function.

```
Calculate R_ABW
Decide the transmission rate
Calculate Q_new

if(Q_new > Q_cur{
        if (PSNR_new > PSNR_cur)
                Change the quality level to Q_new
        else
                Maintain current quality level

} else if (Q_new < Q_cur)
        Change the quality level to Q_new
        While PSNR_new ≤ PSNR_new-1
                Q_new = Q_new-1
} else
        Maintain current quality level
```

Fig. 3 The adaptive rate control scheme pseudo code in the CASS server

3.2 The Energy Efficiency Scheme in the CASS Client

To improve energy efficiency, the CASS client includes a power-saving scheme that reduces the operating time of the wireless NIC. For this power saving scheme, a new buffer model of the client is proposed, as shown in Fig. 4, wherein $Total_B$ is the total buffer size, $qlen_C$ is the current buffer length, $R_{RX}(t)$ is the receiving rate of mobile devices, $R_{Play}(t)$ is the playback rate, $qmax_{th}$ is the maximum threshold and $qmin_{th}$ is the minimum threshold.

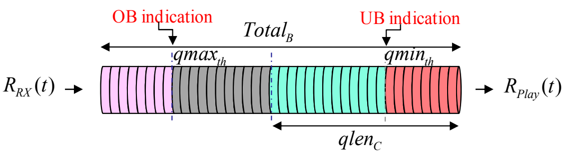

Fig. 4. A proposed client buffer model for the power saving

WNCM monitors the status of the client buffer to manage the active time of the wireless NIC. It decides on the $qmax_{th}$ and the $qmin_{th}$ to give notice of the overflow and underflow of the client buffer. As shown in Fig. 5, if $qlen_C$ is larger than the maximum threshold, WNCM sends an overbuffer indication (OB Ind.) message to the CASS server and turns OFF the wireless NIC to reduce its operating time. If $qlen_C$ is smaller than $qmin_{th}$ and the wireless NIC has been turned OFF, then the wireless NIC should be turned ON and WNCM should send an underbuffer indication (UB Ind.) message to the server to receive the streaming data.

```
if ( qlen_C ≥ qmax_th and wrieless NIC ON) {
        Send OB Ind. to server
        Until receive ACK from server
              Wait ACK
        if (ACK arrive)
              Turn off the WNIC
}

if (qlen_C ≤ qmin_th and wireless NIC OFF) {
        Turn on the WNIC
        Send UB Ind. to server
        Wait the bistream
}
```

Fig. 5 Power-saving scheme pseudo code in the client of the CASS

To prevent the client buffer overflow in the proposed rate control scheme, the $qmax_{th}$ equation is defined as follows:

$$qmax_{th} = Total_B - \int_0^{RTT} (R_{RX}(t) - R_{Play}(t))dt \quad (1)$$

wherein RTT is the round-trip delay time.

To prevent buffer underflow of client buffer the WNCM should use the $qmin_{th}$ equation, as follows:

$$qmin_{th} = \int_0^{RTT} R_{Play}(t)\,dt \quad (2)$$

wherein T_{ON} is the waiting time during the activation of the wireless NIC.

For this reason, CASS can improve the energy efficiency by reducing the transmission of unnecessary bitstreams and the operating time of the wireless NIC.

4. Simulation Results

4.1 An Energy Efficiency Scheme in the CASS Server

This section presents the results of the simulation of CASS in a congested network. To evaluate the performance of CASS, experiments were conducted based on the NS (Network Simulator) of the Lawrence Berkeley National Laboratory [13]. For the experiments, the Soccer-704x576-30-orig-02-yuv video clip was encoded into SVC profile layers using the reference software JSVM (Joint Scalable Video Model) [14], as shown in Table 1.

Table 1. The Content Characteristics of SVC Profile Layers

Quality level index	Frame rate	Spatial level	SNR level	Bitrate (kbps)	Y-PSNR (dB)
1	30	0	0	42.3	28.94
3	30	0	1	89.26	29.0712
6	30	0	2	121.5	33.06
8	30	0	3	137.76	37.36
2	30	1	0	278.3	28.94
5	30	1	1	389.33	31.70
9	30	1	2	555	34.97
11	30	1	3	846	38.27
4	30	2	0	1168	33
8	30	2	1	1365.3	35.14
10	30	2	2	1665	37.23
12	30	2	3	1800	39.74

An NS simulation was performed for the existing rate control (RC) system, which is the network-aware rate control system using SVC, and the proposed CASS system to compare their performance in terms of energy efficiency. The simulation topology is shown in Fig. 6.

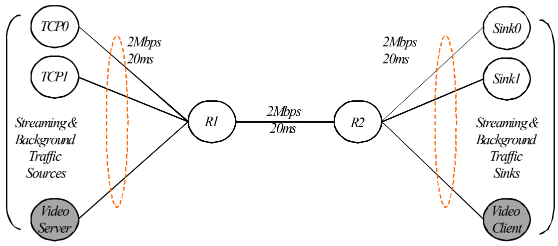

Fig. 6 Simulation topology for both the CASS and existing rate control system

The congested link was between routers R1 and R2. The link, which had a capacity of 2 Mbps and a propagation delay of 10 ms, was shared by two TCP flows and one video stream. Each host was connected to the routers using a 2Mbps link. For the video stream, RTP (Real-time Transport Protocol) was used. We use RTCP (RTP Control Protocol) messages as feedback information

4.2 Comparison of Transmission Rate and PSNR

To evaluate the performance of CASS, the simulation was performed for 500 sec. From 0 to 100th sec, the video server sent a video stream. Beginning at the 100th sec, the video server sent a video stream. Beginning at the 100th sec, the first TCP flow was started and began competing with the existing video stream for bandwidth share. This connection was finished at the 300th sec. The second TCP flow was started at the 200th sec and finished at the 400th sec.

As shown in Fig. 7, the resulting transmission rate and PSNR of CASS are similar to those of the existing RC system. As shown in Fig. 8, however, CASS was able to transmit many video bitstreams, which were larger than the required bitstreams to playback the video on time to the client, because CASS uses a lower quality level than the existing RC system. It is the over-buffering function that can provide more guaranteed time to playback the video than the existing RC system. During this time, the client can turn OFF the wireless NIC to reduce the operating time

To evaluate the energy efficiency of CASS, the energy efficiency rate (ε) was defined as the energy consumption that is needed to perform the video streaming, as shown in the following equation:

$$\varepsilon = \frac{E_{RC}}{E_{CASS}} \tag{3}$$

wherein E_{RC} is the energy that the existing RC system consumes to decode a frame, and E_{CASS} is the energy that CASS consumes to decode a frame. It was assumed that the energy (E) consumed in decoding a frame is represented by:

$$E\,\left[\frac{J}{frame}\right] = \beta\left[\frac{J}{bit}\right] \times \frac{R_{Play}(t)\left[\frac{bit}{sec}\right]}{F\,\left[\frac{frames}{sec}\right]} \tag{4}$$

wherein F is the frame rate of the video and β is the energy needed to decode a bit. β represents the specific constants of the device. From (3) and (4), the following can be derived:

$$\varepsilon = \frac{R^{RC}_{Play}(t)}{R^{CASS}_{Play}(t)} \tag{5}$$

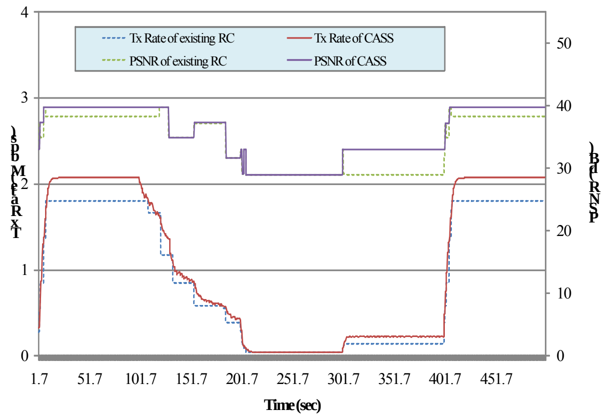

Fig. 7 Comparison of the transmission rate and PSNR for the CASS and the existing rate control system

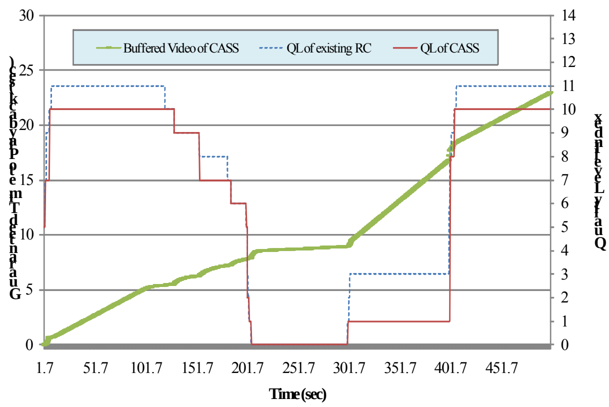

Fig. 8 Comparison of the guaranteed time to playback and the quality level for the CASS and the existing rate control system

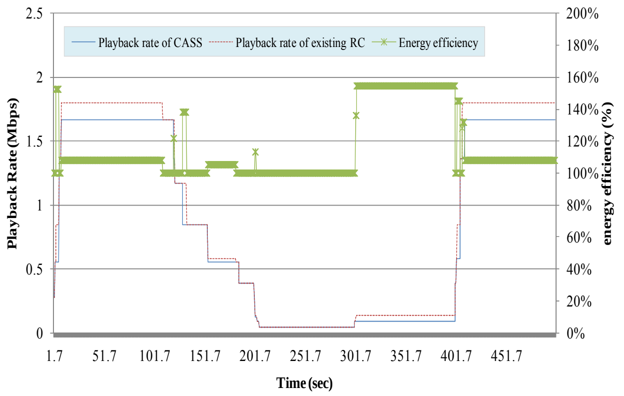

Fig. 9 The energy efficiency (ε) of the CASS compared with the existing rate control system

wherein $R^{RC}_{Play}(t)$ is the playback rate of existing RC system, $R^{CASS}_{Play}(t)$ is the playback rate of CASS. The energy efficiency (ε) for the proposed CASS is illustrated in Fig. 9. CASS can provide higher energy efficiency than the existing RC system by reducing the transmission of unnecessary bitstreams.

5. Conclusions

In the mobile IPTV service, device energy consumption of the devices is an important parameter that affects the quality of experience (QoE), such as with the continuous playback service. This paper proposed the Content-Aware Streaming System (CASS) to improve the energy efficiency by reducing the transmission of unnecessary bitstreams and by reducing the operating time of wireless network interface cards. This system utilizes the PSNR, which is based on content-aware information, and the system utilizes the client buffer occupancy based on a network-aware streaming system that uses SVC.

Our simulation results revealed that the proposed CASS can appropriately control the transmission rates of streaming videos depending on the current network status. Our proposed system can also provide energy efficiency needed without degrading video quality. The stability of the proposed system in heterogeneous wireless networks will be further improved.

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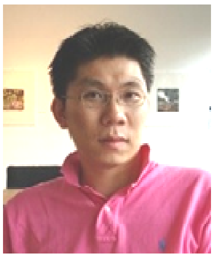

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