Priority and Network-aware Data Control Scheme to Guarantee the Media Quality in LTE Networks

Dongchil Kim and Kwangsue Chung

***Abstract*—For efficient streaming over wireless networks, the LTE (Long Term Evolution) system supports the ARQ (Automatic Repeat reQuest) and HARQ (Hybrid Automatic Repeat reQuest) schemes. However, there is no specification about how to use the ARQ and HARQ parameters in order to guarantee the media quality. To cope with this problem, this paper presents a PNDC (Priority and Network-aware Data Control) scheme that can improve the quality of streaming contents in LTE networks. The proposed scheme controls the number of HARQ retransmissions in lower MAC layer based on the priority of SVC (Scalable Video Coding) frames. It also dynamically adjusts ARQ retransmission timer in RLC (Radio Link Control) layer according to the adaptive ARQ and HARQ interworking. The experimental result shows that the proposed scheme can significantly improve the media quality.**

***Index Terms*—ARQ, HARQ, LTE, multimedia streaming service.**

I. Introduction

With the introduction of various mobile devices (e.g., smart phone, tablet PC) and the continued growth of laptops, there is an explosion of powerful mobile devices in the market capable of displaying high-quality video contents. In addition, these devices are capable of supporting new interactive video applications, and can capture video for video sharing, video blogging, and video broadcasting applications. As a result, future broadband wireless networks (e.g., LTE, WiMAX) will need to be optimized for the delivery of the video-based applications which could include both video streaming and video uploading [1], [2].

For efficient multimedia streaming, SVC (Scalable Video Coding) was recently finalized. Video scalability is achieved in the temporal, spatial, quality (SNR), or any combination of these domains. One example for using scalability is in saving bandwidth when the same media content is required to be sent simultaneously at different resolutions to support heterogeneous devices and networks. However, due to the characteristics of wireless networks such as high error rate, limited bandwidth, multiple transmission rates, time-varying channel conditions and dynamic network users, providing QoS (Quality of Service) for video streaming over wireless networks presents several new challenges [3].

Enabling the delivery of video services to mobile devices over wireless networks is essential to ensure ubiquitous access to video content and services from any location, at any time, with any device and technology. The latest mobile broadband technologies including 3GPP (Third Generation Partnership Project) technologies based on the LTE (Long Term Evolution) and LTE Advanced standards offer much higher capacity with peak rates up to 340 Mbps over a 20 MHz channel. These increased data rates will allow for an enhanced user experience and support for multimedia services at lower transmission cost and with much richer content than 2G and 3G cellular networks.

To provide reliable transmissions over dynamic wireless channels, LTE systems support two schemes: ARQ (Automatic Repeat reQuest) and HARQ (Hybrid Automatic Repeat reQuest). Both ARQ and HARQ schemes retransmit data when data is not correctly delivered to the receiver. While the ARQ scheme operates at the RLC layer, the HARQ works at the lower MAC. Specifically, the HARQ scheme exploits channel coding gains as well as time diversity via retransmissions [4]. Although ARQ and HARQ schemes have been widely used to provide reliable transmissions in wireless networks, they have the following weaknesses. First, ARQ and HARQ schemes do not guarantee media quality for multimedia streaming service using SVC encoding scheme, because they do not consider essential media characteristics such as the priority of media frames. Second, ARQ and HARQ schemes result in high delay in data delivery and low system throughput, because they operate independently. The LTE standard defines parameters which are related to the ARQ retransmission timer and HARQ feedback. However, there is no specification about how to use the parameters in the standard. In addition, many existing works on the ARQ and HARQ schemes focus on analyzing the delay of data in wireless networks [5]-[7].

In this paper, we present a PNDC (Priority and Network-aware Data Control) scheme for multimedia streaming services using the SVC encoding in LTE networks. To improve quality of streaming services using SVC encoding technique, the PNDC scheme controls the number of HARQ retransmissions in lower MAC layer based on the priority of SVC frames. Also, in order to overcome the weakness of between ARQ and HARQ schemes, the PNDC scheme dynamically adjusts ARQ retransmission timer according to the adaptive ARQ and HARQ interworking. This paper shows that the proposed PNDC scheme can significantly improve the quality of streaming contents through video PSNR (Peak Signal to Noise Ratio) and packet loss ratio in LTE networks. The rest of this paper is organized as follows. The basic operations of LTE networks, the SVC encoding scheme, and existing schemes related ARQ and HARQ schemes are presented in Section II. An effective

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The authors are with the Communications Engineering Department, Kwangwoon University, Seoul, Korea (e-mail: dckim@cclab.kw.ac.kr, kchung@kw.ac.kr).

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PNDC algorithm is presented in Section III. The experimental results are provided in Section IV, and finally the concluding remarks are given in Section V.

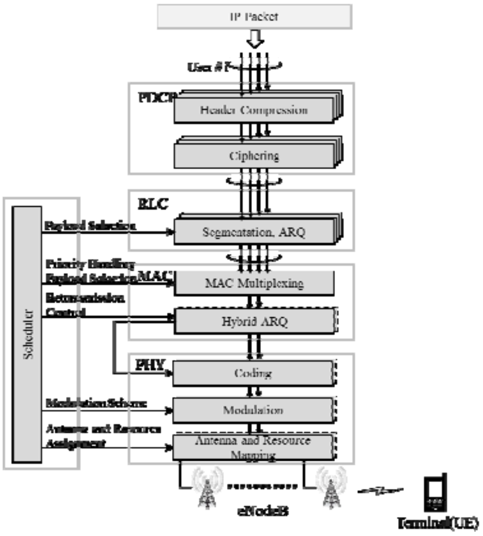

Fig. 1. Radio protocol architecture in LTE (Downlink)

II. Related Works

A. The Basic Operations of LTE Networks

In this section, we introduce the basic operations of the standard of LTE networks. Fig. 1 shows a general overview of the LTE (User-Plane) protocol architecture for the downlink. The PDCP (Packet Data Convergence Protocol) performs IP header compression to reduce the number of bits to transmit over the radio interface. The header-compression mechanism is based on ROHC (Robust Header Compression), a standardized header-compression algorithm also used for several mobile-communication technologies. The PDCP is also responsible for ciphering and, for the control plane, integrity protection of the transmitted data, as well as in-sequence delivery and duplicate removal for handover. At the receiver side, the PDCP protocol performs the corresponding deciphering and decompression operations. There is one PDCP entity per radio bearer configured for a terminal. The RLC (Radio-Link Control) is responsible for segmentation and concatenation, ARQ retransmission handling, duplicate detection, and in-sequence delivery to higher layers. The RLC provides services to the PDCP in the form of radio bearers. There is one RLC entity per radio bearer configured for a terminal. The MAC (Medium Access Control) handles multiplexing of logical channels, hybrid-ARQ retransmissions, and uplink and downlink scheduling. The scheduling functionality is located in the eNodeB (Evolved Node B) for both uplink and downlink. The hybrid-ARQ protocol part is present in both the transmitting and receiving ends of the MAC protocol. The MAC provides services to the RLC in the form of logical channels. The PHY (Physical Layer) handles coding and decoding, modulation and demodulation, multi-antenna mapping, and other typical PHY functions. The PHY offers services to the MAC layer in the form of transport channels [8]. Particularly, for reliable data transmission over unreliable wireless channel, the lower MAC and PHY layers operate retransmission of data unit. However, ARQ and HARQ schemes result in high delay in data delivery or low system throughput, because they operate independently. Also, there is no specification about how to use the parameters in the standard.

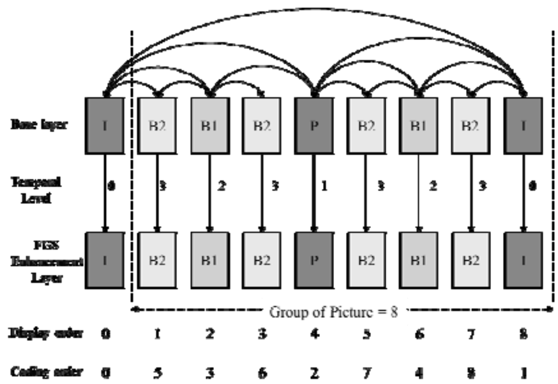

Fig. 2. Example of video coding based on the scalability extension of SVC using hierarchical B-pictures.

B. Scalable Video Coding Scheme

SVC (Scalable Video Coding) scheme has been proposed as an extension of the H.264/AVC standard [9]. The objective of SVC is to encode a video stream with one or more subset bit streams, which can be decoded with a complexity and reconstruction quality similar to that of the data encoded by the H.264/AVC design. SVC is flexible and adaptable because it only needs to encode a video once and the resulting bit stream can be decoded at multiple reduced rates and resolutions. The SVC provides three types of scalability: temporal scalability, spatial scalability and SNR (Quality) scalability. The temporal scalability uses hierarchical B picture to do motion compression as shown in Fig. 2. Decoding the base layer provides low but standard video quality, and decoding the base layer with the enhancement layers improves the quality of video streaming. In Fig. 2, except I-frames (TID: Temporal ID, 0), every frame in the group of picture has to refer to neighbor frames. For example, the second B2-frame (TID: Temporal ID, 3) needs the first B1-frame (TID: Temporal ID, 2) and the P-frame (TID: Temporal ID, 1) to decode. The reference relationship of different frames can be classified into three temporal layers [3]. The proposed PNDC scheme uses characteristics of the SVC encoding scheme.

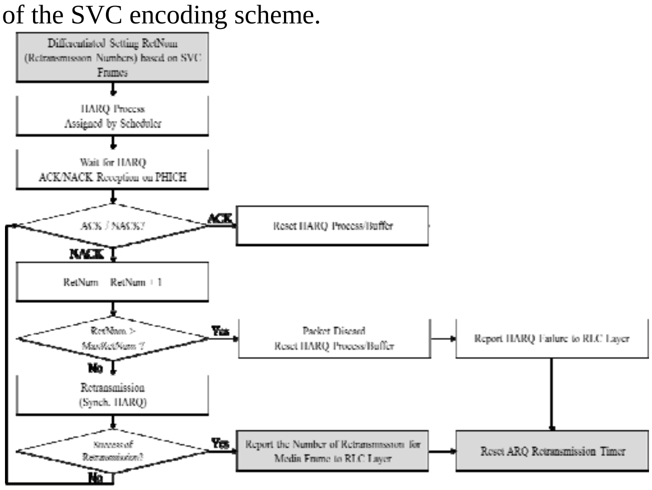

Fig. 3. The operation of the proposed scheme during media data transmission.

C. Existing Schemes Related ARQ and HARQ Schemes

The benefits of an interaction between ARQ and HARQ schemes have been studied in [10], [11]. However, they proposed partial interworking schemes only. In addition, many existing works on the ARQ scheme focus on analyzing the delay of data in wireless networks. In [10], the authors focused on ARQ and HARQ scheme interaction to solve the weakness of the HARQ scheme. That is, the ARQ and HARQ scheme interaction considered in [10] executes only when dealing with HARQ feedback message errors. Specifically, in [10] the HARQ scheme uses ARQ feedback messages to correct HARQ feedback message errors. However, the weakness of the ARQ scheme remains in [10]. The authors in [11] proposed a HARQ feedback message sharing scheme called CL-ARQ to solve the weakness of the ARQ scheme. In CL-ARQ, the ARQ scheme at the receiver does not send ARQ feedback messages at all and the ARQ scheme at the transmitter utilizes HARQ feedback messages. However, CL-ARQ does not consider the HARQ feedback message error, which can cause incorrect operations for both ARQ scheme and HARQ scheme. Thus, existing research focuses on the weakness of one scheme only and targets 3GPP systems [10], [11]. The adaptive ARQ-HARQ interworking scheme considers the interaction between ARQ and HARQ schemes in order to overcome the weakness of both schemes [4]. Specifically, ARQ and HARQ schemes share the (re) transmission and feedback information with each other and then they adapt their operations so that they compensate for their weaknesses. However, this scheme does not guarantee media quality for multimedia streaming service using SVC encoding scheme, because they do not consider essential media characteristics. To cope with these problems, this paper presents PNDC scheme that can improve the quality of streaming contents in broadband wireless networks.

III. Priority and Network-Aware Data Control Scheme

The retransmissions of loss or erroneous data units are handled primarily by the HARQ mechanism in the MAC layer, complemented by the retransmission functionality of the ARQ scheme in RLC layer. The reasons for having a two-level retransmission structure can be found in the trade-off between fast and reliable feedback of the status reports. The ARQ mechanism targets reliable data transmission. On the other hand, the HARQ mechanism targets very fast retransmissions and, consequently, feedback on success or failure of the decoding attempt is provided to the transmitter after each received TBs (Transport Block). Due to the operation independently, the ARQ and HARQ schemes result in high delay in data delivery and low system throughput. To solve this problem, the PDNC (Priority and Network-aware Data Control) scheme is based on the interworking between ARQ and HARQ schemes. To do this, it is necessary that the ARQ and HARQ schemes share their information each other, and thus the proposed scheme utilizes the number of HARQ retransmissions received from receiver's feedback information. Fig. 3 shows the operation of the proposed scheme when media data is delivered to receiver. When the RLC PDUs (Protocol Data Units) from higher layer come to MAC layer, they will be divided into several MAC PDUs. In MAC layer, the number of HARQ retransmissions is differentially applied according to the priority of SVC media frames. The scheduler will try to (re)transmit the TBs when data is delivered with errors and losses. After TBs are transmitted to receiver, the PHICH (Physical HARQ Indicator Channel) carries the HARQ ACK to the transmitter to indicate whether a TB should be retransmitted or not. If the transmitter received the HARQ ACK, the transmitter discards TBs in transmitter buffer and resets HARQ process. On the other hand, if the transmitter received the HARQ NACK, the scheduler sends TBs to receiver and updates retransmission counts. If the current number of HARQ retransmissions is larger than allocated maximum number of HARQ retransmissions, the transmitter discards TBs at transmitter buffer and reports HARQ failure to RLC layer. Otherwise, the transmitter operates HARQ retransmission. When the retransmission of the TBs or the decoding was successful, the receiver reports the number of HARQ retransmissions to RLC. Upon reception of the number of HARQ retransmissions, the transmitter recalculates ARQ retransmission timer.

A. Readjustment of the Number of HARQ Retransmission

To apply the differentiated the number of HARQ retransmissions, we consider wireless channel condition and the priority of SVC media frames. The wireless channel quality is calculated as shown in (1). The $CINR_{max}$ is maximum CINR (Carrier to Interference and Noise Ratio) and the $CINR_{current}$ is current CINR.

$$WirelessChannelQuality(\%) = \frac{CINR_{current}}{CINR_{\max}} \quad (1)$$

The number of HARQ retransmissions is recalculated with the quality of the wireless channel based on CINR. The wireless channel quality is divided by two thresholds, a minimum threshold (min_{th}) and a maximum threshold (max_{th}). When the wireless channel quality is less than the minimum threshold, all frames are applied to recalculate the maximum number of HARQ retransmissions according to the priority of SVC frames. When the wireless channel quality is greater than the maximum threshold, no frames are controlled. If the wireless channel quality is between the minimum and maximum threshold, each of the SVC frames is applied with proportionally recalculated the number of HARQ retransmissions as shown in (2), where Ret_Num_i is the number of HARQ retransmissions of the each packet i belonging to $TID_{current}$ frame, Ret_Num_{max} is the maximum number of retransmissions, TID_{max} is the maximum TID value, and $TID_{current}$ is the current TID value. Each of the SVC frames is differentially controlled by exploiting the TID field.

$$Ret\_Num_i = \left\lceil Ret\_Num_{\max} \times \frac{TID_{\max} + 1 - TID_{current}}{TID_{\max} + 1} \right\rceil \quad (2)$$

B. Adaptive Control of ARQ Retransmission Timer

The ARQ and HARQ schemes result in high delay in data delivery or low system throughput, because they operate independently in LTE networks. In order to overcome the weakness between ARQ and HARQ schemes, the proposed scheme dynamically adjusts ARQ retransmission timer according to the adaptive ARQ and HARQ schemes interworking.

The first TB is delivered to the receiver successfully and the next TB is not delivered successfully. First, we consider the case where the value of the ARQ retransmission timer is too short. In this case, the transmitter retransmits the first TB again before receiving the ARQ feedback message since the ARQ retransmission timer is expired. That is, in the case of the successful reception of TB, the short ARQ retransmission timer results in unnecessary retransmissions that waste resources. In addition, the other TB is not transmitted and thus, the delay of data increases. Second, we consider the case where the value of ARQ retransmission timer is long. In this case, although the next TB is failed to deliver, the retransmission of this TB is delayed. That is, the long ARQ retransmission timer results in large delay of data. In this way, the static ARQ retransmission timer value can influence on the performance degradation in LTE systems. To solve this problem, the proposed scheme dynamically adjusts ARQ retransmission timer according to the number of HARQ retransmissions and the number of users (N_{user}) as shown in (3). Where R_Timer_{new} is the recalculated ARQ retransmission timer value, $RETX_{current}$ is the current number of HARQ retransmissions. If the number of HARQ retransmissions is less than the minimum threshold (min_{th}), it indicates that the TB has been delivered successfully to the receiver. Thus the ARQ retransmission timer increases the maximum ARQ retransmission timer (R_{max}) value. By increasing the value of the ARQ retransmission timer, the ARQ scheme waits for receiving an ARQ feedback message from the receiver without unnecessary retransmission. When the number of the HARQ retransmissions is greater than the maximum threshold (max_{th}), the retransmission timer sets the minimum retransmission timer (R_{min}) value. When the number of HARQ retransmissions is between the minimum threshold and the maximum threshold, the transmitter at RLC layer differentially adjusts the ARQ retransmission timer.

$$R\_Timer_{new} = \frac{\left(\frac{R_{\min} - R_{\max}}{\max_{th} - \min_{th}}\right) \times \left(RETX_{current} - \min_{th}\right) + R_{\max}}{N_{user}} \quad (3)$$

IV. Simulation Results

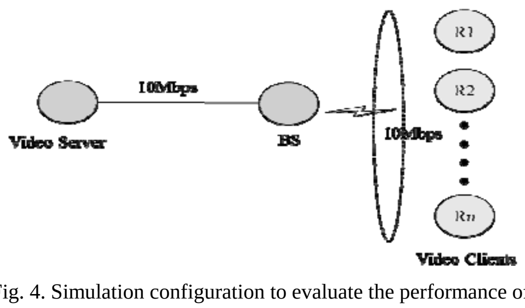

Fig. 4. Simulation configuration to evaluate the performance of the proposed scheme

In this section, performance of the proposed PNDC (Priority and Network-aware Data Control) scheme is evaluated using NS2 (Network Simulator) of LBNL (Lawrence Berkeley National Laboratory). The simulation topology is shown in Fig. 4. In this simulation, the video server transmits video streams over the LTE networks. The video receivers are connected using wireless links. The video traffic trace we used for the experiment is "Highway" video clip which is encoded into SVC profile layers using the reference software JSVM (Joint Scalable Video Model). The "Highway" format is QCIF and the video frame rate is 30 (frames/sec).

Fig. 5 and Fig. 6 show the performance comparisons of the packet loss ratio between the proposed PNDC scheme and standard LTE according to the variation of wireless channel error rate and the variation of users. It is clearly seen that the proposed scheme reduces the packet loss ratio as our scheme controls media data according to the priority of media frames and the number of HARQ retransmissions. By reducing the packet loss ratio, the proposed scheme guaranteed the video quality.

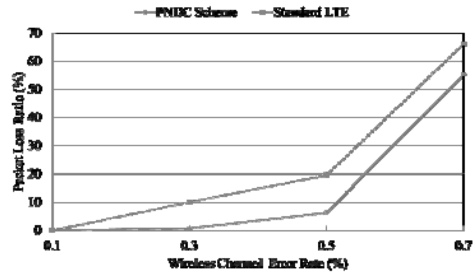

Fig. 5. Comparisons of the packet loss ratio according to the variation of wireless channel error rate.

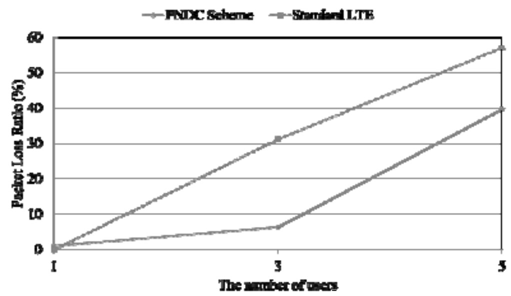

Fig. 6. Comparisons of the packet loss ratio according to the number of users

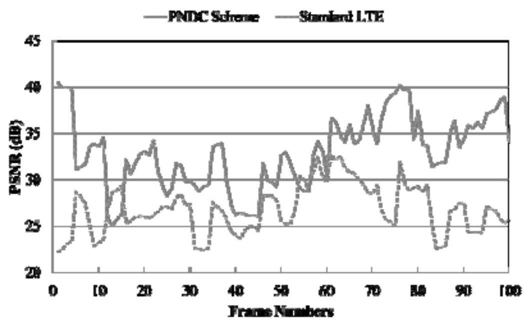

Fig. 7. Comparisons of the PSNR between the PNDC scheme and standard LTE.

Fig. 7 shows the comparisons of the PSNR between the PNDC scheme and standard LTE. The PSNR of the proposed PNDC scheme is higher than that of the standard LTE as our scheme controls the number of HARQ retransmissions based on SVC frames. We note that representing PSNR frame by frame is more tractable than calculating the average PSNR

values of all the frames, as an average PSNR may not map well to the overall subjective impression during a video playback. Therefore, we rely on the frame-wise PSNR to assess the video quality. These simulation results indicate that the proposed method provides seamless and high quality video streaming services.

V. Conclusion

To improve the quality of multimedia streaming services over LTE networks, the broadband wireless communication systems need to consider network states and media characteristics. However, existing schemes do not consider both essential characteristics of video coding techniques and network states. To solve this problem, we propose a PDNC (Priority and Network-aware Data Control) scheme which improves the media quality by controlling the number of HARQ retransmissions based on priority of SVC frames. It also dynamically adjusts ARQ retransmission timer according to the number of HARQ retransmissions through the adaptive ARQ and HARQ interworking. Our simulation results show that the proposed scheme can provide seamless and high quality video streaming in the LTE networks.

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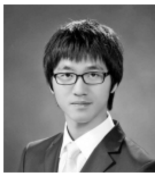

Dongchil Kim received the B.S. degree and M.S. degree from Kwangwoon University, Seoul, Korea, from the Electronics & Communications Department, in 2009 and 2011 respectively. Currently he is a Ph.D. candidate in the Communications Engineering Department, Kwangwoon University. His research interests include multimedia, congestion control, smart TV, and Internet QoS.

Kwangsue Chung (M'93, SM'01) received the B.S. degree from Hanyang University, Seoul, Korea, M.S. degree from KAIST (Korea Advanced Institute of Science and Technology), Seoul, Korea, Ph.D. degree from University of Florida, Gainesville, Florida, USA, all from Electrical Engineering Department. Before joining the Kwangwoon University in 1993, he spent 10 years with ETRI (Electronics and Telecommunications Research Institute) as a research staff. He was also an adjunct professor of KAIST from 1991 to 1992 and a visiting scholar at the University of California, Irvine from 2003 to 2004. His research interests include communication protocols and networks, QoS mechanism, and video streaming.